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Electric vehicles in the next millennium

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Abstract

It is well known that the history of battery electric vehicles (EVs) is a long one that covers a period in excess of one hundred years. It is also well known that, in their early days, these vehicles were capable of out-performing their contemporary internal combustion-engined (ICEV) equivalents in terms of speed and acceleration. Since those days, and indeed until quite recently, there has been a quite remarkable difference between the vast strides made in developing ICEVs in general and cars in particular, and the relatively small improvements made in the capabilities of EVs. It is now being argued that this must change and the purpose of this paper is to consider the extent to which it is practical to expect such a change, on a large scale, in the early part of the next millennium.

Keywords: Batteries; Cost; Driving range; Electric vehicles; Fuel cells; Hybrid systems

1. The Lucas programme—a major event in the renaissance of the electric vehicle

I think that what little reason there was to ask me to give you my thoughts on the future of electric vehicles (EVs) was probably related to the fact that I have spent about half of my working life in and around the EV development business, and all my working life in the transport industry. I have also been involved with hybrid electric vehicles (HEVs). Therefore, perhaps I may commence by making an attempt to establish a semblance of credibility by briefly describing some of the EV programmes with which I have been involved.

My association with EVs commenced at a time when I was employed by a very large public transport organization which provided bus and train services within an area of about 1500 km^2 in and around the city of Manchester. I had spent over 20 years in the field of transport and finding myself being offered the task of setting up a new Lucas Industries facility to develop battery EVs came as a severe shock. The proposal came in 1974 because I had, as a major transport operator, asked Lucas to join with me in an approach to a UK Government Department for some financial assistance to build a battery electric bus which would operate on a route between railway stations in Manchester. The reasons for my interest in this project were two-fold. First, there was a major problem with the reliability of many of the diesel buses at that time and I wanted to find out whether electric buses would live up to the attributes of good reliability and minimal maintenance that had been afforded to EVs for many years. Second, a world shortage of oil at that time was causing an apparent continuous and alarming increase in the price this commodity which, in turn, was giving rise to considerable concern among people in many industries including those involved in transport.

Having subsequently joined Lucas and set up the new company, I was responsible for building the electric bus in question and providing technical support when it entered service. The bus—the performance of which was comparable with diesel buses, except for range—operated successfully for some years and was popular with both passengers and drivers. On the other hand, it was not popular with schedulers because its restricted range (about 70 km in city service) added yet more limitation to its uses, particularly at weekends. Nevertheless, much was learnt from the in-service operation of this vehicle which proved to be remarkably reliable. Experience showed, however, that it would be too difficult to find sufficient applications for such vehicles to provide any reasonable size of market.

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Before the development of the above bus, Lucas had relatively crudely converted one or two 1-tonne vans to electric drive. By crudely, I mean that the batteries had been placed where a payload would normally be carried so that the vehicle chosen did not have sufficient carrying capacity for both the 1-tonne of battery that was necessary to give an appropriate working range and the 1-tonne of payload that operators would require. Despite this, I obtained agreement within Lucas that the battery EV most likely to succeed at that time was indeed a 1-tonne payload van because it would be possible, with relatively minor changes to certain 1-tonne production vans, to modify the drive to battery electric without reducing either the payload volume or the weight. Furthermore, it was possible to show that numerous operators would be completely satisfied with the performance and the range of such modified vehicles because both these factors would be more than adequate for the vehicles to perform the duties carried out daily by very many ICEVs. In addition, the world oil shortage was providing exactly the type of stimulus necessary to promote among fleet operators a real interest in non-oil-based vehicle drive systems. The oil crisis also stimulated the UK Government into being prepared to provide financial support for the Lucas project in the shape of a subsidy on the selling price of vehicles that was expected to decrease as the number of vehicles produced and sold increased. Whilst Lucas met the costs of developing the drive systems and designing the necessary vehicle modifications, the company had the active support of Bedford and what was the Freight Rover in this venture.

The Bedford vehicles underwent a significant testing programme on that company's test tract, and were in fact built on the company's ICE van production line, interspersed between petrol- and diesel-powered versions of CF vans. This method of production was the first of its kind. Some hundreds of Bedford vans and a smaller number of Freight Rover vans were built and sold, all with a working range in excess of 80 km in city traffic, a payload of just under 1 tonne, an acceleration of 0–50 km in 13 s, a maximum speed of 85 kph, and a battery design life of 4 years. The vehicles had, for that time, sophisticated electronic controllers and d.c.–d.c. converters, as well as oil-fired heating and de-misting systems. Lucas designed and constructed the chargers and battery-watering systems. At that time, fast charging was neither required nor practical, and valve-regulated ('maintenance-free') traction batteries had not been sufficiently developed.

