5 INFRASTRUCTURE

5.1 INTRODUCTION AND SUMMARY

The infrastructure required for widespread use of electric and hybrid vehicles (EHVs) consists of four major parts:

- The electric utility industry, which must generate and distribute electric power for recharge.

- Facilities for convenient recharging, which may include some combination of special electric outlets at residential, commercial, and industrial parking places, service stations providing quick battery recharges or battery exchanges, and even electrified highways.

- Extractive industries and mineral resources, which must supply materials needed for batteries.

- Production, sales, and support industries, which must manufacture, merchandise, and service EHVs.

In each of these four areas, existing capabilities are impressive in relation to requirements for introducing EHVs. For example:

- In 1979 the electric utility industry generated 2.2 trillion kilowatt hours of electric energy, three times as much as necessary to electrify all 146 million cars and light trucks on US roads in 1980. In 1979 the industry operated at an average power output which was only 64 percent of its maximum output during the year, and electrifying 20 percent of all US cars and light trucks would have raised average power output to only 68 percent of maximum output during the year.

- Most residential garages and carports have standard 120-volt electric outlets capable of delivering enough energy during the eight-hour period from 11 p.m. to 7 a.m. to drive a four-passenger electric car 30 to 40 miles. Many garages have 220-volt outlets for clothes dryers capable of providing four times as much energy in 8 hours. Average daily auto use in the United States, in contrast, is only about 28 miles.

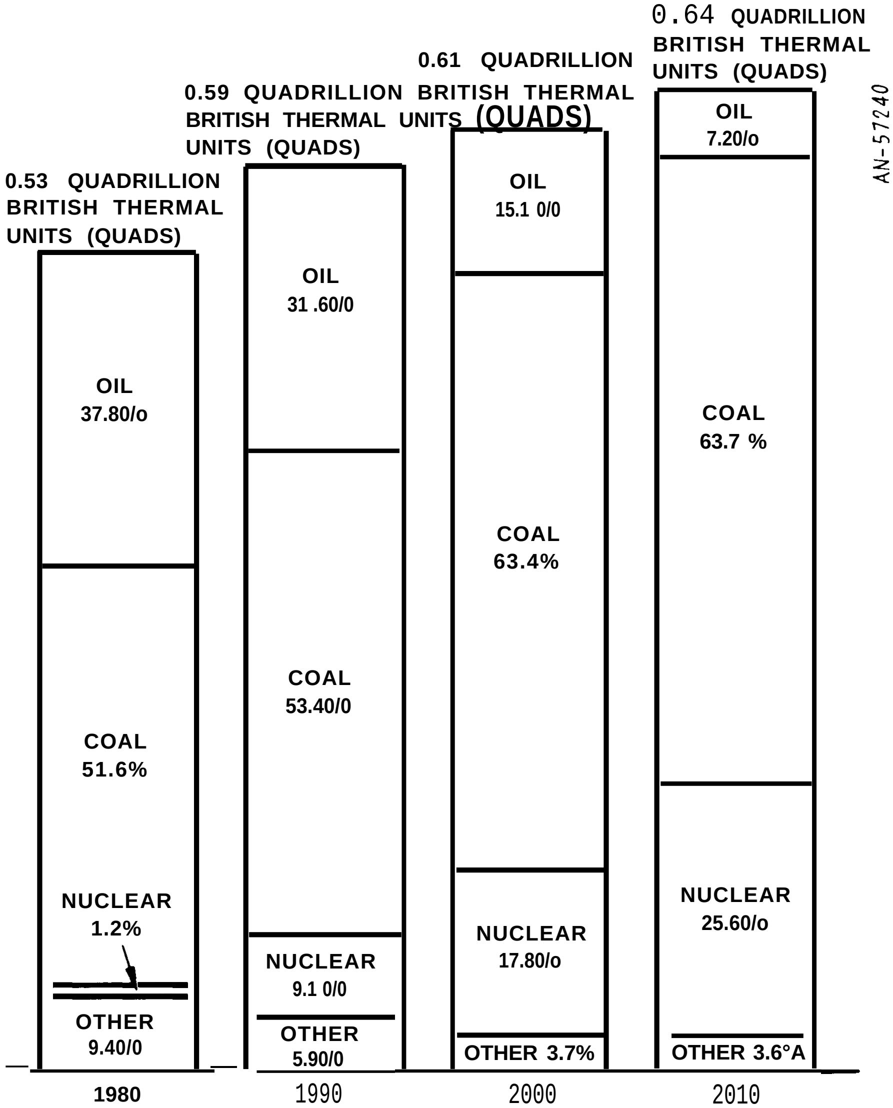
- Extractive industries are already supplying materials demands in the United States which are so great that increases due to mass production of EHVs (300,000 units per year) would only be 5 to 10 percent for near-term battery materials such as lead and nickel. Increases would be much less for more widely used materials such as zinc and chlorine.

o The auto industry already produces millions of vehicles annually. They are sold and serviced through some 22,000 established dealers who already utilize factory-trained mechanics and factory-supplied parts departments.

If a major auto maker undertakes mass production of EHVs, there is little reason to assume that potential buyers will be deterred by lack of electricity or usable electric outlets, that materials suppliers will be unable to deliver sufficient battery materials, or that the auto maker itself will fail to produce, sell, and service the vehicle satisfactorily. On the other hand, there are significant changes to be made. Furthermore, widespread use of EHVs could be encouraged by appropriate changes in the infrastructure, and at the same time, national benefits from any given level of EHV use could be enhanced.

The key to realizing the potential benefits of electrification of light-duty vehicular travel is the electric utility system. Although a fifty percent increase in electricity usage of the average household would occur due to use of an EHV, the electric utility system will have sufficient capacity to handle the additional load. It is estimated that this load would range from 0.53 quadrillion BTU (quads) in 1980 to 0.64 quads in 2010, for 20 percent electrification of light-duty vehicular travel (Fig. 5.1). This represents an increase above projected electricity demand without EHVs of 6.4 percent and 2.1 percent, respectively.

The timing of the recharging load, however, is very important. Even on days of peak demand, millions of vehicles could be recharged without requiring new capacity, if most recharging is accomplished late at night when other demand is low. However, a combination of off-peak electricity pricing and selective load control will be needed to ensure that recharging occurs when the electric utility system can best handle the additional load. Considerable economic forces favor these innovations; they could simultaneously reduce prices for recharge electricity and improve utility profits. A few utilities already offer incentives for off-peak recharging, and industry attention has turned to appropriate rates and metering equipment. Still, it is unclear whether most will have adopted the practice before large-scale introduction of EHVs. It is clear, however, that the widespread use of EHVs is feasible if good use is made of the existing and planned electric utility system. If, on the other hand, much recharging makes use of on-peak or near-peak electricity, the new generating plants will have to be built to accommodate the additional demand. This could present an obstacle to the market penetration of EHVs because of the existing public resistance to the development of new power plants, particularly those employing nuclear fuels. It would also increase costs of producing recharge electricity.



Source: Recharge Capacity Projection System (RECAPS) General Research Corporation

Assumptions: The RECAPS model schedules the use of nuclear, coal, and hydroelectric facilities before oil and gas facilities, and base-load facilities before intermediate and peaking facilities to minimize operating costs. Recharging is controlled to maximize the use of off-peak power available during late night and early morning hours when demand is lowest. The model makes use of capacity and demand projections developed by the electric utility companies in 1979. Energy required was assumed to be 0.5 kilowatt-hours per mile at the charging outlet. This value reflects a mix of cars and light-duty trucks to electrify 20 percent of light-duty vehicular travel in 1980, 1990, 2000, and 2010 (Table 6.1). Vehicles were assumed to be distributed uniformly across the United States based on population. They were also assumed to travel an average of 10,000 miles per year. Electrical distribution system efficiency was assumed to be 90 percent.

Figure 5.1 Electric Energy Required Annually to Electrify 20 Percent of Light-Duty Vehicular Travel, by Type of Fuel Used

The electric utility industry is currently in the process of shifting away from the use of petroleum to other sources of energy. One of the major objectives of the use of EHVs is to further reduce national consumption of petroleum and dependence on foreign oil. Except in a few regions, most energy needed to recharge EHVs would be derived from non-petroleum fuels, primarily coal and nuclear. For 20-percent electrification of light-duty vehicular travel, more than 50 percent of recharging energy would be derived from these sources in 1980, and by 2010 they would account for nearly 90 percent (Fig. 5.1). During this period, the use of petroleum to generate recharge energy would continue to decline.

Most cars used in the United States are parked at family residences at night, where it would be easiest and cheapest to provide high-power electric outlets for recharging. The number of EHVs that could be recharged at residences is limited primarily by the availability of off-street parking. Statistics indicate that about 60 percent of all cars in metropolitan areas (40 percent of all cars) are located at single-family residences with off-street parking.[1] Another 25 percent are located at multi-family dwellings with off-street parking.

Recharging away from home could be accomplished by a system of coin-operated outlets at parking lots, quick-charge service stations, battery exchange stations, and electrified highways. Although the ability to recharge away from home would help remove the range limitations of electric vehicles, the associated costs, which must eventually be borne by the consumer, would be high and will probably limit the extent of ultimate implementation. The fact that in some instances on-peak or near-peak electricity would have to be used for such recharging compounds the problem.

The demand for large quantities of steel, iron, rubber, zinc, copper, and aluminum used in the manufacture of automobiles will be little affected if EHVs replace conventional cars. This is primarily because EHVs will require the same types of structural components as existing vehicles. Although the drivetrain will change considerably, the materials used to manufacture it will be similar to those used in conventional cars. The biggest change will be in the primary demand for those materials used in the manufacture of propulsion batteries. Increases in US demand due to 20-percent electrification of US light-duty vehicles would fall in the 10-75 percent range by 2010. Corresponding increases in world demand would fall in the 5-35 percent range. Although identified resources of all battery materials in the United States, except aluminum, cobalt, lithium, and nickel, would be adequate to electrify much more than 20 percent of light-duty vehicular travel in the 1985-2010 time period, insufficient quantities are economically extractable. However, there are more resources not yet discovered, and it is probable that increased demand could provide the incentives necessary for enlarging the production facilities and increasing exploration for new resources.

