Home Recharging and Household Electric Vehicle Market: A Near-Term Constraints Analysis

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Market-potential studies based on household travel behavior and consumer preferences show that electric vehicles may capture a share of the household motor vehicle market. However, most studies have ignored the implications of home refueling requirements on the market potential of electric vehicles. Using data from the 1985 American Housing Survey, we estimate the number of households that constitute the potential near-term private market for battery-powered electric vehicles. This estimate is based on housing characteristics and general vehicle usage patterns that are conducive, and probably necessary, to owning an electric vehicle. Foremost among these is the ability to recharge the vehicle at home. From these criteria we estimate that the potential private market for current-technology electric vehicles is approximately 28 million households—28 percent of the 1985 housing stock. Sensitivity analyses of household income and daily commute distances suggest that purchase price may have a greater impact on the marketability of electric vehicles than driving range.

Several studies have attempted to estimate the household market potential for electric vehicles (EVs). Various approaches have been used in these studies. A common methodology relies on models that project vehicle purchase behavior based on household characteristics and vehicle use patterns (*1,2*). Discrete choice modes base their estimates of the potential EV market on hedonic utility functions (i.e., one's willingness to pay for specific vehicle characteristics) (*3–7*). Another approach estimates the largest EV market potential based on travel behavior—how many household trips could be made in a limited-range EV (*8–11*). The common assumption among these approaches is that all households (at least all multicar households) belong to the universe of potential EV owners.

In this study we argue that not all households belong to the universe of prospective early-market EV purchasers. Instead, we estimate this total universe on the basis of four criteria not linked to hedonic preferences or economic trade-offs between familiar vehicle characteristics. The resulting subset of U.S. households includes only those that have the necessary infrastructure to recharge an EV and work commute demands that do not preclude using an EV. Analytical approaches that define EV markets in terms of travel behavior and consumer choices are appropriate and necessary for estimating the initial market for EVs. However, analyses of hedonic preferences and economic trade-offs should more appropriately be applied only to that subset of the total population that have household infrastructure and travel characteristics amenable to EV use.

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We use the following criteria to measure the largest possible initial market for battery-powered electric vehicles:

1. Potential EV purchasers must own their primary place of residence,
2. They must have a carport or garage at their primary residence,
3. In addition to the EV, they must have at least one vehicle capable of long-distance trips, and
4. There must be at least one household vehicle that is not used to commute more than 80 mi round-trip to work on a daily basis.

We use these criteria as proxies for determining how many households can recharge an EV at home and do not have commuting demands that would prevent them from using an EV. The resulting subset of American households is a good approximation of the largest near-term potential EV market and represents the target market for EVs. As mentioned, these households should serve as the starting point for market analyses based on economic considerations, overall travel demand, and consumer acceptance.

We confine this analysis to the near term because the most recent data set available that contains all the information required for our analysis is the 1985 American Housing Survey (AHS) (several important questions were omitted from subsequent AHSs). We define the "initial" or "near-term" potential EV market as the largest EV market that could be developed by the year 2000 given our proposed constraints. Hence, the EV performance and recharging capabilities that we assume are compatible with existing and likely near-term EV technology. Advances in EV technology will significantly affect our results only if those advances free EVs from home recharging requirements. In the long run, changes in the American housing stock could have a profound effect on our potential-market estimate.

This study is not a market development strategy. The target market as we define it excludes some households that may well be among the early buyers of EVs. For example, one can imagine scenarios in which renters or single-car households that are extremely motivated by air quality concerns or a desire to experiment with EV technology would buy an electric vehicle (*12*). However, we believe the number of such households will be small in comparison with the total number of potential EV-owning households identified in the following analysis. In any event, we test the effects of our assumptions through a sensitivity analysis.