The vehicles were sold mainly to large UK fleet operators, such as the Royal Mail, Electricity Boards, Water Boards, Local Authorities, and the Police. Some, however, were sold to the operators of a few vehicles; one went to a gentleman who had a working water-wheel which was harnessed to provide electricity to recharge his Bedford. Other vehicles were sent abroad to Australia, New Zealand, Hong Kong, Singapore and Japan, some left-hand drive versions to France and Austria, and about 30 to the USA where General Motors operated them under the name of the 'Griffon'.

All the technical back-up for the vehicles was provided by Lucas engineers and it was fortunate that, after some initial problems, the vans proved to be very reliable. Some vehicles survived in service throughout the 1980s and beyond. It was estimated that collectively their total service had exceeded 32 million km. Even today, a few are still operating.

Within the Lucas development programme, which at one time employed close to 100 personnel, some work on HEVs was undertaken and one five-seat passenger car was designed and built. This utilized an electric Bedford drive system and could be operated either as a series hybrid or a parallel hybrid. The car had a maximum speed of 130 kph, and a pure-electric range of about 70 km. Unfortunately, the project continued for only a brief period. This was because the completion of the car coincided with the decision of Bedford to put the electric CF van into production and the available resources were insufficient to develop both vehicles simultaneously. The Bedford programme obviously took priority.

At an earlier date, Lucas had produced two electric taxis which met the London Public Carriage Office's requirements for taxi cabs in London. These performed very well, but because the vehicles were not hybrids, they were incapable of performing long inter-city journeys if requested—a limitation which was not acceptable to the authorities.

In 1981, Lucas and the UK battery company, Chloride, joined forces and Lucas Chloride EV Systems was formed. One result was that, coincidentally with the production-line build of Bedford and Freight Rover electrics, 2.5-tonne payload electric Dodge 50 trucks were also manufactured on a production line and entered service in some numbers. In addition, a small fleet of battery electric Renault Masters was produced; these vehicles operated successfully in France for several years (for further details of the Lucas and other EV programmes, see Ref. [1]).

With the end of the oil crisis, interest in EVs faded. There were a number of reasons for this, which included the following.

(i) The volume of vehicles built was insufficient to make it possible to reduce their production cost and the Government ceased to provide the subsidy which had made their cost reasonably attractive to operators.

(ii) As batteries came to the end of their lives, operators became increasingly reluctant to lay out the fairly large sums necessary to put new batteries into ageing vehicles.

(iii) No one knew then, and it is doubtful that they know now, what the residual value of a second-hand EV is, particularly if a significant number become available on the market at any one time.

(iv) Although the vehicles performed their duty cycles to the satisfaction of most of their operators, the problems which arose when an operator wished to move them from one location to another were severe, and particularly so when the distance of the move was greater than the vehicle's range. Not only did additional staff have to be given training, but chargers had to be disconnected and rewired elsewhere, support equipment for watering and charging batteries had to be relocated, and so on.

With the advent of on-board battery chargers, this last problem has been reduced, but not necessarily eliminated if electric power supplies at a new location require modification to meet the specific needs of EVs. The other problems are not that difficult to overcome, but they are counter to the wishes of EV operators who want fewer, and not more, problems.

2. Electric vehicle development 1974–1998

Before speculating on what is likely to happen in the field of electric and hybrid electric vehicles in the next millennium, it is appropriate to consider the changes which have taken place in the quarter century since the start of the Lucas project.

Considering pure-battery EVs in the first instance, the developments which have taken place are not as great as had been hoped and expected. It is of course true that sophisticated a.c. drives are replacing d.c. counterparts and that chargers, which can provide vehicles with fast charge without reducing battery life, are available. Moreover, the chargers can be mounted on board vehicles with, in some cases, the sharing of some of the electric components of the vehicles' controllers. It has also been shown that opportunity charging, even without fast-charge capability, can be a satisfactory means of extending the range of vehicles in a number of applications. In general, however, vehicle performance has not changed much. Some alternative battery systems, developed over the past 25 years, are just capable of doubling the range of vehicles powered by lead–acid batteries, but at a very high cost. It is difficult to name many electric manufacturers who are building large numbers of EVs equipped with such batteries. Further, there has been little or no significant progress in developing vehicle heating and air-conditioning units which do not either rely on a fossil fuel for their energy input or cause a significant range reduction when powered by the vehicle's battery.