World resources of all materials considered appear to be sufficient to electrify much more than 20 percent of light-duty vehicular travel in the US, as well as supply the projected demand from other users. This additional demand would necessitate significant expansion of capacity, however, and worldwide adoption of EHVs at the same level as in the United States would multiply resource and production requirements by 3-4 times.

Most manufacturing plants, materials, and operations will be little changed by the introduction of EHVs. The functions of those people who distribute, lease, and sell vehicles will also remain virtually unchanged. Those industries that would be affected are the electrical and electronic component manufacturers who produce motors, controllers, and chargers, as well as the battery manufacturing industry. Growth in employment, production, distribution, and market share is expected for each of these industries.

With at-home recharging and the high reliability of electric drive, fewer garages and service stations will be necessary. Service personnel will require some training in maintenance of electrical components, but most service will be for familiar components such as steering, brakes, suspension, and the like. In addition, electric motors, controllers, chargers, and battery-related parts are more reliable than corresponding components of an internal combustion engine system. This, coupled with the extensive capabilities of the major manufacturers to produce and maintain new technology vehicles, should help to minimize problems associated with support.

5.2 THE UTILITY SYSTEM

Recharging EHV propulsion batteries will require the use of the electric utility system, private distribution systems, and EHV recharge systems (Fig. 5.2). The purpose of the electric utility system is to deliver electric power to the consumer. This system consists of power plants to generate electricity, high-voltage transmission lines that carry the electricity from the power plants to urban areas, substations which prepare the electricity for use by consumers, and a distribution system which delivers the electricity to specific residential, comnercial, and industrial users.

Since most recharging of EHVs is likely to be concentrated in residential areas, it might be necessary to expand the capacity of the residential distribution system if extremely large numbers of EHVs are utilized. Primarily this would entail increasing transformer capacities to accommodate additional household demand. Although a detailed analysis of electric utility distribution system requirements, potential problems, and costs has not been performed, it is expected that the existing system could accommodate 20 percent electrification of light-duty vehicular travel through 2010.

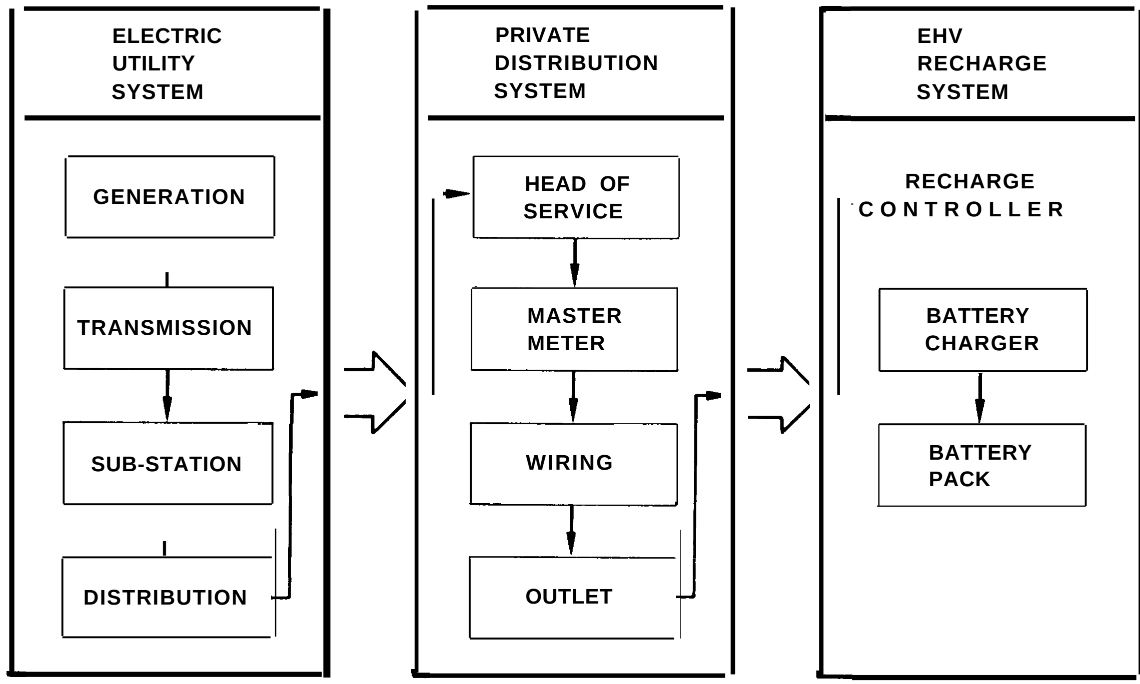


Figure 5.2 Electric and Hybrid Vehicle Recharging Infrastructure

The purpose of the private distribution system is to receive and distribute electricity on the consumer's property. This system connects to the electric utility system at a transformer located near the consumer's property. The connection is made with the head of service, which essentially is a junction box. The remainder of the system consists of a device which meters electricity usage, wiring which distributes the electricity within the user's residence or business, and--in the case of EHVs--an electric outlet used to supply the vehicle with recharge energy.

The purpose of the EHV recharge system is to store electrical energy in the vehicle's propulsion batteries, This system consists of a device to control and time the recharging process, a battery charger to convert alternating current to direct current at the proper voltage, and a battery pack which stores the energy. The charge controller and charger may be physically located on or off the EHV itself.

A variety of controller techniques and hardware are currently available for use in this application. Although a complete technical discussion of what is available is beyond the scope of this report, it is important to understand the two major functions of this type of device. First, it should interrupt service on command from the utility, so that overloading of the electrical system during occasional hours of very high demand can be avoided. This selective load control has long been used in various regions within the United States for industrial users and for residential water heating appliances. Second, it should provide separate metering for off-peak electricity consumption, which can then be encouraged with a special off-peak rate. This reduced rate can profitably be offered by electric utility companies during hours of low demand because most power is then provided by existing base load units using inexpensive fuels.

In the most advantageous situation, the electric utility works with both interruptible loads and off-peak pricing. In this case, the utility installs in each participating household both an off-peak meter and a remote controller for electric water heaters, air conditioners, or other large loads such as EHV battery chargers. Then the utility can interrupt lower-priority service if peak prices are insufficient to keep demand within available capacity. This may happen if higher late-afternoon prices alone prove insufficient to occasionally discourage the operation of air conditioners, for example, on extremely hot summer days when demand is high.

In order to induce customers to accept remote controllers and the associated possible inconveniences, utility companies generally offer reduced rates as an incentive. In addition, since the utility gains the added benefits of load leveling and possible higher utilization rates, they often provide the required hardware at no additional cost to the consumer.

Interruptible, off-peak recharging of EHVs constitutes a new load which would utilize existing equipment and lower-cost fuels more intensively. Resultant costs per kilowatt-hour would be low so that the utility could offer bargain rates for recharging and at the same time increase its profits. Thus both the utility and the consumer could benefit substantially from interruptible and off-peak recharging. Accordingly, the utility impacts presented here assume that EHVs are recharged during late night and early morning hours at reduced off-peak rates, under control of a utility-operated remote device. There has been little study of on-peak recharging, but it would clearly increase costs, increase petroleum use, and reduce sharply the number of EHVs which could be accommodated without additional generating plants. At the peak hour, relatively little coal-fired or nuclear capacity is ordinarily idle, so much more generation of recharge electricity would require use of petroleum-fueled facilities than very late at night.

The use of EHVs would increase the average household’s electricity usage roughly 50 percent. Overnight recharging would require 13.2 kilowatt-hours per vehicle for an average driving day. This is nearly 20 percent greater than the daily requirement for a residential water heater, the biggest energy user among typical household appliances (Table 5.1). Even with reduced rates for interruptible and off-peak recharging, an EHV would be a major factor in total household electricity costs, probably adding about 25 percent to the total bill.

TABLE 5.1

USE OF ELECTRIC ENERGY IN HOUSEHOLDS

	Annual Energy Use, kWh[1]	Annual Energy Cost, $1980[2]	Average Daily Energy Use, kWh
Electric or Hybrid Car	4,828	145	13.2
Water Heater	4,040	242	11.1
Kitchen Range and Oven	3,061	184	8.4
Room Air Conditioner	2,387	143	6.5
Lighting	1,870	112	5.1
Freezer	1,534	92	4.2
Refrigerator-Freezer	1,268	76	3.5

[1] Assumes approximately 0.5 kWh per mile is required for a near-term, four-passenger, subcompact electric car driven 27.4 miles per day (10,000 miles per year). Estimates for the other appliances were taken from a report entitled "Energy Efficiency Program for Appliances," Midwest Research Institute, Kansas City, MO, February 1977.