Two previous constraints analyses of household EV markets use AHS data. Hamilton used 1974 data to estimate potential noncommercial applications of EVs (*13*). Kaiser and Graver used 1976 AHS data to estimate the number of likely EV-owning households as part of their analysis of electrical infrastructure (*14*). Our analysis differs from these studies in three ways. First, we update the data to 1985—the latest AHS data set that contains all the variables required for our analysis. Second, we use a different set of criteria to define the potential market for EVs. Finally, unlike our analysis, both previous studies assume that the EV ownership criteria are independent. We show the magnitude of error resulting from this assumption using the 1985 data.

We limit our market-potential analysis to privately owned passenger vehicles. The fleet market that has already been analyzed in detail will probably constitute a large part of the overall initial EV market (*15,16*). However, even if commercial fleets provide the first EV market, recently passed legislation gives reason to believe that widespread penetration of EVs in the private sector will not lag far behind.

LEGISLATIVE PROGRAMS DRIVING EV MARKETS

Several recent government actions encourage the use of electric vehicles because EVs provide an excellent prospect for mitigating urban air-quality problems. Electric vehicles essentially eliminate transportation-generated emissions of carbon monoxide (CO) and hydrocarbons (HC)—a primary ozone precursor (ozone is typically the main component of urban smog). Emission of nitrogen oxides (NO_x) will also be sharply reduced with the implementation of EVs compared with gasoline vehicles (*17,18*).

At the national level, EV implementation will most likely be facilitated by the recently passed amendments to the Clean Air Act that require certain vehicle fleets (e.g., delivery vans and taxis) in ozone and CO nonattainment areas be composed partially of clean-fueled vehicles. The law requires that 30 percent of all light-duty vehicles added to these fleets be clean-fuel vehicles starting in 1998. This requirement increases to 70 percent by 2000 (50 percent for heavy-duty trucks for every year after 1997) (*19*). The same legislation established a California clean-fueled vehicle pilot program. This program requires that 150,000 clean-fueled vehicles be sold in California each year for model years 1996 through 1998 and 300,000 a year thereafter.

California has adopted a program more specifically targeted at promoting EVs. In 1998 the state will require that 2 percent of the light-duty vehicles that each automobile manufacturer sells in California emit essentially no pollutants at all. This will rise to 10 percent of unit sales (about 200,000 vehicles a year) by 2003. Electric vehicles represent the only automobile technology currently under development that can meet these rigid zero-emission standards. Other states are expected to follow California's lead. Already, 12 northeastern states and the District of Columbia have committed to proposing regulations based on California's stringent automobile emission standards.

In Los Angeles an initiative has been passed that calls for the local sale of at least 10,000 electric and electric-gasoline hybrid vehicles by 1995. Three companies were awarded contracts to produce the 10,000 vehicles, which will consist of 1-ton vans, ¼-tone microvans, minivans, pickups, and four-passenger sedans.

The effectiveness of EVs at fulfilling the air quality mandates in government legislation depends on the total number of vehicle miles of travel that these vehicles can satisfy. This in turn depends on the marketability of EVs. The objective of our analysis is to determine the largest possible near-term EV household market on the basis of home refueling requirements and compatible commuting behavior.

STATUS OF TECHNOLOGY

The current capability and short-term prospects for improvements in EV technology and performance affect the possible size of the EV market. Technological variables such as recharging efficiency, battery performance, and total battery capacity along with the electrical capacity of a housing unit determine the necessary recharging requirements and thus the suitability of the structure for recharging an EV. In this section we briefly describe the status of EVs and state the EV technology assumptions used in our subsequent analysis.

We assume the first commercially available EVs will exhibit performance characteristics similar to existing prototypes. More specifically, they will have a driving range of 100 to 150 mi and an efficiency of 0.33 kWh/mi from the outlet. Without specifying a battery type, we assume that charging can be accomplished at nearly a constant rate (i.e., there is essentially no trickle charge), there are no gases emitted during charging, there is no significant "memory effect" from cyclic shallow discharges, and deep discharges are not detrimental to battery life. In general, lead acid batteries, the only battery type commercially available for EVs today, do not exhibit all the characteristics assumed in our analysis. However, several battery types—including advanced lead acid batteries—are being designed and developed specifically to overcome these problems (*20*).