Presumably it is the lack of development progress with pure EVs that has stimulated at least some of the very clever HEV concepts which have appeared, such as the Toyota Prius and the Ford P2000 (Fig. 1). At this point, I begin to find myself in some difficulty because some hybrids are effectively ICEVs with an electric drive which assists when required. A few years ago, such designs may not have been contemplated in a paper primarily about electric drives but, as time passes, some distinctions are bound to become blurred.

A major problem with both EVs and HEVs has been their cost, which in the case of hybrids is exacerbated by having two drive systems in one vehicle. Fortunately, the automotive industry is so good at meeting challenges of this nature that who can say what can be achieved? For example, it is claimed that micro-turbines together with their associated generators and accessories can be produced cheaply, mainly because they have a very low component count. These turbines are capable of operating on a wide variety of fuels and are considered to produce a very low level of pollutants, but with one or two exceptions such as Volvo and Chrysler, these claims have not been subjected to any extensive field testing. If what is claimed proves to be true, then such vehicles would be expected to play a large part in the transport scene in the coming new millennium. The world certainly needs a low cost, low emission, multi-fuel engine, and unless one is available, we are likely to be left contemplating the enormous task of replacing today's vehicles and their complex infrastructure with another. More than this is in fact necessary because if many of today's vehicles are to be replaced by battery or fuel-cell powered vehicles, then it is essential that whatever produces and uses the electricity or the methanol or the hydrogen, etc., has to be part of a clean process and not one which produces unacceptable pollutants, as could easily be the case.

At present, the great hope for the future, and in some quarters the great belief, is the fuel cell. What is a fuel cell? It is a device, invented in the early part of last century, which converts the chemical energy of a fuel directly into electricity without the use of a heat engine. In practice, the efficiency of fuel cells operating on hydrogen is often in the region of 50%, which is, of course, greater than that of most, if not all, heat engines.

Hydrogen is the preferred fuel for fuel cells but its storage presents a problem. One of the ways of overcoming this problem is to convert a liquid fuel, such as methanol, into hydrogen. This was done in the 5-kW unit made by the Shell Oil as long ago as 1964. The unit was installed in the world's first fuel-cell powered car. Shell also produced a 300-W nett cell in 1965 which converted methanol directly into electricity, so it is not the case that this technology is new. The principal problem at the time this work was carried out was the cost of the unit—but the system worked! Unfortunately, despite the very large levels of investment and effort over the last 35 years, cost still remains one of the main problems to be overcome in most types of fuel-cell system.

Although a number of fuel-cell powered cars have been built recently by automobile manufacturers, the only vehicle so far offered for sale is the Zevco London taxi which was launched in London in July 1998. The propulsion system is a hybrid arrangement: a battery drives the vehicle and is recharged by a 5-kW fuel cell. The vehicle uses bottled hydrogen as fuel and has a service range of 145 km, a performance similar to its diesel counterpart. This