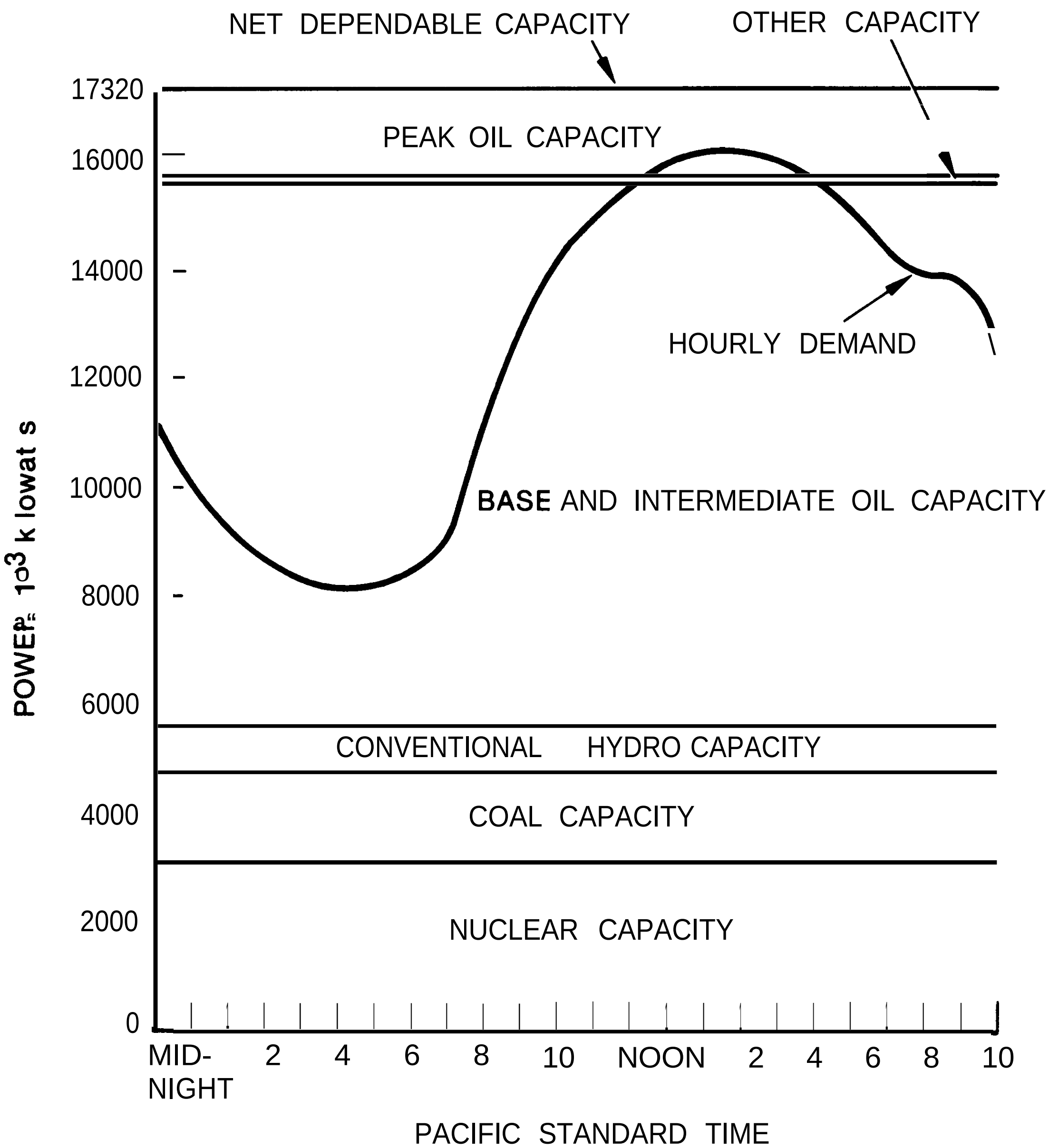
[2] Assumes that the price of electricity used for electric and hybrid vehicles is 3 cents per kWh to encourage off-peak recharging. The price assumed for the other appliances is 6 cents per kWh, even though they may also make some use of off-peak energy.

The utilities will be able to handle the additional load generated by EHVs because the pattern of demand typically fluctuates such that nearly half of a utility's potential capacity is unused much of the time. men on those days when demand is the greatest, sufficient capacity is available to electrify as much as 50 percent of light-duty vehicular travel (given off-peak recharging) without requiring any additional capacity beyond that now planned. With greater improvements in power sharing between utilities, this percentage could be even larger. For example, analysis of the projected hourly demand on the peak summer day of 1985 for Southern California Edison shows that the load during the late night and early morning is very much less, leaving idle almost half the capacity required to meet the peak hourly demand of the day (Fig. 5.3). Even after allowance for maintenance and repair, much of this idle capacity could reasonably be put to use for recharging EHVs.

In most parts of the United States, the hours of maximum demand come in the late afternoon on hot summer days. During the winter there is a secondary late-afternoon maximum resulting from extensive use of electric heating and lighting on cold, dark winter days. Annual minimum demand is typically recorded during the spring or fall, and ordinarily on weekends when commercial and industrial activity is least. During this time, as is the case during most of the year, there is a large idle capacity available throughout all hours of the day. As a result, it would be possible to accommodate recharging of EHVs even during peak hours on many days.

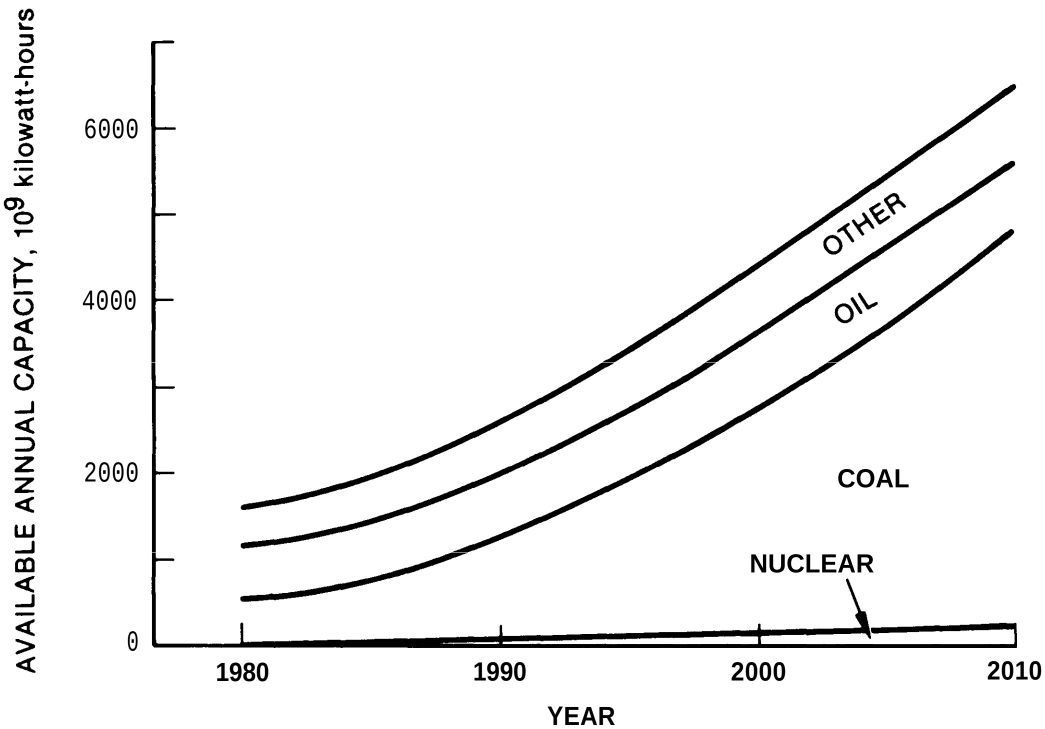
Total “available annual capacity” is defined as the difference between the electricity that can be generated using all of the normally-available generating units in the United States, adjusted to reflect maintenance and equipment failure, and the country’s annual total demand for electricity. Projections of available annual capacity for 1980-2010 are shown in Fig. 5.4. The availability of coal as a major fuel for use in generating recharge energy is projected to undergo rapid growth during the next 30 years. By the year 2010, nearly 70 percent of all available capacity could be generated by coal, whereas oil and nuclear power would account for only 12 and 3 percent, respectively. However, the specific fuel mix of available capacity varies greatly from company to company and region to region. In the year 2000, it is projected that the Northeast, Mid-Atlantic, and West regions will have significant capacity available from oil; the East-Central, Mid-America, and Mid-Continent regions will have even more significant coal capacity available; and the Northeast, Mid-Continent, and West regions will have the most nuclear capacity available (Fig. 5.5). The dominance of the ‘other” fuel category in the Texas region is primarily due to the extensive use of gas.

If electric vehicles require less than total available capacity for recharge, utilities which have both oil-fired and other available capacity will avoid the use of oil wherever possible. Accordingly, for



Source: Recharge Capacity Projection System (RECAPS), General Research Corporation

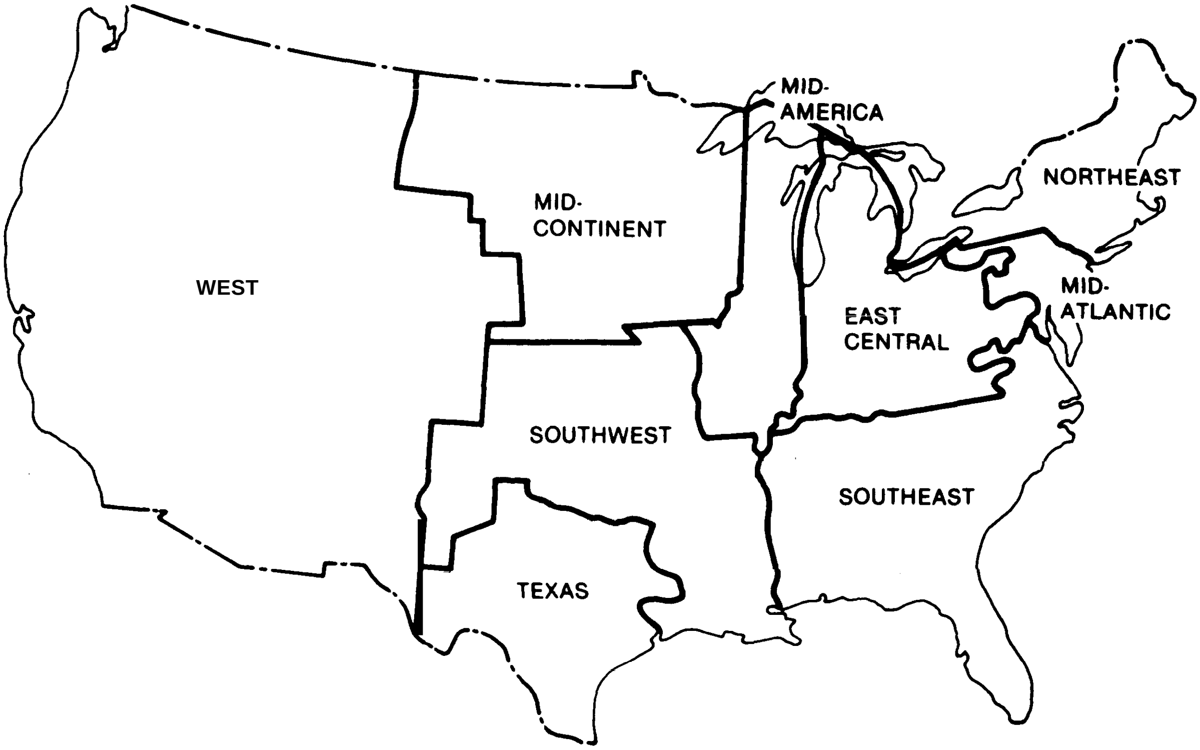
Figure 5.3 Hourly Demand and Net Dependable Capacity for a Single Utility (Southern California Edison Company, projected peak summer day, 1985)



Source: Recharge Capacity Projection System (RECAPS), General Research Corporation

Assumptions: The RECAPS model schedules the use of nuclear, coal, and hydroelectric facilities before oil and gas facilities, and base-load facilities before intermediate and peaking facilities to minimize operating costs. The model makes use of capacity and demand projections developed by the electric utility companies in 1979.

