Market for Electric Vehicles: Learning from Experience

LAURIE MICHAELIS

Following the zero-emission vehicle mandate of the California Air Resources Board (CARB), other states and countries are beginning to view electric vehicles as a means of reducing urban air pollution. However, duplication of the CARB mandate would face strong opposition from automobile makers and might not be effective in the marketplace. Successful introduction of electric vehicles in the short term will depend on car buyers' choosing cleanliness and quietness of electricity over the combined speed, power, range, and convenience of vehicles with internal combustion engines. This change in consumer choice could be forced by legislation or encouraged by taxes. Experience with attempts to introduce alternative fuels and to promote the use of transit can give insight into the effectiveness of different measures; such experience indicates that restrictions on the use of conventional vehicles are likely to be more effective than incentives for using electric vehicles. In the long run, electric vehicles will succeed in the market only if there is a radical shift in either technology or consumer preferences.

Around the world, electric vehicles are being developed, marketed, sold, and used, mainly as a result of the California Air Resources Board (CARB) mandate for the introduction of zero-emission vehicles (ZEVs). Automobile makers in North America, Europe, and Japan, aiming to maintain their Californian market share and to prepare for possible future developments in other markets, have at least tried to minimize risk by converting existing car models to operate on batteries and by undertaking new electric car designs. In some parts of the world, including France, Canada, and Switzerland, surplus baseload electricity generating capacity provides a supply-side push for the development of electric vehicles, and these countries have seen some of the first significant electric vehicle trials and marketing efforts.

Analysis of the market prospects for electric vehicles emerges from a variety of viewpoints. Analysts have their own justifications, based on differing perceptions of the mechanisms influencing the car market, for expectations ranging from the complete failure of electric vehicle technology to its emergence as the main successor to the internal combustion engine. This paper will outline the rationale behind the viewpoints and provide a synthesis.

Perhaps the most important point at the outset is that markets, especially those that depend strongly on culturally influenced tastes and on technology, are unpredictable. Attempts to predict the course of market penetration of a technology generally hinge on addressing limited sets of factors in this unpredictability. Thus, social scientists tend to focus on improving their understanding of what drives people's demand for the technology, whereas engineers may concentrate on the potential for designing and developing the technology to meet the needs of users.

Environment Directorate, Organization for Economic Cooperation and Development, Two rue André-Pascal, 75775 Paris Cedex 16, France.

VIEWS OF MARKET FOR ELECTRIC VEHICLES

The views commonly found among the various disciplines involved in the electric vehicle market can be characterized as follows:

- *Engineers* usually design technology and infrastructure to meet a need or solve a problem. They may also have aesthetic preferences for particular solutions, such as electric drivetrains. These analysts can help to identify the range of consumers for whom electric vehicles are technically the best solution as well as the extent to which technology can provide a better match with consumer needs (*1,2*).
- *Microeconomic analysts* extend the engineering approach to take cost into account, often seeking the least-cost means of meeting a need. The market for electric vehicles then depends on their overall discounted lifetime cost relative to conventional vehicles. This approach is taken by DeLuchi (*3*) in his comparative analysis of gasoline, fuel cell, and electric vehicles; by the International Energy Agency (*4*) in a comparative analysis of gasoline, diesel, and compressed natural gas (CNG) vehicles; and by Energy Technology Support Unit (*5*) in a systems analysis study of energy technology options. The market identified for electric vehicles depends very much on the assumptions about costs. The expectation of high capital costs but low running costs leads to the conclusion that the best market is to be found where annual mileage is high. According to this approach, battery, electric motor, and motor controller costs must be reduced substantially and performance must improve if a significant market is to be found (*5*).
- *Econometric analysts* assume that consumer attitudes and preferences are the main determinant of market share and base analysis of future market developments on historical revealed or stated preference. Such analysis is perhaps best exemplified by Bunch et al. (*6*), who develop a model for the market share of a variety of alternative fuel and electric vehicles based on their characteristics (cost, range, performance, fuel availability, emissions, etc.) and on a stated preference survey in Southern California. The conclusion of this approach is that given the high cost and low performance of electric vehicles, they are unlikely to have a market without the pressure of regulations such as the CARB ZEV mandate.
- *Decision analysts* develop models of decision making and priority ranking. One description of decision making is given by Dietz and Stern (*7*), who develop a model of choice based on a limited number of variables or influences. Dietz and Stern emphasize the importance of peer group pressure and opinions in choice. Another model of the decision making process is discussed by Komor and Wiggins (*8*) for energy conservation measures; this analysis aims to go beyond linear correlations between the probability of consumers' taking action and the various factors that influence them (expected resulting change in comfort, peer group agreement, and

familiarity: "friends have done it," ease of taking the measure, and low cost of the measure). Instead, a decision tree is constructed, with each of these factors influencing the probability of action.