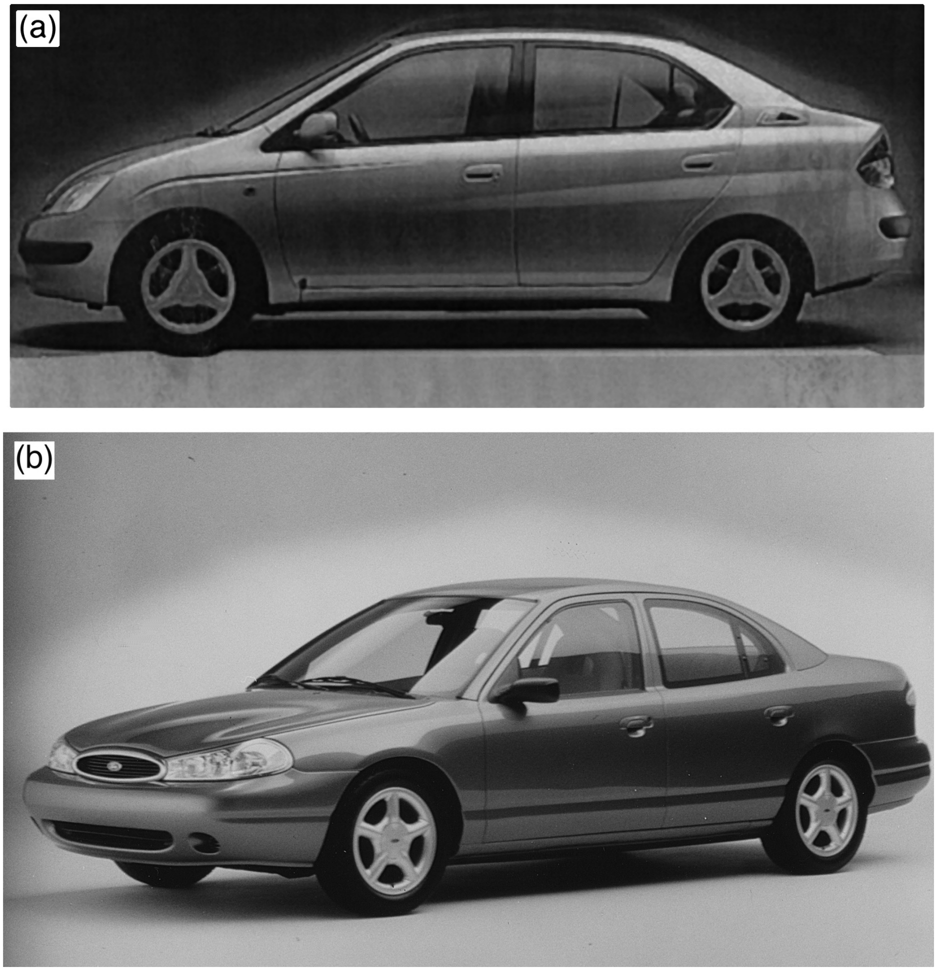

Fig. 1. (a) Toyota Prius; (b) Ford P2000.

design works well because the stop–start nature of the traffic provides time for the low output of the fuel cell to replenish the energy drawn from the battery during previous spells of vehicle motion. At a later date, this type of taxi may be fitted with a cryogenic hydrogen-storage system, perhaps placed between the two layers of a sandwich-floor construction of the vehicle. With such an arrangement, it is expected that the fuel cell would be refuelled with very cold liquid hydrogen in minutes and, thereby, would extend the vehicle's range dramatically, but only in stop–start traffic.

What the world really needs are vehicles fitted with fast-response, high-output fuel cells together with on-board clean reformers which would enable a liquid fuel to be turned into hydrogen on vehicles. Initially, the most likely liquid fuel would seem to be methanol, but arranging for methanol to be widely available would necessitate some large changes in infrastructure. If all this is possible, then refuelling vehicles with liquid fuel would be, in principle, little or no different from today. The eventual aim is said, by those developing high-output fuel cells, to be the development of reformers which can produce hydrogen from gasoline. In this case, only the current gasoline infrastructure would be required.

Interest and investment in fuel cells is increasing, and the joint arrangements between the Canadian fuel cell company Ballard and motor industry giants Mercedes and Ford (Fig. 2) would appear to be an almost irresistible force on a course aimed at solving some daunting problems. Development is also being undertaken in Japan and, almost certainly, elsewhere.

The Ballard unit is a proton exchange membrane (PEM) fuel cell and amongst early examples of road vehicles fitted with this are buses in the USA. Quite apart from the technical problems still to be resolved, the problem of cost is very great. The automotive industry has an enormous ability to reduce component costs by making parts in very large numbers and with increasing efficiency. It seems that the industry believes that volume build is capable of reducing the cost of fuel cells. This is probably true except, for example, where it is found to be impossible to use a material other than a precious metal to make a part.