Figure 5.4 Annual Capacity Available for Generating Recharge Electricity



REGION	REGIONAL CAPACITY, 10^9 kWh	PERCENT OF REGIONAL CAPACITY NUCLEAR	COAL	OIL	OTHER
NORTHEAST	225.0	13.5	4.0	59.7	22.8
MID-ATLANTIC	262.9	0.1	31.5	50.6	17.8
EAST CENTRAL	799.1	1.4	83.8	8.2	6.6
SOUTHEAST	992.0	1.2	64.4	20.4	14.0
MID-AMERICA	392.7	1.1	81.0	16.8	1.0
SOUTHWEST	580.0	1,3	58.9	16.1	23.7
MID-CONTINENT	172.8	9.4	76.2	14.2	0.2
TEXAS	331.4	0.1	32.7	8.5	58.7
WEST	637.5	8.0	45.0	27.7	19.3

Source: Recharge Capacity Projection System (RECAPS), General Research Corporation

Assumptions: The RECAPS model schedules the use of nuclear, coal, and hydroelectric facilities before oil and gas facilities, and base-load facilities before intermediate and peaking facilities to minimize operating costs. The model makes use of capacity and demand projections developed by the electric utility companies in 1979.

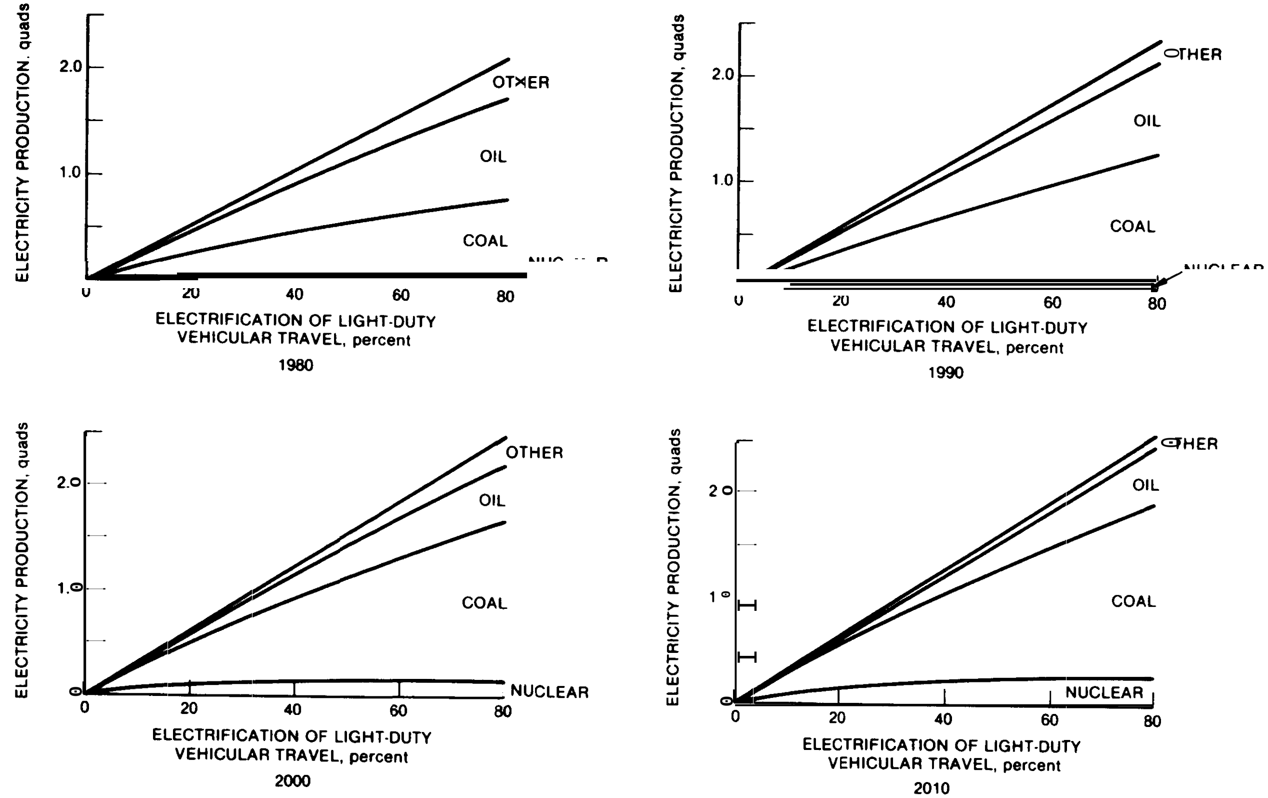
Figure 5.5 Regional Fuel Mix of Annual Capacity Available for Generating Recharge Energy in 2000 low levels of electric vehicle use coal would become much more important in relation to oil for recharging (see Fig. 5.6).

As with total available capacity, the mix of fuels required to recharge EHVs at any given level of usage would differ greatly from region to region. Because of this variation, it will be important to explore the possibility of encouraging EHV use first in those cities where it would provide the greatest reduction in petroleum usage. Thus far, these regional-type issues and their associated impacts, institutional barriers, policy implications, etc. have not been studied in detail. However, an analysis of the regional fuel mix impacts for one-percent electrification of light-duty vehicular travel was performed to determine where initial EHV implementation could best be directed (Table 5.2). At this level of market penetration, the best areas for EHV use in terms of saving petroleum would be the Mid-Atlantic, the East-Central, and the Mid-Continent regions. The least attractive would be the Northeast and West Regions. Some of these regions are so large and diverse, however, that individual cities within them are much more attractive for EHV use than the entire region. Denver in the West region is a good example; it is far less reliant on petroleum-fired capacity than the other major cities in the region (San Diego, Los Angeles, San Francisco, and Seattle).

At the one-percent level of travel electrification, the Mid-Atlantic, East-Central, and Texas regions would make heavy use of coal, and the Mid-Continent region would make heavy use of nuclear power. Since this level of EHV use would require only a relatively small portion of the total annual unused capacity available, the regional fuel mix would vary greatly. For example, although the Mid-Atlantic is dominated by oil in terms of total available capacity, very little would be used for one-percent electrification of light-duty vehicular travel. Instead, unused coal capacity would be sufficient to provide the necessary energy.

Although regional impacts on all fuels have not been analyzed for 20-percent electrification of light-duty vehicular travel, an analysis has been made which considered the national impact on petroleum usage over the entire range of possible market penetrations (Fig. 5.7). With the passage of time, less and less petroleum would be needed to recharge EHVs because of the efforts of industry to shift to coal and nuclear facilities. On the other hand, as more EHVs are used in any given year, an increasing percentage of the recharge energy would come from petroleum. For example, in 2010 petroleum usage in generating recharge electricity would increase from 8 percent up to 20 percent as electrification of light-duty vehicular travel increased from 20 percent to 80 percent.

The utilization of EHVs would shift consumption of oil from automobiles to the electric utility industry. However, it would do so at a



Source: Recharge Capacity Projection System (RECAPS), General Research Corporation

Assumptions: The RECAPS model schedules the use of nuclear, coal, and hydroelectric facilities before oil and gas facilities, and base-load facilities before intermediate and peaking facilities to minimize operating costs. Recharging is controlled to maximize the use of off-peak power available during late night and early morning hours when demand is lowest. The model makes use of capacity and demand projections developed by the electric utility companies in 1979. Energy required was assumed to be 0.5 kilowatt-hours per mile at the charging outlet. This value reflects a mix of cars and light-duty trucks to electrify 1 to 80 percent of light-duty vehicular travel in 1980, 1990, 2000, and 2010 (Fig. 5.2.1). Vehicles were assumed to be distributed uniformly across the United States based on population. They were also assumed to travel an average of 10,000 miles per year. Electric distribution system efficiency was assumed to be 90 percent.

Figure 5.6 Projected Use of Fuels for Recharging Electric and Hybrid Vehicles

TABLE 5.2

REGIONAL FUEL MIX FOR ONE-PERCENT ELECTRIFICATION OF LIGHT-DUTY VEHICULAR TRAVEL IN 2000

Region
Northeast
Mid-Atlantic
East-Central
Southeast
Mid-America
Southwest
Mid-Continent
Texas
West
National Totals

Source: Recharge Capacity Projection System (RECAPS), General Research Corporation.

Assumptions: The RECAPS model schedules the use of nuclear, coal, and hydroelectric facilities before oil and gas facilities, and base-load facilities before intermediate and peaking facilities, to minimize operating costs. Recharging is controlled to maximize the use of off-peak power available during late night and early morning hours when demand is lowest. The model makes use of capacity and demand projections developed by the electric utility companies in 1979. Energy required was assumed to be 0.5 kilowatt-hours per mile at the charging outlet. This value reflects a mix of cars and light-duty trucks to electrify one percent of light-duty vehicular travel in 1980, 1990, 2000, and 2010 (Table 6.1). Vehicles were assumed to be distributed uniformly across the United States based on population. They were also assumed to travel an average of 10,000 miles per year. Electrical distribution system efficiency was assumed to be 90 percent.