Most prototype EVs are equipped with an onboard charger integrated into the vehicle electronics. We assume that near-term EVs will be equipped with onboard battery chargers, and thus can simply be plugged into a wall outlet.

We analyze battery-powered EVs because they are the focus of most ongoing EV research and are likely to be the first commercially available EVs. However, there are other types of EV. One alternative to the battery-powered EV is the hybrid EV (HEV). In one type of hybrid, a gasoline tank and a small internal-combustion engine are added to the electric drive to extend the range of the vehicle. However, regulations and incentives encouraging the use of EVs are motivated primarily by air quality concerns. If HEVs are to provide environmental benefits similar to those of dedicated EVs, they will have to run primarily on battery power—the gasoline or diesel engine would have to be used sparingly, perhaps only as an emergency backup. In this case home recharging is still an essential requirement for HEVs, and the market for hybrid vehicles will be similar to that of battery-powered EVs.

Framework for Analyzing Potential EV Market

To estimate the number of potential EV households, we determine which housing unit conditions are needed to accommodate an EV and identify household travel patterns that would preclude using an EV. Our conditions and requirements are based on insights gained from the literature. Much of what we wish to measure is not well understood (such as the amount of driving-range reserve that prospective EV buyers will demand) or lacks supporting data for a more robust analysis (the only measures of household travel in our data set are daily work commute distances and modes). In this section we lay out the logic for each of our conditions and test the sensitivity of the logic to different assumptions.

Our analysis is based on household and commuting data from the 1985 AHS. The AHS is conducted jointly by the U.S. Departments of Commerce and Housing and Urban Development. The AHS, formerly the Annual Housing Survey, is conducted every 2 years. It contains approximately 47,000 randomly sampled housing units enumerated in the 1980 census and approximately 6,500 units built since 1980 (*21*). The sampling unit is the structure, not the occupants.

Criteria Definition

We limit the potential market to those households that can recharge an EV at home, even though theoretically there are several means by which EVs can be recharged away from home. However, these methods are expensive, difficult to implement, and will not be developed until there are enough EVs to justify a large investment in the necessary recharging infrastructure. Furthermore, even if away-from-home recharging becomes available, it is likely that EV owners will do most of their recharging at home; certainly, enough so that they will not buy an EV if they cannot recharge at home. Battery-powered EVs will not become ubiquitous without home recharging.

Restricting EV Purchases to Homeowners

Analyses of the EV market seldom distinguish between homeowners and renters even though renters will probably be unable to recharge an EV at home. Relatively few rental units have the necessary facilities for recharging a personally owned EV, and it would be expensive to equip parking spaces with separately metered recharging outlets.

Cost estimates for installing multivehicle recharging facilities with a 240-V 50-amp electrical capacity range from $100 to $900 (1991 dollars) per stall, depending primarily on the number of recharging stalls, whether the recharging facility is installed at a new or existing housing structure, where the facility is located relative to the electrical source, and whether the charging stalls are opened or covered (*14,22,23*). Moreover, the landlord would have to agree to put in the recharging unit (outlet, wiring, etc.).

An investment in recharging facilities would be risky for landlords. They are unlikely to provide recharging facilities for EV owners unless installation and operation are safe and trouble-free, and only if they are certain of recouping their investment within a reasonable period of time. The only way to guarantee this would be to charge the EV-owning tenant enough per month to ensure complete payback within the current lease period because subsequent tenants may not have use for the recharging station. In most cases, the renter who owns an EV would probably be obligated to essentially buy the recharging station outright.

We expect that renters will not assume the installation cost of the recharging infrastructure unless they anticipate remaining at the residence long enough to justify the investment. Although this condition applies to homeowners too, the AHS data show that renters generally have a much shorter tenure at their residences than do homeowners.

Furthermore, many apartment complexes do not have the parking capacity for EV. Multifamily structures often have parking lot capacities designed for one parking space per unit; renters who own EVs will require a parking space for their second vehicle (as per Criterion 3) in addition to a designated space for EV recharging.