- *Psychological/attitudinal analysts* relate choice to consumer attitudes, needs, and personality attributes or to personal needs. Concerns about environmental issues are linked to action on these issues only by those who perceive the benefit of their action for themselves. Van Raaij and Verhallen (*9*), discussing energy conservation, explore the association between behavior and personality types. This approach is often used to estimate the potential market share of a new product using information about the number of people of each personality type in the population. Diekstra and Kroon (*10*) identify a range of needs or motivations associated with car use, ranging from freedom and power to love and protection.

Some analyses incorporate more than one of these views, and more views can be identified, but these are the main approaches that have been used in published literature. All are important in shedding light on factors that will influence the development of a market for electric vehicles, but none of them offers a complete or rigorous analysis of the issues. As such it is not surprising that their conclusions differ.

In combination they provide useful information. The engineer and microeconomist together tell us that pure electric vehicles are likely to be attractive only to users with high annual mileage and low variance in daily mileage with no need to be able to make trips of more than 100 mi. This characteristic restricts them to commercial and public-sector service applications and typically indicates a maximum market on the order of 5 to 10 percent of all light-duty vehicles.

Hybrid vehicles, which are attractive from the engineering point of view for their flexibility, are unattractive from the microeconomic point of view because they combine high capital with high running costs. They may have a larger market niche than pure electric vehicles: they would be of interest to those with a high annual urban mileage, low variance in daily urban mileage, and the need to use the same vehicle for long trips. These long trips would have to be frequent to justify the cost of the hybrid.

When information from the economist is combined with that from the engineer and the microeconomist, it can be seen that even if electric vehicles appear to meet the needs and cost constraints of consumers, they would not be the preferred technology given current preferences. This does not mean that there is no hope for electric vehicles, but it does mean that if a market is to be established for electric vehicles, preferences must change. The anthropologist, sociologist, and psychologist provide some insight into how this might happen.

CHANGING MARKETS

Before considering the ways that markets can be changed, it is important to consider whether we want them to change, or who wants them to change and who would prefer that they did not change, and why. As for electric vehicles, there are various reasons that some might wish to introduce them and others might prefer that they were not introduced to the market.

In favor of electric vehicles,

- There is an energy-related interest in electric vehicles because the electricity used to recharge their batteries can be derived from a wide variety of sources, reducing dependence on petroleum and fossil fuels in general and providing an opportunity to switch to renewable energy sources.
- There is a potential environmental interest in electric vehicles for their ability to reduce urban air pollution and noise as well as greenhouse gases in some cases (depending on the electricity source).
- Electric utilities may be interested in electric vehicles because not only do they provide a new market, but they can be recharged at night, providing a market for off-peak power.
- Some technologists may be interested in electric vehicles because they use a more aesthetically pleasing route of energy conversion than vehicles with internal combustion engines.
- Vehicle users may be interested in electric vehicles because they perceive them as clean, environment-friendly, quiet, durable, simple to drive, and technologically advanced. They may also be interested in attributes such as the capability to recharge the battery at home (*11*).

To the detriment of electric vehicles,

- Car manufacturers might prefer not to have electric vehicles introduced because they think it would increase their manufacturing costs, increase their exposure to risk, and require them to change their base of component suppliers (*12*).
- Oil companies might prefer not to have electric vehicles introduced because they could reduce the market for their main product.
- Some transportation and environmental interest groups might see electric vehicles as a distraction from the real need in the transport sector: a reduction in traffic volumes to address the combined problems of social equity, congestion, accidents, pollution, noise, and land use for roads.
- Vehicle users might be dissuaded from buying the vehicles by their high cost, lower acceleration, top speed, range, and carrying capacity and by long recharging times and inadequate recharging infrastructure.

