# 1 SUMMARY

In the electric vehicle, an electric motor replaces the conventional gasoline engine, and a storage battery replaces the gasoline tank. The battery may be recharged from a standard electrical outlet, thus making the vehicle independent of the gasoline pump. It is this prospect which has primarily motivated widespread public interest, a government program of development and demonstration, and a project at General Motors to market mass-produced electric cars in 1985.

For the first time since the early 1900s, many expect electric vehicles to enter the US automotive market in substantial numbers. Yet their prospects are far from obvious. The degree to which new technology will improve the performance and cost of electric vehicles is uncertain. Sales of electric vehicles are difficult to forecast and may be insufficient to displace many gasoline-powered vehicles, Electric utilities may generate recharge electricity in oil-fired power stations, in part offsetting reductions in gasoline use for vehicular fuel. Overall, electric vehicles may not compare favorably with competing alternatives such as much-improved conventional vehicles and synthetic fuels.

In the past, electric vehicles generally have not been competitive with gasoline-powered vehicles because they have been expensive and restricted in driving range. This has been primarily due to the weight, cost, and limitations of the electric storage battery. Batteries available during the 1970s may be accurately likened to a gasoline tank for a subcompact car costing over $1,000, weighing over 1,000 pounds, requiring replacement every 10,000 miles, and holding only 2 gallons. This sort of fuel storage limits driving range to about 40 miles and adds depreciation costs of 10 cents per mile to operating expenses. Furthermore, refueling in a few minutes at any convenient service station is not possible. Instead, recharging a storage battery usually requires 8 to 12 hours.

Major technological advances, however, appear imminent. In the near term (before 1990), electric cars with useful ranges of 100 miles may become available. Purchase prices, however, will probably exceed those of comparable conventional cars by up to 75 percent, largely because of the weight, bulk, and cost of the required batteries. Overall life-cycle costs will also exceed those of conventional cars, by perhaps as much as 25 percent. Despite improved battery life, battery depreciation will remain high enough to offset savings expected from low maintenance costs and low electricity costs. There is a possibility, however, that advanced battery technology which might come in the 1990s could bring 150-mile ranges, initial prices only a third higher than those of comparable conventional cars, and life-cycle costs which are actually lower, even with electricity and gasoline prices (in constant dollars) no higher than those of 1980.

Though improvements in electric motors and controllers were assumed for these projections, the critical assumptions are longer life and higher energy content of future batteries. Near-term batteries which may be successfully mass-produced before 1990 include lead-acid, nickel-iron, nickel-zinc, and zinc-chlorine systems with 2 to 3 times more energy storage per pound than batteries available during the 1970s, and operating lifetimes as much as 4 times longer. It is uncertain which of these near-term candidates will succeed, however, and it is not guaranteed that any will achieve the performance and life projected here. More advanced batteries for the 1990s, such as improved zinc-chlorine systems or high-temperature lithium-metal sulfide batteries, may be able to store 4 to 6 times the energy per pound of 1970s batteries, and last for the useful life of the vehicle. When and if such advanced batteries will be successfully developed is very uncertain.

A 100-mile range for the electric car is not only a reasonable prospect for the later 1980s, it is also a goal which has been stated by both the US Department of Energy and General Motors. Though enough for most urban travel, it would probably suffice for only about 80 percent of the total annual mileage driven by typical US cars, which are used for long-distance travel as well as urban travel. The remaining 20 percent would be shifted to another conventional car. Thus, the electric car which replaces the typical conventional car will probably displace only about 80 percent of its annual petroleum use (even if no petroleum is used to generate recharge energy) .

In multi-car households, trips beyond the capability of an electric car could usually be shifted to a conventional car with little inconvenience. Inadequacy for some 20 percent of typical travel, however, indicates that even the 100-mile range between recharges would be an important limitation to many motorists. The hybrid-electric car relieves this limitation by including an internal-combustion engine as well as an electric motor and storage battery for propulsion. Electricity alone would be used for driving within the speed and range capability of the electric motor and battery. For more demanding driving, the engine could be started to provide power, endurance, and quick refueling capability like that of the conventional car.

The simplest hybrid of this sort would utilize the internal combustion engine only for extending range beyond that possible using electricity alone. The necessary engine would be quite small (15-25 horsepower, just adequate for freeway cruising at speeds up to 55 mph), and it would be started only after battery depletion during long trips. In most urban driving the engine would not be operated at all. The range-extension hybrid would thus provide most of the benefits of the pure electric vehicle, yet impose no range limitation or sacrifice of mobility. Furthermore, it could be little or no more expensive than the pure electric vehicle, because the weight and cost of the engine could be offset by reductions in the weight and cost of the required battery.

Petroleum saving of the range-extension hybrid would be about the same as that of the 100-mile electric car. That is, substitution of the hybrid for a conventional car would reduce petroleum consumption by 80 percent (assuming no use of petroleum for generating recharge electricity). Though its range on electricity alone would be less than that of the all-electric vehicle, this range could be utilized on every trip, including part of long trips which pure electric cars could not make.