For these reasons we exclude all renters from the initial target market. However, it is possible that local utilities may assume the cost of recharging facilities on rented properties, in which case renters could play an important role in EV markets. We perform a sensitivity analysis to show the potential market gain when renters are included as prospective initial EV purchasers.

Need for Garage or Carport

We anticipate that EV owners will want a safe and secure covered place close to their houses to charge their vehicles. We assume this place is an existing garage or carport. A homeowner with no garage or carport could set up a recharging station, but this would involve additional costs. There would probably be a relatively long underground run from the service panel to the outlet, a recharging pole, weatherproofing for the outlet and pole, and some kind of security device (to prevent unauthorized plugging and unplugging). All these are extra-cost requirements compared with recharging in a garage. We assume that there would be relatively few people willing to set up an outdoor recharging station under these circumstances.

Furthermore, many residences without a garage or carport must park their vehicles on the street. EV owners who park on the street can not be guaranteed a vacant parking space near their outlet even if they could set up a curbside recharging station.

Some homeowners who do have garages or carports currently use them for purposes other than parking vehicles (workshops, converted bedrooms, storage, etc.). The AHS data specifically exclude garages that have been rendered permanently unusable for parking vehicles. However, AHS data do not identify garages that have not been permanently converted for other uses but that nevertheless are not being used for vehicle storage.

Owning a garage or carport does not guarantee the necessary electrical infrastructure to recharge an EV. Unfortunately, there are no data that enable us to determine how many households have an outlet in their garage or carport or how much electrical capacity is available within a specific dwelling unit. In the absence of these data, we assume that households meeting all our criteria either have the necessary electrical infrastructure to recharge an EV adequately for its intended use, or the occupants would be willing to install an electrical outlet in their garage or carport that is capable of sufficiently recharging an EV. We summarize the likely costs homeowners will incur if they do not already possess the outlet needed for EV recharging.

Cost estimates for installing a 240-V, 50-amp receptacle in a carport or garage range from approximately $100 to $675 (1991 dollars), depending primarily on how far the outlet is from the electrical source and whether it is installed in a new or existing structure (*14,22,23*; estimates from local electricians, unpublished data, 1991). A 240-V, 50-amp circuit would be capable of recharging an EV with our assumed performance characteristics at the rate of 28.5 mi of driving range per hour of charging (36.5 mi of driving range per hour of charging if charging is limited to 3 hr or less as per the "continuous load" restrictions stated in the National Electrical Code).

The lower-bound cost estimate represents the best installation scenario (not having to install an outlet at all would be the best overall scenario) for which there is sufficient service entrance panel capacity and a 240-V, 50-amp receptacle is installed close to the panel. The high cost estimate represents the opposite situation, in which the panel must be replaced and a 240-V, 50-amp receptacle is installed far from the panel. Generally, costs for replacing a circuit with one of higher amperage and voltage will typically be closer to the lower end of the cost range, and installing a receptacle in a new home during construction is much less expensive than retrofitting an existing house.

Although the cost of a recharging station in a rental unit could be as low as the cost in an owned unit, it is not likely. It is more likely that renters would incur costs near the high end of the range (as much as $900) to install recharging capability because most rental units are not equipped at all to handle vehicle recharging (this is further justification for excluding renters). On the other hand, many people who own their residence will probably face few or no additional costs to upgrade their electrical infrastructure because they already have adequate electrical capacity in their garage.

All single-family homes with an attached garage built since 1974 are required by the National Electrical Code to have at least one electrical receptacle in the garage that is not dedicated to a "permanent" appliance. Furthermore, on the basis of an informal survey of electricians nationwide, we believe it is likely that most garages and carports have at least a 110-V, 15-amp outlet that perhaps could be used for recharging an EV. Therefore, our assumption that electrical infrastructure requirements in owner-occupied homes will not alone prohibit the purchase of an EV seems reasonable.