Government and Electricity Industry Interest in Electric Vehicles

The implications of electric vehicles for energy and the environment depend heavily on the location in which they are used and the fuel and technology used for power generation. Where fossil fuels are used for power generation, primary energy use and hence greenhouse gas emissions for electric vehicles are likely to be of the same order of magnitude as those for gasoline or diesel vehicles (*1,13*). Table 1 compares emissions of local pollutants from electric vehicles with those from conventional and alternative fuel internal combustion engine vehicles. As the table indicates, emissions of carbon monoxide and volatile organic compounds (VOCs) fall when electric vehicles replace gasoline vehicles. However, NO_x and, in some instances, SO_x (not shown in the table) increase, especially where coal or fuel oil play a large part in power generation.

Electric vehicles will result in low levels of air pollution where the marginal source of electricity is nuclear power, hydroelectric, or renewables other than biomass. This applies in several Organization for Economic Cooperation and Development (OECD) countries, including Austria, Finland, France, Iceland, New Zealand, Norway, Sweden, and Switzerland, as well as parts of the United States and Canada. There may also be an environmental interest in electric vehicles where electricity is generated in remote regions or outside the area of concern.

TABLE 1 Operational Emissions from Alternative Fuel Cars

	CO	Non-methane VOC	NO_X	PM	Life-cycle Greenhouse Gases (CO_2 equivalent) note (e)	Notes
Internal Combustion Engine Vehicles: Estimated Exhaust Emissions, g/km						
Reformulated Gasoline/ 3 Way Catalyst/Closed Loop	0.7-1.5	0.06-0.14	0.08-0.3	0	222-268	(a)
Diesel/Oxidation Catalyst	0.2-0.5	0.1	0.6-0.8	0.2-0.3	183-266	(b)
CNG/3 Way Catalyst/Closed Loop	0.5-1	0.03-0.1	0.1-0.4	0	174-253	(c)
Hydrogen	0.01-0.02	0.005-0.01	0-0.5	0	29-48	(c)
Electric Vehicles: Estimated Power Station Emissions, g/km						
US Average Generating Mix	0.02	0.002	0.31	0	244-248	(d)
EU Average Generating Mix	0.04	0.007	0.64	0	214-218	(d)
Coal	0.03	0.003-0.02	0.51-1.33	0	344-358	(d)
Oil	0.03	0.005	0.34	0	297-301	(d)
Gas (Combined Cycle Gas Turbine)	0.08-0.12	0.004-0.01	0.14-0.26	0	174-188	(d)
Nuclear	0	0	0	0	59-63	(d)
Hydro	0	0	0	0	44-48	(d)

a. Based on (15,16)

b. Based on (16).

c. Based on (16,17,18)

d. Based on electric vehicle energy consumption and emissions from (1,13); US electricity generation emission factors from (19)and US generating mix and transmission/distribution losses from (20). Fossil fuel fired electricity generation also results in SO_2 emissions estimated at 0.9g/km for coal, 0.5g/km for oil-fired electricity (1,19). Technology changes driven by emission regulations are resulting in a rapid reduction in emissions of NO_x and SO_2 from power generation.

e. Ranges taken from (1,13,19). Emissions associated with vehicle manufacturing are based on the current fuel mix in the industry. Life-cycle greenhouse gas emissions from electric vehicles using electricity from nuclear power or hydro are mostly associated with vehicle manufacture.

The electricity supply industry is likely to be most supportive of electric vehicles as an off-peak power market where power plants with high fixed costs and low variable costs (e.g., coal and nuclear) are used to meet marginal demand. This suggests a different set of countries (*14*): Australia, Belgium, Denmark, France, Germany, Greece, Spain, the United Kingdom and, again, parts of the United States and Canada.