The acceleration capability of electric (and range-extension hybrid) vehicles will be low, like that of many diesel cars, but nonetheless adequate to keep up with traffic in city streets and on freeways. US motorists have often preferred higher acceleration, however, and this can be provided by a high-performance hybrid design. In this hybrid, slow driving would be accomplished without use of the internal-combustion engine. At the driver's demand for high acceleration or high speed, however, the engine would be started instantly to add the necessary extra power. An engine several times larger than that of a range-extension hybrid is required by the high-performance hybrid to achieve the acceleration and speed capabilities of recent full-size US sedans. Typically, however, the weight and cost of the larger engine are more than offset by reductions in the size of the associated electric motor and battery. It is estimated that the initial prices for high-performance hybrids would be intermediate between the prices of conventional cars and all-electric cars.

The reduced capability of the electric drive, however, necessitates more extensive use of the internal-combustion engine in the high-performance hybrid. As a result, the annual petroleum consumption of such a hybrid is estimated at 30 to 60 percent that of a comparable conventional car. In addition, the on-off mode of internal-combustion engine operation also leads to technical problems and risks associated with cold starts, engine longevity, and smooth driveability. Though government development efforts are focused on the high-perfomance hybrid, the range-extension hybrid entails substantially less technical difficulty and risk, while offering the potential for substantially greater petroleum saving.

Hybrids are generally expected to enter the marketplace several years after electric vehicles. Pure electric vehicles are simpler and less risky to develop. Moreover, hybrids cannot be successfully developed until satisfactory electric drive components and storage batteries have been developed. Though high battery energy is less important for hybrids, long battery life remains critical. Without it, costs of battery depreciation will be so high for either hybrid or electric vehicles that wide market acceptance is unlikely.

The electric utility industry and electric outlets in garages constitute the key elements of the infrastructure required for operating electric vehicles. So long as recharging is done late at night, existing power plants and power lines are generally adequate, though addition of higher-capacity outlets specifically for battery recharging would be desirable in many garages.

Electric generating capacity already existing and planned in the US could recharge tens of millions of electric vehicles each night. The reason for this is that at present, demand for electricity late at night is ordinarily much less than during the peak hour of the day, which usually occurs in the late afternoon. In 1979, US electric utilities operated at an average power output equal to only 64 percent of their maximum power output during the year. If 25 percent of all cars and light trucks in the United States had been electric, recharging would have increased average utility power output to only 68 percent of the maximum achieved during the year. Given recharging late at night, this increase could have been readily accommodated.

At present, few utilities have rate structures or metering and control equipment to encourage recharging late at night. Many utilities are moving towards peak and off-peak pricing, however, which would provide substantially lower electricity prices for late night recharging. Utilities are also moving towards selective load control. Under this arrangement, lower electricity prices would be given to electric vehicle users whose battery chargers could be briefly interrupted (by remote control) at occasional times of excessive total demand for electricity.

Until utilities offer these innovative rates, however, users of electric vehicles are likely to begin recharging immediately at the end of each day's driving. This would be the most convenient method and--under most existing rates--no more expensive. But it would add to existing peak loads, straining available and planned generating facilities. It would also require more petroleum than recharging late at night, when more coal-fired electric generating capability would otherwise be available to generate recharge power.

In recent years, electric utilities have avoided use of petroleum-fired generating plants and installed new generating facilities using other sources of energy. In 1979, this resulted in the use of petroleum for only about 15 percent of all generation in the US. In many areas of the country, utilities use little or no petroleum and so could accommodate electric vehicle recharging without any substantial additional use of petroleum. Elsewhere, however, where utilities have a mix of facilities and fuels available, it is petroleum-fired plants which are idled as demand drops each night; and it is these plants which would have to be restarted to recharge electric vehicles overnight. Overall, some 30 percent of recharge energy would come from petroleum if electric vehicles were distributed uniformly in the United States in 1980. By 2000, this figure will fall to little more than 10 percent, owing to the greater reliance planned on non-petroleum energy sources.

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Though much of the electricity supply infrastructure needed for electric vehicles is already in place, some vehicles are not readily accessible to recharging outlets. Although the data are poor, it appears that roughly 25 percent of cars and light trucks in the US are parked on the street overnight, rather than in a garage or carport where electric outlets are either already available or could be installed (for roughly $100-300). Only about half of all US cars and light trucks in personal use are at single family housing units with off-street parking, where electricity is most readily available. Adding electric outlets in parking garages and parking lots may cost $400-500 per parking space, a significant expense (though much less than the differential between the prices of electric and conventional vehicles) . An alternative to home recharges would be service stations offering quick recharges or battery swaps, but this would be a much more expensive way to deliver electricity to vehicles.