Need at Least Two Vehicles

Because the first-generation mass-produced EVs will require several hours to recharge and will have a significantly shorter driving range than conventional gasoline vehicles, we assume the EV-owning household will keep at least one vehicle that is capable of long-distance trips. We posit that every household will want the option of making long trips without having to rent or borrow a vehicle (although we acknowledge that occasionally renting a vehicle may be the most economical solution). Therefore, we assume that the EV will replace an existing household vehicle or be added to the household's stock of vehicles, but that it will not be the only vehicle in the household.

Given this assumption, the number of potential EV-owning households at any given time (assuming they meet the other three criteria) is the number of multivehicle households that might add or replace a vehicle, plus the number of single-vehicle households that are in the market for a second vehicle. However, we do not have data on the number of single-vehicle households that are in the market for a second vehicle. Moreover, we do not know to what extent the introduction of EVs would affect the rate at which single-vehicle households become multivehicle households, or the rate at which multivehicle households would become one- or zero-vehicle households. Instead of attempting to estimate these effects, we use the number of current (1985) multivehicle households as a proxy for the number of potential EV-owning households. (We recognize that the percentage of multivehicle households—and hence the potential EV market—appears to be growing. Thus, our estimate may be considered a lower bound.)

It is also possible that some households would be willing to rely on an EV as its only vehicle. For example, a household that makes long trips only infrequently may be willing to rent or borrow a gasoline vehicle to fulfill their long-distance travel demands. We do not attempt to estimate the number of households that would be content with an just an EV, but we do relax the two-vehicle constraint in a sensitivity analysis.

Commute Distance Requirement

The regularity in timing and distance of work commute trips allows us to exclude households in which commute distances and characteristics of the household's current stock of vehicles would prohibit EV ownership regardless of other household travel. However, we do not require that the EV be used only for commuting purposes.

Households are excluded from the potential EV market only if the number of household members who commute more than 40 mi one way to work in a car, van, or truck, or report a variable work-trip distance (and hence might travel more than 40 mi), is equal to or greater than the number of vehicles available to the household.

This criterion implies that an EV could be used by any commuter with a round-trip distance to work of less than 80 mi. Given an EV with a range of 100 to 150 mi, an 80-mi commute would allow a buffer of 20 to 70 mi. The precise buffer required depends on what length of reserve the consumer will demand to ensure against running out of "fuel" and whether daily recharging is viewed as a significant inconvenience. Focus group participants have expressed concern about running out of "fuel" while driving an EV (*24,25*). However, some EV purchasers may be willing to accept more frequent recharging or a smaller buffer in exchange for a lower purchase price.

It is likely that the required reserve range of an EV will be a function of daily travel demands. Therefore, people with shorter commutes—say, less than 20 mi round trip—may be willing to opt for an EV with less than 50 mi of range if they bought it primarily as a commute vehicle. As the role of personal automobiles is reevaluated and expectations about multipurpose usage of vehicles change, EVs could become the most-used vehicles in many households.

To summarize, we define the potential near-term private EV market to be the subset of households that are occupied by the owner, have a garage or carport, have two or more vehicles, and do not have commute patterns that preclude the use of an EV. Although the criteria we propose are not mandatory for EV ownership, we posit that households not meeting all of the criteria will generally be unable to use an EV in the near term because of prohibitive travel demands or the inability to recharge at home. We believe households not meeting these criteria are very unlikely to buy an EV and therefore should be excluded from the universe of potential near-term EV-owning households for the purpose of further analyses.

RESULTS

According to our analysis, 27.9 percent of the 1985 U.S. housing stock (27.89 million out of 99.93 million U.S. households) has the potential to own an electric vehicle. These housing units are owner-occupied and have a carport or garage. The occupants have at least two vehicles and do not have prohibitive daily commute demands. This estimate is subject to a sampling error of ± 0.36 million households at the 95 percent confidence level. The geographical representation of potential EV households is generally the same as the total housing distribution.

If, like previous constraint analyses, we had assumed that all the criteria were independent (i.e., the same household could be erroneously excluded more than once from the potential EV market if it failed to meet more than one criterion), our potential near-term EV household market estimate would be 15 million households. This is 46 percent less than our actual estimate of 27.9 million households.