Consumer Interest in Electric Vehicles

One way to explore the potential electric vehicle market is to look at the historical market for technologies and fuels, especially those that have been promoted by governments or industries. There are many possible case studies—the best known are those of ethanol in Brazil and CNG in Canada and New Zealand. However, there are few real success stories among attempts to change the fuel used by car drivers. Three can be readily identified: LPG, still a minor fuel but one with an OECD-wide market share 18 times that of CNG in 1992 (*14*) and more than 20 percent of the light-duty vehicle fuel market in The Netherlands; diesel, which has become a major alternative to gasoline in many European and other countries; and unleaded gasoline, which has almost completely replaced leaded gasoline in North America and Japan and is rapidly doing so in Europe. Looking at experience with these three fuels can give some indication of the conditions required for a new fuel to enter the market. It is helpful to start by characterizing the three fuels and the vehicles that use them (Table 2).

Several points are illustrated in Table 2: consumers are more likely to use an alternative fuel that, does not require them to change their vehicle, is cheaper than the conventional fuel, is widely available, and is marketed intensively with a well-known brand name. Where a fuel or the vehicles that use it have disadvantages relative to conventional vehicles, a greater price incentive is needed to encourage its uptake. Thus, both diesel and LPG have achieved a significant market share only in countries where they are available at very low prices relative to gasoline—$0.30 to $0.60 less per liter or one- to two-thirds of the gasoline price. Unleaded gasoline requires discounts of only about $0.05/L to achieve larger market shares.

Table 3 gives details of discounted cash flow calculations for gasoline, diesel, LPG, and electric vehicles in France. Purchase and running costs for the gasoline and diesel vehicles are typical for France in 1992 (*2*). The price and tax rate for LPG and electricity are based on the average prices and taxes for light fuel oil and electricity, respectively, for domestic users in France for 1992 (*20*). The electric vehicle price range is based on that used by Deluchi (*3*). The lower ends of the alternative vehicle price ranges are intended to correspond to mass-produced original equipment manufacturers

TABLE 2 Alternative Fuel Vehicle Attributes and Market Share

Attribute	Unleaded Gasoline vs. Leaded Gasoline	Diesel vs. Gasoline	LPG vs. Gasoline.	Electric Vehicle vs. Gasoline
Need for change of car	Works in existing models, in some cases modifications required. Required in cars with catalytic converters.	Require OEM diesel car	Most existing models can be converted to dual-fuel LPG/gasoline.	Require OEM electric car
Car Retail Price (incl. tax)	Same	$0 to $2 800 higher	$250 to $1 100 higher	$5 000 to $10 000 higher
Fuel Retail Price (incl. tax)	11 ¢ lower to 3 ¢ higher per litre gasoline equivalent	1 to 65¢ lower per litre gasoline equivalent France about mid-range	10 to 60¢ lower per litre gasoline equivalent: Netherlands amongst lowest	50¢ to 85¢ lower per litre gasoline equivalent
Performance	Slightly lower acceleration and top speed reported in some cases	Lower top speed Early models were noisy and had starting problems in cold weather	Slightly lower acceleration and top speed in converted cars	*Either* lower acceleration and top speed with somewhat reduced carrying capacity and range *or* similar acceleration and top speed with greatly reduced carrying capacity and range
Range on Full Tank	Same	Longer	Shorter for same size tank	About one fifth to one third
Fuel Availability	Rapid uptake to near universal availability in most of OECD	Near universal availability	Limited availability	Limited availability initially but home recharge possible
Maintenance	Same	More frequent oil changes	Same	Less with mature technology
Reliability	Same	Better	Same	Better with mature technology
Vehicle life	Same	Up to twice as long for high annual mileage drivers	Same	Potentially much longer
Environmental Attributes Perceived by Public and Media	Perceived as "green" fuel	Perceived by some in Europe as environmentally better. Meets emission standards without catalyst. Emerging concern about particulates.	Perceived as environmentally better.	Perceived as environmentally "best"
Marketing	Enthusiastic and competitive oil company marketing making use of "green" image.	Limited car company marketing as "sensible" alternative to gasoline. French manufacturers most committed	Limited local marketing.	Depends on support from governments, major car manufacturers and utilities.
Outcome	Rapid uptake to near 100% of market	Slow uptake to 10% to 50% of market, highest in France	Moderately rapid uptake to < 30% of market in Netherlands, < 10% elsewhere	?

(OEM) vehicles and, with the exception of some diesel vehicles, are not likely to be achieved for several years.