The materials supply industry is also a vital component of the infrastructure required to support electric and hybrid vehicles. In addition to the materials required in conventional cars, electric vehicles will demand large quantities of new materials for batteries. Expanding extraction and refining capabilities to support production of several million electric vehicles annually in the 1990s appears feasible. Much higher levels of production, however, could bring problems. In this context, world resources of some battery materials appear no more abundant than world resources of petroleum. Mass production of nickel-iron and nickel-zinc batteries, for example, could lead to substantial increases in imports of nickel and cobalt. Formation of international cartels to control supplies and prices is a possibility. Other types of batteries, however, rely on materials which are abundantly available in the United States (lead, zinc, chlorine, lithium, sulfur) . Moreover, once an inventory of batteries is established, effective recycling of battery materials should drastically reduce needs for additional new materials from either imports or domestic production.

The motor vehicle industry could produce, sell, and service electric and hybrid vehicles without drastic changes in its structure. The major change required would be a shift of activity and employment from service stations to battery manufacturing and sales. Though service has often been a problem for the electric vehicles produced recently in very small quantity by small businesses, it appears the major auto makers have the organizations, procedures, and expertise to achieve reliable designs, effective training of mechanics, and adequate provision of spare parts for electric and hybrid vehicles.

The market penetration of electric and hybrid vehicles is uncertain, raising significant risks for both government and industry development programs. Existing projections of the number of electric and hybrid vehicles in the US fleet by the year 2000 range from about one percent all the way up to about 10 percent. At the low end of this range, mass production of electric and hybrid vehicles may not be profitable or economically viable.

Market penetration depend strongly on many uncertain factors:

- o Future battery technology, and particularly the operating life and consequent depreciation costs.
- o The performance, fuel economy, and reliability of future competing conventional cars, which are likely to improve continually.
- o The availability of liquid fuels for motor vehicles, in eluding gasoline from domestic or imported petroleum, gasoline made from shale oil or coal, methanol, and liquified petroleum gases (LPG).
- o The cost of liquid fuels relative to the cost of living and the cost of recharge electricity.

All these factors have important effects on the relative benefit to the motorist of electric and hybrid vehicles which are wholly or partially independent of liquid fuels, but considerably more expensive to buy than comparable conventional vehicles.

For electric (but not hybrid) vehicles, marketability also depends strongly on the value consumers attach to range between refueling or recharging, a subject about which little is known. On the one hand, travel surveys show that on a typical day, 95 percent of all motorists drive less than 100 miles, and 95 percent of secondary drivers (drivers traveling least at multi-driver households) travel less than 50 miles. On the other hand, consumer surveys show motorists attach large dollar values to long range and quick refueling capability. (From one survey, it appears urban motorists would pay over $4,000 extra to increase driving range from 50 to 200 miles.)

Generally, operators of commercial vehicle fleets also indicate demanding range requirements as well. In a few commercial applications, however, range and speed requirements are low and driving conditions (frequent stops and starts with long periods of idling) adversely affect the life and fuel consumption of conventional vehicles. In these applications, such as mail delivery, utility meter reading, and servicing of urban coin telephones, electric vehicles promise to be competitive in the near future. Only a few percent of all commercial fleet vehicles, however, are in such service.

The principal benefits and costs of large-scale use of electric vehicles are illustrated by the following:

- o Energy. Nationwide electrification of 20 percent of annual car and light truck travel in 2010 would reduce automotive petroleum use by around 18 percent. If electric vehicles were introduced only in regions where utilities would use little or no petroleum for generating recharge electricity, up to 70 percent of annual travel could be electrified with almost no use of petroleum.

- Environment. Electrification eliminates exhaust emissions from vehicles but would increase sulfur oxide emissions from fossil-fueled power plants. On balance there would appear to be an improvement in air quality, but it is small. Stringent controls are being applied to pollutant emissions both from motor vehicles and electric utilities. Thus pollutant emissions from other sources will largely mask changes due to vehicular electrification. Because electric propulsion is extremely quiet, it would reduce traffic noise; but again, reductions would be small because of the dominant roles played by large trucks and tire noise. Tire noise, of course, will be the same for both electric and conventional vehicles.

- Economy. Use of electric and hybrid vehicles would increase motorists' cost of travel, at least until gasoline becomes much more expensive or very advanced batteries are developed. Changes elsewhere in the economy would be relatively small. The motor vehicle industry accounts for less than 4 percent of US employment, and many jobs within it (production of vehicle bodies, running gear, and tires; vehicle distribution and sales; parts supply) would be little changed by electrification. Year-to-year changes required for 20 percent electrification of US light vehicle travel by 2000 or 2010 would be very small.

- Resources. Known resources of most battery materials would be adequate for electrifying 20 percent of US car and light truck travel; but problems would arise for many battery types if there were to be worldwide vehicular electrification on a large scale. Increased demand due to electrification would increase prices particularly for lithium, cobalt, and nickel. Generalized data suggests that increasing prices would lead to increased exploration, improved methods of extraction, and thus expanded reserves and resources; but this is at best speculative.

- Transportation. Electric vehicles could provide substantial mobility in the absence of petroleum, with potentially low maintenance, high reliability and a smooth, quiet ride. Today's levels of mobility, however, would be impaired by the range limitation of electric vehicles, and high acceleration capability would be unavailable or uneconomic. Hybrids could provide unimpaired mobility and, with higher use of petroleum, unimpaired acceleration capability as well.