A comparison of AHS data from 1985 and 1987 suggests an upward trend in the percentage of American households that can accommodate an electric vehicle. Whereas the housing stock increased only 2 percent between 1985 and 1987, the percentage of households that are potential EV purchasers, according to our criteria except for household commute distances, rose approximately 6 percent in that same period. (We did not use the 1987 AHS data set for the complete analysis because neither it nor any AHS data set since 1985 contains information on household commute distances.)

Sensitivity Analysis

In this section we examine the effects of relaxing, in turn, each of our assumptions about which households can recharge and use an EV. The results are summarized in Table 1.

TABLE 1 Sensitivity Analysis Results

	Scenario	% of Households
0	Base case -- all criteria	27.89
1	Base case plus rental units that otherwise qualify	32.31
2	Base case plus rental units that otherwise qualify minus all households with at least one non-relative	30.67
3a	Base case minus condominiums and cooperatives	27.42
3b	Base case minus condominiums and cooperatives and households with at least one non-relative	26.60
4a	Base case plus households with only one vehicle that otherwise qualify	37.85
4b	Base case plus rental units that otherwise qualify with garage/carport constraint relaxed for all households	47.05

Case 1: Rental Units

If we relax the criterion that excludes renters, the total potential EV market increases by 15.85 percent, to 32.31 million households (Case 1 in Table 1). However, for reasons presented previously, it is highly improbable that a significant number of renters would be able to accommodate an EV until well after EVs are commonplace.

Case 2: Nonrelated Household Members

Furthermore, we are inclined to exclude renters for another reason: many renters share a residence with a nonrelative who may own at least one of the household vehicles. Prospective EV buyers living in households in which all vehicles are owned by unrelated individuals do not meet our two-vehicle criteria.

Because of the nature of the data, we were unable to determine who in the household owns each vehicle. However, examination of the rented housing unit composition shows that of the 4.42 million rented units that meet the other three criteria for EV ownership, 19.0 percent have at least one person who is not related to the head of the household. If we assume that the owner of each of these housing units has only one vehicle and the rest belong to unrelated individuals (an extreme case), our potential renters market estimate decreases from 4.42 million to 3.58 million. Consequently, the number of rented housing units that could accommodate an EV (as per the other three criteria) is more appropriately given as a range from 3.58 million to 4.42 million households.

The same type of analysis of owner-occupied households revealed that a maximum of only 0.80 million households (less than 3 percent of the estimated potential EV household market) could possibly be excluded given this nonrelative constraint. Case 2 in Table 1 shows the effect of excluding households with at least one nonrelative.

Case 3: Condominium and Cooperative Owners

A strong argument could also be made to exclude owner-occupied condominiums and cooperatives from the potential EV market for the same reasons that we exclude renters. Basically, condominiums and cooperatives are less likely than single-family detached homes to have reserved parking next to an outlet. Furthermore, condos and coops that do not have an accessible recharging receptacle may be less capable of installing one because condo and coop owners are often subject to stringent homeowner association guidelines on permissible changes to the building. If we exclude condos and coops, the market potential decreases 1.69 percent to 27.42 million households (Case 3a). If we further exclude households with nonrelated members (Case 3b), the potential market drops to 26.60 million households. This represents the lower-bound market potential estimate in this analysis.

Case 4: One-Vehicle Households

Finally, our assumption that one-vehicle households will not purchase an EV excludes 9.96 million households from the estimated market. Rejecting this hypothesis would increase the total EV household market potential 35.71 percent to 37.85 million housing units (Case 4a). We expect that there are relatively few single-vehicle households willing to replace their sole petroleum vehicle with an EV unless car rental agencies move to exploit this potential market by serving residential areas. If we relax the homeownership requirement in addition to including single-vehicle households, the potential market estimate increases to 47.05 million households (Case 4b). This represents the upper-bound market potential estimate in this analysis.