Even when the higher vehicle cost is taken into account, and assuming that drivers choose between vehicles using a 30 percent discount rate, the levelized cost of driving an LPG or diesel vehicle can be much lower than that of driving a gasoline vehicle. The table indicates further that if electric vehicles and the electricity that they use were completely exempt from tax, they might be cheaper to operate than gasoline vehicles including tax in some circumstances. Without such exemptions they will probably remain considerably more expensive to operate than gasoline vehicles.

A simple engineering/microeconomic interpretation of the evidence presented so far in this paper would be that electric vehicles have little hope of being taken up in the market place, short of technological breakthroughs (probably in several areas of electric vehicle engineering but principally in battery technology) to reduce their cost and improve their performance. Bunch et al. (*6*) go a little farther than this and analyze the stated preference for vehicle attributes of potential vehicle buyers in Southern California. Their results indicate that given current preferences (which include a high value placed on vehicle cleanliness), not only are purchasers likely to be unwilling to buy low-performance, low-range electric vehicles that are more expensive than gasoline vehicles, but they are unlikely to buy them unless they are much cheaper than gasoline vehicles.

Other analytical approaches give different results. Turrentine and Sperling (*11*) have investigated the effects of offering test drives

TABLE 3 Cost of Running Alternative Fuel/Electric Cars

	Gasoline	Diesel		LPG		Electric	
		High	Low	High	Low	High	Low
Pre-tax vehicle cost ($)	15 168	17 443	15 168	16 083	15 384	24 768	20 928
Post-tax Car Cost ($)	**18 626**	**21 402**	**18 626**	**19 742**	**18 889**	**30 338**	**25 653**
Max. Distance Travelled (km)	160 000	200 000	320 000	160 000	160 000	320 000	320 000
Life (Body-Limited) (Years)	10.00	10.00	10.00	10.00	10.00	10.00	10.00
Pre-tax Price of Fuel ($/litre)	0.26	0.26	0.26	0.23	0.23	1.50	1.50
Fuel Excise Tax, $/litre gasoline equiv.	0.70	0.33	0.33	0.13	0.13	0.27	0.27
Fuel Retail Price, $/litre gasoline equiv.	**0.96**	**0.59**	**0.59**	**0.36**	**0.36**	**1.77**	**1.77**
Fuel Consumption (litres gasoline equiv./100km)	7.60	6.08	6.08	7.27	7.27	3.00	2.00
Cost per Service ($)	96	96	96	96	96	64	64
Distance Between Tyre Changes, km @$235	40000	38000	38000	40000	40000	30000	30000
Distance Between Servicing (km)	10000	6667	6667	15000	15000	10000	10000
Repair cost ($) per 1000 km	373	428	373	395	378	607	513
Cost of Catalyst ($) (Replaced Every 100 000 km)	768	768	0	768	768	0	0
Annual Licence Fee ($)	86	86	86	86	86	86	86
Insurance: ($)	658	727	658	686	664	950	833
Levelised Costs per km (US 1992$) (discounted costs divided by total discounted km driven in vehicle lifetime)							
Fuel (inc. taxes)	**0.073**	**0.036**	**0.036**	**0.026**	**0.026**	**$0.053**	**$0.035**
Levelised vehicle costs (vehicle purchase minus resale)	**0.303**	**0.348**	**0.303**	**0.321**	**0.307**	**$0.493**	**$0.417**
Levelised fixed costs (insurance, licence)	**0.049**	**0.053**	**0.049**	**0.050**	**0.049**	**$0.068**	**$0.060**
Levelised variable costs (maintenance, tyres, catalyst, oil, tolls, fuel)	**0.050**	**0.060**	**0.053**	**0.049**	**0.047**	**$0.063**	**$0.054**
TOTAL COST	**0.474**	**0.497**	**0.440**	**0.446**	**0.429**	**$0.676**	**$0.566**
Cost ex-tax	**0.349**	**0.395**	**0.348**	**0.361**	**0.347**	**$0.557**	**$0.465**

Notes: Derived from (21), based on Renault Clio, 1.4 litre RT, 4 cylinder, 5 door; French Fuel and Electricity Prices and Taxes Discount rate 30% Annual km 15 000

and a variety of other approaches to improve consumers' understanding of electric vehicle attributes and their own requirements. About three-quarters of participants said that their view of electric vehicles had improved as a result of the study, and a significant proportion said that they would be prepared to buy electric vehicles if they were no more expensive than gasoline vehicles.