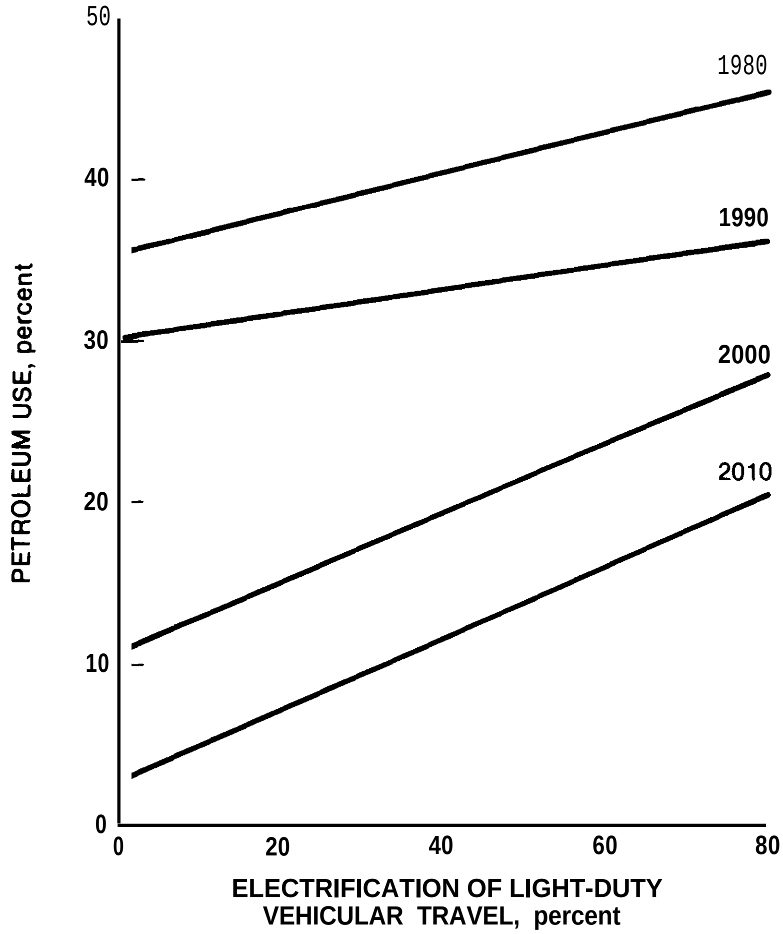


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Figure 5.7 Percent of Recharge Energy Demand from Petroleum greatly reduced rate because much of the energy would be derived from coal and nuclear power plants. Even though this would result in a net national reduction in oil consumption, it would increase the use of petroleum by the electric utility industry. This is because increases in demand tend to require the operation of some peaking and intermediate units, rather than base generating units, and these generally are less efficient and require the use of petroleum. In February of 1980, the mix of fuels used by the electric utility industry to satisfy national demand was 10 percent nuclear, 52 percent coal, 23 percent oil, and 25 percent from other sources.[3] These figures not only represent an effort to convert generating units from oil use to alternative fuels, but also reflect changes in fuel selection policy which establish oil as one of the least cost-effective fuels. In comparison, the projected mix required to generate energy needed to electrify 20 percent of light-duty vehicular travel in 1980 would be 1 percent nuclear, 52 percent coal, 38 percent oil, and 9 percent from other sources.

5.3 CHARGING PROVISIONS

5.3.1 Chargers

Electric and hybrid vehicles require a charger to interface between the electrical outlet and the batteries during recharging. The charger converts ordinary alternating current (AC) to the direct current (DC) necessary for battery charging, delivering it at the proper voltage for the type of battery being recharged, its state of charge, and the overall rate of recharge. Little attention has been given in the past to developing superior chargers for on-road electric vehicles, but the engineering design problems should not pose any insurmountable obstacles. Development goals are to produce chargers which:

- Maximize battery life by controlling amount and rate of recharge.
- Have high efficiencies. Present chargers deliver 60 to 70 percent of input electricity to the batteries; these efficiencies should be raised to 90-95 percent to minimize electricity losses and thereby minimize drain on utilities and costs to consumers.
- Reduce harmonics in electrical transmission lines. Chargers can vary current in such a way as to increase energy losses in the electrical distribution system and interfere with control signals the utility sends over its transmission lines.
- Include timers so EHV owners can plug in the charger when they park the vehicle, but delay charging until the hour off-peak rates become applicable.

- o <u>Provide interrupt mechanisms</u>. A small radio receiver could accept signals from the utility to automatically turn off the charger during peak loads. Lower electricity rates would probably be offered to persons with interruptable service.

Since chargers must be compatible with the type and size of batteries, charger manufacturing and sales must be coordinated with battery pack manufacturing and sales. Many electric and hybrid vehicles will come equipped with on-board chargers which are compatible with the type of battery in the vehicle. Lead-acid, nickel-zinc, and nickel-iron batteries will use similar chargers, but the amount and rate of charge should be adjusted to the rating of the battery pack to reduce the possibility of damage to the batteries. Lithium-metal sulfide batteries will require chargers which monitor each cell individually, since overcharging any cell can cause severe damage. Zinc-chloride batteries will probably use off-board chargers; these chargers will be larger in size since they must circulate coolant through the battery during recharging.

A charger which operates from a standard 120-volt, 15-ampere household outlet will probably be included with the purchase of an EHV. Such a charger can in 8 hours provide energy for about 35 miles of driving. A more powerful charger which operates from a 220-volt, 30- or 50-ampere outlet (such outlets are found in some homes for use with dryers or electric ranges) might be offered as standard equipment or as an optional extra with EHV purchase. This charger could accept a "quick charge;" i.e., it could provide energy for approximately 100-220 miles of driving in eight hours, or energy for about 50-100 miles of driving in one hour.

5.3.2 <u>Home Recharging Facilities</u>

At-home recharging is the most convenient and least expensive method of recharging personal EHVs, and until EHVs become numerous, will probably be the only recharging means which is readily available. The only equipment required in addition to the charger is an electric outlet accessible to the EHV parking area. The EHV owner may wish to install a high-powered electrical outlet in the parking area so the batteries may be quick charged, and an additional meter so vehicle recharging can utilize off-peak rates for electricity.

The number of vehicles that could be recharged at home is limited by the availability of off-street parking with an accessible electric outlet. In metropolitan areas, where the majority of EHVs would probably be located, between 50 and 85 percent of vehicles can be parked off the street (Table 5.3). However, these include cars at multi-family dwellings which are much less likely than single-family houses to have access to an individually metered electrical outlet. Approximately 60 percent of all cars in metropolitan areas are located at single-family dwellings with off-street parking. If each of these residences had facilities to recharge only one electric vehicle, about 35 percent of

TABLE 503

ESTIMATED AVAILABILITY OF CARS AND OFF-STREET PARKING

	United States	Outside SMSAs	In SMSAs* Total	In SMSAs* In Central Cities	In SMSAs* Outside Central Cities	Los Angeles Long Beach SMSA	Washington DC SMSA
population, thousands	211,391	56,427	154,964			6,926	3,015
Occupied Housing Units, thousands	70,830	19,586	48,674	22,566	26,109	2,520	981
With Parking, percent	83	77	85	86	84	94	71
Single Family, percent	63	75	61	52	70	61	56
With Parking, percent	78	73	80	80	79	94	54
Multifamily, percent	37	25	39	48	30	39	44
With Parking, percent	91	87	92	93	91	94	93
Persons Per Unit	2.98	2.88	3.18			2.75	3.07
Cars Available (estimate), thousands	85,178	23,321	59,628	23,278	36,778	3,243	1,302
Percent of US Total	100	27	70	27	43	4.6	1.5
Cars Per Occupied Housing Unit	1.20	1.19	1.23	1.03	1.41	1.28	1.33
Cars as Percent of Available Cars							
At 1 Car Units	39.4	44.1	36.9	43.7	32.5	37.1	32.1
Single-Family	24.0	32.9	21.5	22.7	20.8	20.4	14.9
Multi-Family	15.4	11.2	15.4	21.1	11.8	16.7	17.2
At 2 Car Units	45.6	42.2	47.3	43.0	50.2	45.9	48.0
Single-Family	35.0	34.5	36.7	31.5	39.9	34.4	35.3
Multi-Family	10.5	7.5	10.6	11.4	10.3	11.8	12.7
At 3 or More Car Units	15.1	14.0	15.8	13.3	17.3	17.0	19.9
Single-Family	13.0	12.5	13.7	11.1	15.3	14.5	16.9
Multi-Family	2.1	1.5	2.1	2.2	2.0	2.5	3.0
Cars with Parking, percent†	56-83	65-77	52-85	62-86	58-84	67-97	47-71

Source: Current Housing Reports Annual Housing Survey, 1974, Part A, US Department of Commerce, Bureau of the Census, Washington, D.C., 1976.

*SMSA - Standard Metropolitan Statistical Areas

†Assumes each housing unit with parking has either one space (lower limit) or as many spaces as cars available (upper limit).

all cars in metropolitan areas (25 percent of all cars) would have easy access to recharging facilities.[3] These percentages may rise slightly in the future since many metropolitan areas require that new housing units include off-street parking areas.

During the construction of a single-family dwelling, the individual cost of installing an additional high-powered (e.g., 250-volt, 50-ampere) outlet for EHV recharging would be modest, about $100. Installing additional equipment and extending the wiring in existing single-family dwellings would cost approximately $300 (Table 5.4). Electric companies provide meters free; however, they would probably charge for an additional meter to monitor off-peak electricity use (e.g., Potomac Electric and Power Company currently charges $2 per month for off-peak meters.