Varying EV Range Requirements

Another important consideration is the effect of household commute distances on EV market size. So far we have used commute distances to exclude households from our market estimate. Now we will show more specifically how commute distances affect our potential market estimate.

Although we chose an 80-mi round-trip commute distance as the cutoff point above which a current-technology EV is not likely to be useful for commuting, we recognize that actual EVs may have driving ranges that are shorter or longer. It is likely that manufacturers will offer EVs that have a range of more than 100 mi—already several prototype EVs have achieved ranges exceeding 100 mi. On the other hand, some individuals may wish to lower their vehicle purchase costs by purchasing an EV with a shorter range.

In Figure 1 we show how varying the shortest household commute distance (as per Criterion 4) affects the size of our potential market estimate. The *x*-axis represents the daily work-trip distance of the household member with the shortest commute. Each column is cumulative—that is, it includes all shorter commute distances. Note that the *y*-axis, the number of households, begins at 23 million rather than zero so that changes are visible on the graph.

The greatest change is between households for which the shortest round-trip commute is 10 mi or less and those 50 mi or less. There is virtually no change in the size of the potential market above a 50-mi round-trip commute, which suggests that current-technology EVs have two to three times the range needed to meet the minimum daily commute demands of most potential EV households. The potential EV market increases only 0.78 percent (216,334 households) when the shortest household commute is increased from at most 50 mi round trip to at most 100 mi round trip (this is essentially the same as increasing the effective range of an EV commute-vehicle from 50 to 100 mi).

Other studies that estimate EV market potential on the basis of vehicle performance characteristics and household travel demand indicate that EV range limitations may not be critical if a household's desired vehicle range is based on satisfying daily travel demands (*8,9,11*). Yet focus group studies and market estimates based on consumer choice models using revealed or hypothetical preferences suggest that the limited range of an EV is perceived as a significant problem (*3,7,24,25*). One can infer from these studies that, regardless of how frequently they actually travel long distances, people desire a vehicle versatile enough to make long trips.

Effect of Income on Market Size

We did not use income as a variable in identifying the initial target market, but it clearly will play an important role, and thus we examine the income distribution of our estimated potential market.

There is reason to believe that the life-cycle cost of EVs may eventually be less than those of conventional gasoline vehicles (*18,26–29*). However, EVs will probably still have higher purchase prices than gasoline vehicles. Batteries are currently very expensive and will continue to be so. Furthermore, there will be very few inexpensive used EVs available until EVs become widespread. The larger initial cost will most likely deter households with lower incomes. Not only do lower-income households have less money to spend on new vehicles, but there is evidence that suggests that these households use a much higher implicit discount rate when making automobile purchase decisions (*6,30*). Because of this, they may be less willing to wait for life-cycle cost savings to amortize the higher initial cost of an EV.

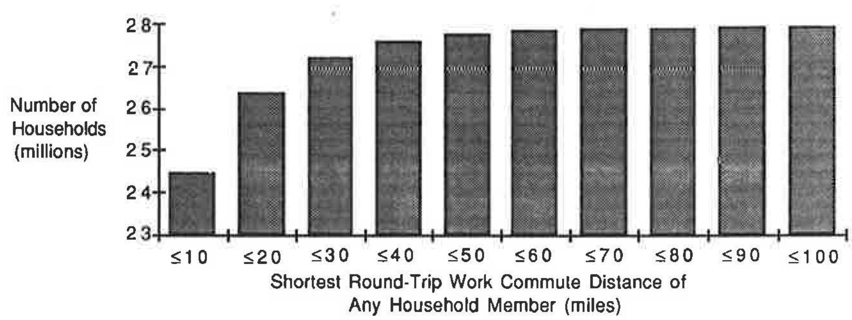

FIGURE 1 Potential EV market versus shortest household work commute.