Approaches based on the analysis of personality types and attitudes indicate that electric vehicles will be taken up initially by "innovators" (people who are prepared to invest in the latest technology, regardless of cost). Their further uptake in the market will depend on the extent to which consumers see them as offering personal benefits in comfort, convenience, cost, and their local environment.

Given that the introduction of electric vehicles appears to depend on drivers' changing their behavior, if not their preferences, it might be helpful to look at experience elsewhere with attempts to bring about behavioral change.

Experience with Public Transport—Lessons for Policy

Experience with public transport may be relevant to the market for electric vehicles. Various views of the comparison between electric vehicles, public transport, and conventional cars are summarized in the following.

From the engineering viewpoint, electric vehicles are less convenient than conventional cars but more convenient than public transport. Owners of electric vehicles must plan their trips around battery recharging and within limited vehicle range, whereas public transport users are constrained by service schedules and routes. Electric vehicles are likely to have less cargo and passenger capacity than conventional cars, and they probably are slower than conventional vehicles although faster on a door-to-door basis than public transport.

From the microeconomic viewpoint, electric vehicles are unattractive compared with conventional cars because their costs are much higher, whereas public transport costs are usually lower per passenger kilometer on average (*5*). However, variable costs at the time of use for the user are usually lower for cars than for public transport (where the user may have to pay the full costs as a variable cost) and lower for electric vehicles than for gasoline vehicles.

Diekstra and Kroon (*10*) describe some of the more compelling motivational aspects of cars as consumer products:

- Freedom of movement,
- Power,
- Individualism/status/communication,
- Love object,
- Narcotic,
- Womb,

- Archetypal identification,
- Winning territory,
- Identification/anthropomorphization,
- Common interest, and
- Time-filler.

Of these features, the ones that may be lacking in electric vehicles are in their roles in providing freedom of movement, power, and narcotic effects (which Diekstra and Kroon link to high-speed driving). Public transport, conversely, provides very few of these features.

Analysis of behavior with regard to public transport may give some indication of the way consumers respond to a less convenient and more expensive transport option. Experience indicates that people's willingness to use public transport depends partly on the quality of the service provided and that ridership can be increased by improving services and information. However, improvements in public transport have rarely proved to be an effective means of stemming the rise in private transport use unless they are combined with measures to limit the attraction of car travel such as access and parking constraints (*22–24*).

Simply making electric vehicles available, even at a lower cost than gasoline vehicles, may not lead many drivers to switch to using them, unless technology progresses to the point that they offer greater convenience than gasoline vehicles. However, if they are cheaper than gasoline vehicles, they may be used by people who could not afford a gasoline vehicle or as additional cars in multiple-car households: that is, they are likely to lead to additional car use rather than to a switch from gasoline to electric car use.

But if electric vehicle use is encouraged by making it more expensive or more difficult to use gasoline vehicles—whether through higher gasoline taxes, taxes on gasoline cars, or parking and access restrictions that do not apply to electric vehicles—drivers are more likely to switch to electric cars.

CONCLUSIONS

There may be energy and environmental reasons for using electric vehicles in several OECD countries, in particular France and parts of the United States.

Electric vehicles using current technology are less convenient than gasoline vehicles. Experience with alternative fuels indicates that drivers require substantial financial incentives to persuade them to switch to any form of transportation that is less convenient than the gasoline car. However, if there is no inconvenience the financial incentive required is minimal.

Mass-produced electric vehicles will probably be more expensive to make but cheaper to operate than gasoline vehicles. Their overall levelized costs will most likely be higher than those for gasoline vehicles. Without a change in consumer attitudes and preferences, they are therefore unlikely to find a significant market without government intervention and short of a significant leap forward in electric vehicle technology.

If governments wish to encourage the use of electric vehicles, they will have more success with policies that discourage the use of gasoline cars than with subsidies for, or information about, electric vehicles. The most effective policies for encouraging electric vehicle use in urban areas will be similar to the policies that discourage gasoline car use, principally restrictions and charging for parking and access.

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Publication of this paper sponsored by Committee on Alternative Transportation Fuels.