The costs for the installation of electric outlets for multi-family dwellings include individual meters, circuit breaker panels, and outlets. The cost per stall is estimated to be about $400 for covered parking and $500 for uncovered parking[4] (Table 5.4). These costs would also apply for installing recharging facilities in commercial garages.

Because of the greater convenience and lower cost of recharging at single-family dwellings, these households are the most likely candidates for EHV ownership, at least initially. In major cities, many vehicles are parked in apartment or commercial garages. Private and public sector EHV policies which encourage the installation of recharging facilities in multi-car garages would open the opportunity to urban apartment dwellers for EHV use.

5.3.3 Recharging Away From Home

There are a number of methods and facilities for recharging away from a vehicle's home base, such as biberonnage (recharge from electric outlets at parking places in commercial and industrial parking lots, at on-street parking places, or in municipal parking lots), quick-charge service stations, battery exchange stations, and electrified highways. Such facilities would provide the same refueling service to electric vehicles as gas stations provide to conventional vehicles. The ability to recharge away from home would help remove the range limitation, one of the main obstacles to widespread acceptance of electric vehicles. Gas station owners, battery manufacturers, electric utilities, commercial businesses, employers, and government agencies could all become involved in the implementation of these facilities, but whether profit

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* Since the range of hybrid vehicles is not limited by battery charge, away-from-home recharging is not necessary, although hybrid vehicles may make use of these facilities.

TABLE 5.4

COST OF HARDWARE AND INSTALLATION FOR ELECTRIC OUTLETS FOR RECHARGING
(Outlet Rating: 240 Volts, 50 Amps Maximum)

	Covered	Uncovered[1]
Single-Family Dwellings[2]		
From meter through outlets		
New Construction	$ 90	$105
Existing Construction	293[3]	271[4]
Multi-Family Dwellings or Parking Lots		
Cost per stall including individual meters[5]		
New Construction	392	497
Existing Construction	392	508

Source: W. C. Harshbarger, Installation Costs for Home Recharge of Electric Vehicles (Draft), General Research Corporation RM-2291, January 1980.

Assumptions:

1. Includes locking, waterproof covers on outlet.
2. Cost of meter not included.
3. Circuit breaker panel mounted on interior wall, extend existing wiring through walls.
4. Circuit breaker panel mounted on exterior wall.
5. Based on a line of ten stalls; includes individual meters, circuit breakers, and outlets.

will be a sufficient motivating factor is unknown. Although the convenience of being able to refuel during trips may be appealing to electric vehicle owners, charging during peak daytime hours could overburden utilities. The extensive requirements for facilities and their high cost may be an important obstacle to the implementation of away-from-home recharging, at least until a high level of electric vehicle penetration is reached.

Biberonnage refers to the practice of recharging an electric or hybrid vehicle whenever it is parked away from its home base. The battery could be “topped off” or partially recharged over short periods of time at numerous locations. An on-board charger would be a necessity, as would be electric outlets at many parking places. The concept is similar to the practice in very cold climates of providing electric outlets in parking places so heaters may be used to prevent the engine block from freezing. The costs for installing recharging facilities would be roughly $500 per outlet, similar to that for installations in apartment parking lots and garages (Table 5.4). In addition to commercial garages, electric vehicles could conceivably be parked by a parking-meter type of device into which coins could be deposited for electricity delivered.

A first step to biberonnage would probably be the provision of recharging facilities by employers so that their employees could recharge their electric vehicles for the return home. However, since the majority of people work during the day, off-peak electricity rates would not apply, making recharging at work more expensive and more burdensome on electric utility capacity than recharging overnight at home. Recharging facilities for visitors in commercial districts might be supplied by businesses to attract shoppers. Local governments might supply recharging facilities in municipal parking lots to encourage EHV use downtown.

Another possibility for range extension is quick-recharge service stations. It is possible to recharge a fully-discharged propulsion battery to 50-60 percent of its capacity in an hour or less; exact times and amounts depend on the type of battery. A quick-charge station could then provide enough energy during a lunch hour, a business meeting, or a shopping excursion to increase the effective daily range of an electric vehicle by 50 percent or more.

To accept a quick charge, an EHV would have to be equipped with a 220-volt charger or, if the vehicle was of a standard design, the on-board charger could be bypassed and the station’s charger used.

Quick-charge stations could be located in regular gas stations, but special facilities with high electrical capacity would be essential. An 80-percent recharge in 45 minutes would require over ten times the average power for an overnight recharge. Due to the high cost of special facilities, operating personnel, peak-hour electricity rates, and business profit, a quick charge would be much more expensive than an overnight recharge at home. Therefore drivers of electric cars would be unlikely to incur the expense and inconvenience of quick charges except when essential to their travel plans. If electric cars achieve their projected ranges, the need for quick recharges would be infrequent, generally only on intercity trips. In consequence, quick-recharge stations are unlikely to be as common as today's gas stations.

A third facility which could provide range extension is a battery swapping station. With proper design, a depleted battery pack can be removed from a car and replaced with another fully-charged battery in two or three minutes. The effect is to make refueling as quick and easy as for conventional cars.

Battery swapping imposes a number of restrictions on electric vehicles. First, the vehicles must be designed so that the battery can be easily removed, yet be safely contained in collisions. Second, the battery sizes must be standardized so that stations do not have to stock a wide variety of battery packs to fit different cars. Third, the leasing of batteries, as opposed to outright ownership, is essential. Otherwise the user could not safely trade his battery for another which might be near the end of its life, and consequently of much less value. Swapping stations, perhaps in conjunction with battery manufacturers, would necessarily be involved in lease administration. One advantage of battery leasing is that it lowers the initial price of an EHV, spreading battery equipment costs over the life of the vehicle. On the other hand, it introduces administrative expenses beyond those of simple ownership.

The cost of a battery swap has been estimated to be between $4 and $7, depending on the size and location of the station. This is much more than the cost of a home recharge because of the cost of facilities, equipment, battery stocks, and personnel; but it may be a reasonable price to pay for extending range by a hundred miles. The swap cost would certainly be less than the cost of renting a conventional car for the occasional long trip.

A very different concept of providing range extension to electric vehicles and decreasing the gasoline use of hybrid vehicles is electrified highways, which electromagnetically transfer energy to vehicles. An electrified highway would have a power strip installed flush with the road surface in the center of one lane. The power strip safely carries an alternating electric current which produces a magnetic field. When

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* Land costs are a significant portion of facility costs, and are usually much higher at access points to busy freeways than along minor highways.

an electric vehicle equipped with a power pickup drives over the power strip, the energy is magnetically coupled through a clearance gap between the source and the pickup device. The batteries are recharged while driving over the power strip, and the stored energy can be used for travel on non-electrified roads.

A study of an electrified highway system estimates[6] that the power pickup would add about $300 to the cost of an EHV. The roadway power source, including installation in an existing highway, is estimated to cost nearly $350,000 per lane-mile. However, it would only be necessary to equip a few heavily traversed major routes with the roadway power system to provide area-wide service with electric or hybrid vehicles.

Electrified highways are amenable to the inclusion of automatic vehicle controls. The magnetic field from the roadway power source can provide guidance and transmit other data to vehicles. Automatic vehicle control appears to be a feasible means of achieving large increases in the capacity of existing highway systems. Controlled vehicles could in theory be safely operated at high speeds with short headways.[8] These concepts are in the preliminary stages of development. Since the public has demonstrated a strong preference for individual automotive transportation over mass transit systems, yet is reluctant to fund new highway construction, increasing the capacity of existing highways becomes increasingly important. Electrified highways could provide dual benefits of providing range extension for EHVs and guidance control for all vehicles.

5.4 MATERIALS

5.4.1 Materials Required for Automobiles

Since many similarities exist between electric and hybrid vehicles and conventional cars, a shift to EHVs would affect materials usage only to the extent that the electric motor, controller, and battery differ from the internal combustion engine system of a conventional vehicle.

The primary materials used in typical present-day automobiles are steel and cast-iron, plus aluminum, rubber, plastic, and other nonmetals (Table 5.5). Future automobiles will require considerably less material overall, with higher proportions of light materials, such as aluminum and plastic, increasing their shares from 6 percent to 12 percent and 7 percent to 9 percent of vehicle weight, respectively. EHVs will require greater amounts of structural materials (30 to 70 percent more structure and weight in near-term electric vehicles, depending on battery type) to carry the added weight of the batteries. However, since autos are rapidly being downsized, thereby using less structural material, a switch to EHVs will slow the rate of decrease, rather than increase, the consumption of structural materials.

TABLE 5.5

MATERIALS IN TYPICAL US AUTOS, 1980 AND 1990

Material	Weight, lb 1980	Weight, lb 1990	percent 1980	percent 1990
Steel	1600	1368	56.9	54.2
Cast Iron	384	200	13.6	7.9
Aluminum	178	299	6.3	11.9
Copper, Brass	27	14	1.0	0.6
Zinc	12	8	0.4	0.3
Lead	22	18	0.8	0.7
Other Metals	20	35	0.7	1.4
Rubber	144	128	5.1	5.0
Glass	74	70	2.6	2.8
Plastic	188	231	6.7	9.2
Other Non-Metals	167	151	5.9	6.0
Total	2816	2522	100.0	100.0

Source: R. W. Roig et al., Impacts of Material Substitution in Automobile Manufacture on Resource Recovery, VOl. 1, Results and Summary, US Environmental Protection Agency, Office of Research and Development, EPA-600/5-76-007a, July 1976.

The electric motor which replaces the gasoline engine will be made largely of iron and steel, like the conventional engine. It will, however, include windings of copper wire weighing perhaps 55 pounds for a typical 330-pound motor.[9] This is considerably more than the copper content of automobiles today, and might double the copper content of the average car. The US auto industry now uses about 8 percent of all the copper consumed in this country. Thus, the maximum effect, assuming a complete shift to electric cars, would be to increase copper demand less than 10 percent. If EHV production built up over a period of years, the additional copper requirement would have little effect on production or on reserves and resources.