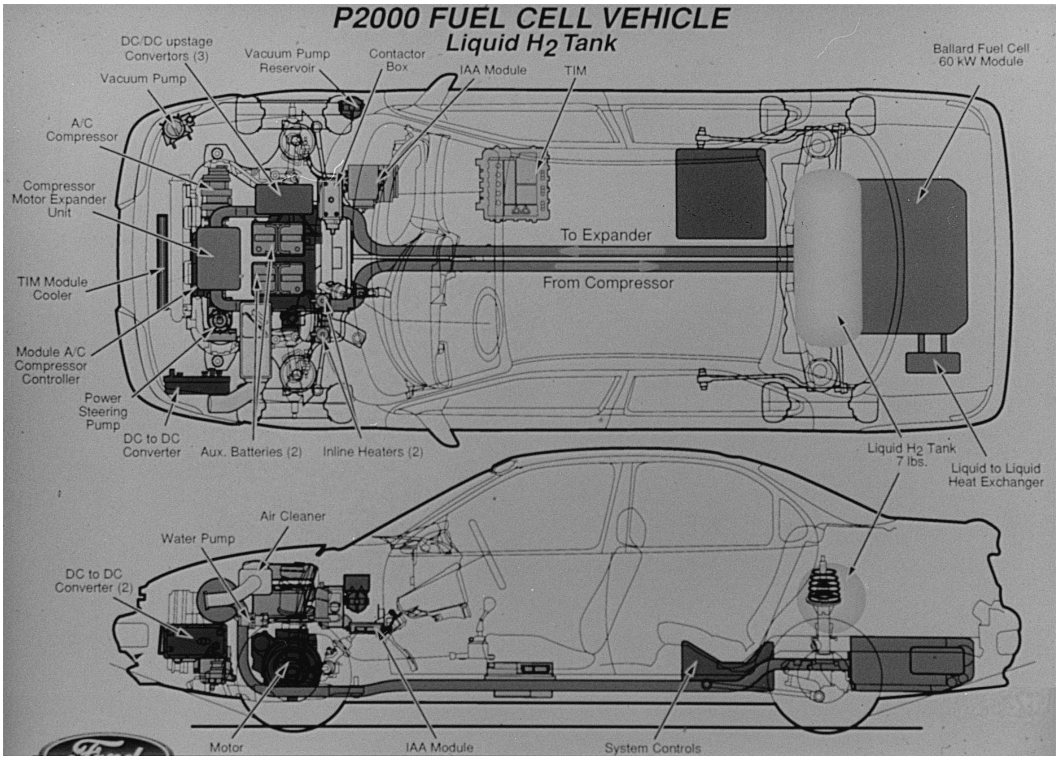

Fig. 2. Ford P2000 electric vehicle fitted with 60-kW Ballard fuel cell.

Perhaps an example of this limitation exists today in the catalytic converters which are fitted in the exhaust systems of ICEVs.

3. Electric vehicles in the near-future

The following are my views on the prospects for EVs in the near future.

(i) Assuming that something like catastrophic global warming does not start to occur, it is unlikely that Draconian legislation, world-wide, will force any large-scale reduction of the rate at which the world population of cars is increasing.

(ii) In spite of the current rash of bullish statements being made about the probable growth in the number of fuel-cell powered vehicles in the first decade of the new millennium, I do not, at this time, see the evidence to support the view that they will make significant in-roads into the world-wide production of ICE cars during the next 25 years. I hope I am wrong and I shall be very happy if I am! In my opinion, a route of steady progression will be opened up from where EVs are today to where they have to be if atmospheric pollution is to be greatly reduced. Certainly, ICEV manufacturers now seem to be intent on reducing the weight of their future products (without sacrificing safety). Ford Motor, for example, is now claiming that a 40% reduction in weight is possible. It is also the case that some manufacturers are in the process of developing vehicles which can, at least experimentally, be fitted with alternative drive systems. One interesting development along these lines is a diesel Daimler Benz bus with an electric transmission which will presumably make a pure electric or a hybrid electric version relatively easy to achieve.

(iii) I do believe that the number of battery electric vehicles in the world will increase, probably encouraged by legislation aimed at improving the air quality in cities. The majority of these vehicles will be commercial vehicles and buses with relatively short ranges. Some of the vehicles will have their range extended by opportunity charging, some by battery exchange, and some by employing fuel-cell–battery hybrid systems. There is no reason to expect that battery development will advance at an increasing rate.

It is essential that all EVs are fitted with a simple-to-use, but comprehensive, form of self-diagnostic equipment. This would help to reduce the need for the re-training of maintenance staff and would be capable of giving early warning of problems such as cell imbalance in batteries. After all, diagnostic systems are now fairly common in ICEVs. It is also important that emergency services are made aware of any permanent influx of EVs in their areas, particularly as the system voltage of modern vehicles is increased.

There will also be a greater use of engine-driven cars fitted with an electric drive for use if engines are banned in inner-city areas (e.g., the Audi Duo), and of electric drives added to ICEVs to enhance their performance and reduce their emissions (e.g., the Toyota Prius).

Overall, I see no reason at all to disagree with the reported comments of John Wallace of the Ford Motor which were that he could foresee a situation where battery-powered and fuel-cell cars may well coexist with HEVs and ICEVs. This is indeed bound to be the case for quite a long time, for it would be a remarkable technology which suddenly replaced all the road transport drive systems of today in one fell swoop.

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References

[1] D.A.J. Rand, R. Woods, R.M. Dell, Batteries for Electric Vehicles, Chap. 1, Research Studies Press, Taunton, England, 1998.