5.4.2 Materials Required for Batteries

Depending on the type of battery, large quantities of chlorine, graphite, iron, lead, nickel, sulfur, and zinc will be used, plus smaller quantities of aluminum, boron, cobalt, copper, lithium, and potassium (Table 5.6). These materials, plus (in some cases) hydrogen

TABLE 5.6

BATTERY MATERIALS REQUIRED FOR A REPRESENTATIVE FLEET OF ELECTRIC AND HYBRID VEHICLES

	Average Amount of Battery Materials Required per Car, lb								
	Near-Term Batteries						Advanced Batteries		
	Lead-Acid		Nickel-Iron	Nickel-Zinc		Zinc-Chloride*	Zinc-Chloride*	Lithium Metal Sulfide	
Material	EV	HV	EV	EV	HV	EV	EV	EV	HV
Aluminum								56	28
Boron								2	1
Chlorine						57	52	121	61
Cobalt			8	14	11				
Copper			41	6	5			15	8
Graphite						129	92		
Iron			127					62	31
Lead	956	723							
Lithium			4					29	15
Nickel			164	264	207				
Potassium			69	73	57			55	28
Sulfur	153	116						39	20
Zinc				160	125	55	55		
Battery Weight	1580	1195	1055	890	696	840	599	440	221

Source: M, K. Singh and W. J. Walsh, Electric, Hybrid and Baseline Conventional Material Characteristics (Draft), Transportation Energy Systems, Argonne National Laboratory, April 1978, Table 1.

*Source: H. Catherino et al., Cost Analysis of 50 kWh Zinc-Chlorine Batteries for Mobile Applications, COO-2966-1, US Department of Energy, Division of Energy Storage Systems, January 1978.

and oxygen, make up over 95 percent of the weight of each battery. Some batteries may also use small amounts of such materials as antimony and yttrium, but it is possible that other materials could be substituted. Projected requirements are approximate, and could differ considerably in the battery designs which may eventually prove most satisfactory.

5.4.3 Demand for Battery Materials

Demands for materials to manufacture batteries for EHVs will increase the existing and projected demand for these materials. Every battery type requires quantities of at least one material which will significantly affect demand. The percent increases in the baseline primary (newly-mined) demand for battery materials sufficient to electrify 20 percent of the light-duty vehicular travel are shown in Table 5.7. The greatest increases in demand would be experienced if enough electric vehicles to electrify 20 percent of light-duty vehicular travel were built in 1985; the effects of EHV manufacture decrease in later years as the baseline demand rises. In 1985, EHV manufacture could increase the demand in the United States for graphite over 65 percent, the demand for cobalt and nickel 30 to 50 percent, the demand for lead 30 to 40 percent, and the demand for lithium almost 30 percent. The increase in the United States[1] baseline demand for any of these materials is less than 30 percent by the year 2010. The production of lithium-metal sulfide batteries will more than double the United States[1] demand for lithium in the year 2000 if enough electric vehicles are manufactured to electrify 20 percent of the light-duty vehicular traffic. The effect on world demand is much smaller. In the near term, the increase in world demand for any material is less than 20 percent, 10 percent in the long term, except in the case of lithium where world demand could increase by as much as 50 percent.

For a given level of travel electrification, hybrids affect material demands less than electric vehicles because they require smaller batteries.

5.4.4 Adequacy of Battery Material Resources*

The extraction of materials for the purpose of manufacturing batteries will deplete considerable portions of the known deposits of some

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* Resource: A concentration of material in the earth's crust naturally occurring in such form that economic extraction is currently or potentially feasible.
Reserve: That portion of the resource from which a usable material can currently be economically and legally extracted.
Identified Resource: Specific bodies of mineral-bearing materials whose location, quality, and quantity are known from geologic evidence supported by engineering measurements.
Potential Resources: Unspecified bodies of mineral-bearing material surmised to exist on the basis of broad geologic knowledge and theory.

TABLE 5.7

PERCENT INCREASE IN PRIMARY DEMAND FOR BATTERY MATERIALS DUE TO ELECTRIFICATION OF 20 PERCENT OF LIGHT-DUTY VEHICULAR TRAVEL

	Percent Increase in Projected Baseline Primary Demand															
	1985				1990*				2000				2010*			
	US		World		US		World		US		World		US		World	
Batteryand Material	EV	HV	EV	HV	EV	HV	EV	HV	EV	HV	EV	HV	EV	HV	EV	HV
Near-Term Batteries																
Lead Acid:																
Lead	40	30	9	7	37	28	8	6	31	24	6	5	27	21	5	4
Sulfur	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nickel-Iron:																
Cobalt	27		10		25		8		18		6		15		5	
Copper	1		0		1		0		1		0		0		0	
Iron	0		0		0		0		0		0		0		0	
Lithium	29		15		22		11		14		7		11		5	
Nickel	32		8		27		7		21		5		18		4	
Potassium	n/a		n/a		n/a		n/a		n/a		n/a		n/a		n/a	
Nickel-Zinc:																
Cobalt	50	39	17	13	44	34	14	11	32	25	10	8	26	20	8	6
Copper	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nickel	51	40	12	10	44	34	11	8	34	27	8	7	28	22	7	5
Potassium	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Zinc	4	3	1	1	3	3	1	1	3	2	1	1	2	2	1	0
Zinc-Chloride:																
Chlorine	0		0		0		0		0		0		0		0	
Graphite	66		10		60		7		50		5		43		4	
Zinc	1		0		1		0		1		0		1		0	
Advanced Batteries																
Zinc-Chloride:																
Chlorine									0		0		0		0	
Graphite									36		4		31		3	
Zinc									1		0		1		0	
Lithium-Metal Sulfide:																
Aluminum									0	0	0	0	0	0	0	0
Boron									0	0	0	0	0	0	0	0
Chlorine									0	0	0	0	0	0	0	0
Copper									0	0	0	0	0	0	0	0
Iron									0	0	0	0	0	0	0	0
Lithium									104	54	48	25	76	40	35	18
Potassium									n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Sulfur									0	0	0	0	0	0	0	0

Source of Baseline Demand Figures: US Bureau of Mines, Mineral Facts and Problems, 1975 Edition, US Government Printing Office, 1976.

* Interpolated and extrapolated from 1985 and 2000 data.

materials. Depending on the type of battery, over 30 percent of the United States' reserves of lead and cobalt would be used in the number of EHVs which would serve to electrify 20 percent of the light-duty vehicular travel in the United States. The United States does not currently produce nearly enough of the nickel required for nickel-iron or nickel-zinc batteries or enough graphite for the zinc-chlorine batteries. The advanced lithium-metal sulfide battery will require almost twice as much lithium as is projected to be in the United States' recoverable reserves by 2010; the requirement equals nearly 70 percent of the United States[1] resources.

Twenty percent of light-duty vehicular travel in the United States could be electrified without using more than 7 percent of the world's identified resources of any single material, except in the case of lithium for advanced lithium-sulfur batteries. These batteries could use up over 30 percent of the World's lithium resources to power EHVs.

Table 5.8 shows how the cumulative demand for these materials from 1974 to 2010 compares with the 1974 reserves and resources, both without EHVs and with electric or hybrid vehicles. The **1974** US reserves cannot provide enough of any material except boron (and lead in the absence of EHVs). Even the 1974 world reserves would be insufficient except for cobalt, iron, nickel, and aluminum. Cobalt supply has an additional problem--it is produced primarily as a byproduct of copper mining, so its availability may be limited by the amount of copper mined. However, cobalt may also be extracted from nickel byproducts, so increased mining of nickel for batteries may increase the amount of cobalt available.

The United States could most readily supply the materials needed for lead-acid batteries, but it is unlikely that the availability of resources will be a constraint on the production of any of the batteries considered here.

The increasing demand for battery materials will be a strong incentive for the development of identified resources. With these, the US could meet its demand for all materials except aluminum, lithium, and sulfur* The United States has only small reserves of bauxite, the main source of aluminum at the present time. However, the United States has large resources of other aluminum sources such as the kaolin-type clay which could meet most of its aluminum raw material needs if the technology is developed. Sulfur can be recovered from secondary sources, such as power plant desulfurization procedures necessary to comply with environmental regulations. The current demand for lithium is very small, so there has been little incentive for exploration. Identified reserves and resources of lithium seem likely to be only a small fraction of deposits actually available in the earth's crust, and increased demand will encourage exploration for new deposits.

TABLE 5.8

ADEQUACY OF BATTERY MATERIAL RESOURCES WITH AND WITHOUT 20 PERCENT ELECTRIFICATION OF LIGHT-DUTY VEHICULAR TRAVEL

	Cumulative Primary Demand 1974-2010 as a Percent of 1974 Resources[1]											
	Recoverable Reserves[2]						Identified Resources[3]					
	US			World			US			World		
Battery & Materials	w/o EVs	with EVs	with HVs	w/o EVs	with EVs	with HVs	W/O EVs	with Evs	with HVs	W/O EVs	with Evs	with HVs
Near-Term Batteries												
Lead-Acid:												
Lead	82	117	108	134	147	144	40	58	54	67	73	72
Sulfur	299	300	300	163	163	163	109	110	109	60	61	60
Nickel-Iron:												
Cobalt	114	146		77	83		77	99		44	48	
Copper	139	140		136	136		31	31		30	30	
Iron	107	107		34	34		24	24		16	16	
Lithium	118	147		106	118		42	52		37	42	
Nickel	5870	7665		79	85		78	102		39	41	
Potassium	N/A	N/A		N/A	N/A		Y/A	N/A		N/A	N/A	
Nickel-Zinc:												
Cobalt	114	168	156	77	88	86	77	114	106	44	51	49
Copper	139	140	140	136	136	136	31	31	31	30	30	30
Nickel	5870	8760	8135	79	89	87	78	117	109	39	43	42
Potassium	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Zinc	182	189	188	145	146	146	70	73	72	23	23	23
Zinc-Chloride:												
Chlorine	A	A		A	A		A	A		A	A	
Graphite	722	1058		344	372		43	72		11	12	
Zinc	182	185		l&5	145		70	71		23	23	
Advanced Batteries												
Zinc-Chloride:												
Chlorine	A	A		A	A		A	A		A	A	
Graphite	722	1058		344	364		43	64		11	12	
Zinc	182	185		145	145		70	71		23	23	
lithium-Metal Sulfide:												
Aluminum	5620	5623	5626	46	46	46	1124	1127	1125	28	28	28
Boron	46	47	46	35	35	35	46	47	46	35	35	35
Chlorine	A	A	A	A	A	A	A	A	A	A	A	A
Copper	139	140	140	136	136	136	31	31	31	30	30	30
Iron	107	107	107	34	34	34	24	24	24	16	16	16
Lithium	118	315	219	106	192	151	42	111	77	37	68	53
Potassium	N/A	N/A	N/A	N/A	N/A	N/A	N/A	h/A	N/A	N/A	N/A	N/A
Sulfur	299	299	299	163	163	163	109	109	109	60	60	60

Source: US Bureau of Mines, Mineral Facts and Problems, 1975 Edition, US Government Printing Office, 1976,

N/A . Data not available

A - Adequate

Numbers greater than 100 indicate that 1974 resources or reserves are inadequate to supply all required materials.

NOTES:

1. Resource: A concentration of material in the earth's crust naturally occurring in such form that economic extraction is currently or potentially feasible.
2. Reserve: That portion of a resource from which a usable material can currently be economically and legally extracted.
3. Identified Resource: Specific bodies of mineral-bearing material whose location, quality, and quantity are known from geologic evidence supported by engineering measurements.

To some extent this may be true of other battery materials as well. Potential US nickel reserves may be over 800 times as large as known reserves. For nickel, zinc, and lithium, potential reserves are much larger than known resources, and world-wide they are vastly more than would be required to electrify all US automobiles and still produce enough material to satisfy the projected demand for other uses. Increased demand will encourage increased production of identified resources and exploration for new reserves. Beyond potential reserves, there are presumably resources which are subeconomic at present prices with present methods of extraction which might become available if increasing demand causes a price increase sufficient to make extraction of these resources economical.

5.4.5 Recycling

Initially, materials for batteries will come from primary (i.e., newly mined) sources. However, the size of the EHV fleet will eventually stabilize; then additional primary resources would be necessary only to the extent that materials were lost in recycling and manufacturing. The recycling of lead from automotive batteries has been estimated at over 80 percent.* For most future batteries, recycling processes have yet to be developed, but they are expected to be very efficient, with recovery rates well over 90 percent. In consequence, the eventual effects of recycling losses on primary resources would be relatively small. Significant quantities of battery materials would need to be derived from primary sources only for the production of the initial fleet. Recycling facilities will be built when recycling becomes more cost effective than the extraction of raw materials, but recycling should be encouraged both to slow the depletion of natural resources and to minimize the environmental problems associated with the disposal of used batteries.

5*5 PRODUCTION AND SUPPORT

The EHV industry is currently in its infancy, as were today's automobile and aircraft industries in 1900-1910 when horseless carriages and flying machines were being produced by hand in limited quantities. Today's EHV industry consists primarily of small businesses which are pioneering development on a very small scale. Currently about 20 firms are manufacturing electric vehicles, producing less than 10,000 vehicles in 1980.[10] Unlike the major automobile manufacturers, these businesses are very limited in the expertise and resources they can devote to the design and test of vehicles, have very low production capacities, and very little experience in providing parts and service. However, if EHVs are going to replace any significant number of conventional vehicles in

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* The rate would be higher if more batteries were returned for recycling.

the near future, the production and support of EHVs will be accomplished by the major automobile manufacturers who do have the necessary capabilities. In 1979 the United States ICE auto industry produced nearly 8.5 million cars in nearly 4000 manufacturing plants which were sold and serviced at over 20,000 dealers. A total of over one half million establishments are involved in the sales and servicing of these vehicles.[11] General Motors is planning to market an electric vehicle in 1984, and other large companies (General Electric, Chrysler, Gulf & Western, etc.) are developing EVs.

5.5.1 Production

Electric vehicles will differ from future conventional vehicles primarily in the drive train and power supply. Hybrid vehicles will have the major components of internal combustion vehicles plus an electrical propulsion system. The body and accessories of EHVs will be essentially the same as conventional cars. Since there are great similarities among all the types of vehicles, most of the manufacturing plants, materials, and operations will be unchanged. Expansion in various industries will be required in the industrial capacity to produce motors, controllers, and chargers. Major impacts will occur in the battery manufacturing and recycling industries.

The major constraint to the immediate manufacture of substantial numbers of electric or hybrid vehicles is the lack of capacity for battery production. A sizable lead-acid battery industry exists for starting, lighting, and ignition batteries or golf-cart propulsion, but this battery is not appropriate for electric or hybrid vehicles. But at least the basic production techniques and bases for expansion exist. Other types of batteries are only produced in limited quantities or are in the experimental stages. Some require special handling techniques, such as the high-temperature lithium-metal sulfide batteries, which could make production more difficult. Gearing up for production of these batteries would take a number of years.

The manufacturing of hybrid vehicles would require the use of the same facilities and personnel as the manufacturing of conventional vehicles, since hybrids will also contain an internal combustion engine, although it will be smaller. The automotive industry will have to retool, to some extent, to produce the modified equipment, but the industry periodically retools to produce new vehicle lines in any case.

The manufacturing of electric vehicles would have a greater effect than hybrids on the production facilities of automotive industries since the equipment and personnel involved in the manufacturing of the internal combustion engine will no longer be required.

Both electric and hybrid vehicles will require motors, controllers, and chargers. Expansion of the electric motor production plants and the construction of facilities to produce controllers and on-board chargers will require some time and capital investment, but no obstacles to producing these parts are foreseen, especially if increases in electric and hybrid vehicle penetration are gradual, over a period of ten years or so.

The motors required for EHVs are not significantly different from electric motors now produced, although new motors will probably be specifically designed to fit the needs of electric and hybrid vehicles. A large electric motor manufacturing industry already exists, and with some expansion should easily be able to produce the required quantities. As the major motor vehicle manufacturers begin to produce significant numbers of electric and hybrid vehicles, they will most likely begin to make the motors themselves since the production requires techniques similar to those for the production of conventional vehicle parts.

The electronics industry has expanded enormously in recent years. Although EHV controls would be a new product, the industry should be able to design and produce suitable equipment. Again, the automotive industry will probably produce electric and hybrid vehicle controls, since they already produce other types of electronic devices.

Battery chargers such as those used to recharge starting, lighting, and ignition batteries and forklift batteries are currently being manufactured; but, due to their size and low efficiency, they are not very well suited to recharging electric and hybrid vehicles. Little attention has been paid to designing a suitable charger for electric and hybrid vehicles, but the technology is available, and their production should not cause any major problem (see Sec. 5.3.1).

Once substantial numbers of electric or hybrid vehicles are in use, a recycling industry must be functioning to cut down on the requirement for primary materials. Only lead-acid batteries are currently recycled. As yet, techniques have not been developed for recycling most other batteries. However, the recycling industries would have a longer lead time to develop processing capacity than the actual vehicle production industries would have. A recycling industry would develop if recycling is more economical than extraction, but the costs are unknown. In any case, recycling should be encouraged because of the environmental hazards of resource depletion and waste disposal.

5.5.2 Support

After EHVs leave the factory, they are distributed, marketed, sold, maintained, and repaired. The major auto manufacturers already have a large nationwide infrastructure for these purposes, but small vehicle manufacturers currently have little or no support for their products.

The Department of Energy is sponsoring a demonstration program in which some 500 EHVs are operating at a number of sites across the country. The current DOE demonstration program is encountering problems associated with the repair and maintenance of EHVs. However, these current problems stem primarily from the limited capabilities of the small manufacturers providing the vehicles. They are not inherent in EHV technology, which has the clear potential to reduce service requirements and improve vehicle reliability. By 1984, when GM has announced it expects to market an EV, their resources and expertise with mass production, distribution, and associated maintenance should minimize the problems presently encountered by the small manufacturers. With proper design and test, parts supply, and personnel training, all of which are routine for large manufacturers few problems should arise. Electric drive is inherently simple and in its few vehicular applications (industrial lift trucks, London's milk delivery vehicles) has been relatively trouble-free. Although hybrids will be complicated by the interface with an ICE, the engine itself will be smaller and simpler than conventional engines, and will be used less.

Maintenance of EHVs will also be enhanced because electric motors, controllers, chargers, and battery-related parts may be more reliable and simpler than those of an ICE. Electric highway vehicles now being built have been no more reliable than conventional ICE vehicles, but this appears to be primarily the result of inexperience and very small-volume production without the extensive testing and design verification which precedes high-volume production. In addition, much of the power system will consist of solid-state electronic components. Maintenance of these devices is generally limited to fault detection and module (circuit board) replacement rather than complete disassembly and repair. This should provide a major benefit, in terms of maintainability, and the cost should not be excessive since the price of electronic equipment has dropped drastically in the past few years. Complex control electronics, furthermore, are not a unique problem of EHVs: every GM car in 1981, for example, includes electronic engine controls directed by a microcomputer, and computerized instrument panels are likely to follow soon in many car models.

Another potential problem area is the time lag between the introduction of new technology vehicles and the ability of private maintenance shops to service these vehicles. It currently takes about one year before motor manual publishers produce and distribute appropriate maintenance literature. However, this time period generally coincides with the dealer warranty period, which tends to minimize any initial problems.

Any new technology will cause some problems for its users until the “bugs” are worked out of the designs and production techniques, and until maintenance personnel gain experience with the new systems. However, if the massive infrastructure which is already in place is used to supply training and parts for EHVs, rather than the current small EHV producers building their own infrastructure, satisfactory support of EHVs could be accomplished in the minimum time.

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