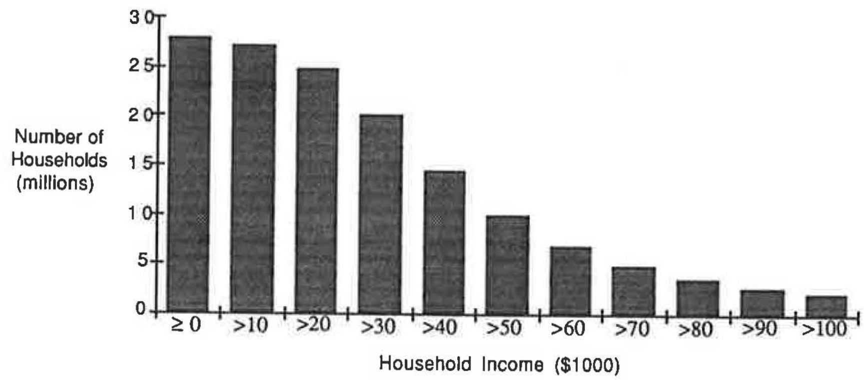

FIGURE 2 Potential EV market by household income.

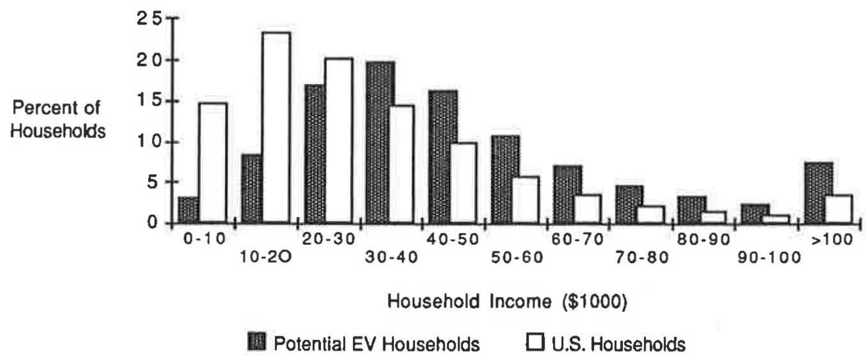

FIGURE 3 Household income distributions.

Without specifying a cutoff income level below which households would not buy an EV, we show in Figure 2 the distribution of household income levels for our estimated potential EV market. The income measure we use is the total pretax income (from all sources) for the reference person and all household members related to the reference person. (The reference person is the housing unit's owner, co-owner, or the owner's spouse.) Income is measured in 1985 dollars.

The number of potential EV-owning households drops markedly as the hypothetical income constraint is raised. The number of households that meet our four criteria and have household incomes greater than $20,000 is 24.70 million; the number meeting the criteria and earning more than $100,000 is only 2.10 million. These numbers are presented only as examples, not as conditions or predictions.

Income and Age of Potential EV Market Versus General Population

Our potential EV market is wealthier than the general population of American households (potential market included). The respective income distributions are illustrated in Figure 3. This comes as no surprise, given that our potential EV market is made up of households that own their residence and have more than one vehicle available.

Although we make no attempt to correlate income and EV purchase behavior, our results show how income may affect the potential EV market if it proves to be a critical factor in the decision to purchase. If EV purchases are highly dependent on income, our criteria will more effectively define the near-term potential EV market. Households not meeting our criteria will be even less likely to purchase an EV than previously argued because they generally have lower incomes.

Senior citizens and retired individuals are often cited as good candidates for EVs because they typically drive less than the general population. However, households composed entirely of retirement-age individuals (at least 65 years old) are underrepresented in our market estimate. Households in which all members are of retirement age make up 14.14 percent of all U.S. households but only 7.0 percent of the potential EV market. This does not mean that senior citizens will not be among the first to buy an EV; instead, it means that households consisting entirely of retirement-age individuals are less likely than the general population to meet all four of our proposed criteria.

CONCLUSIONS

Summary

Our assessment of the 1985 housing stock reveals that approximately 28 million households in the United States were owner-occupied, had a garage or carport, possessed two or more vehicles, and had daily commute demands that did not preclude EV utilization. We believe, as per the arguments presented in this paper, that given current and likely near-term EV technology, each of these households is a candidate for EV ownership. Projections of EV market penetration based on consumer choice theory, hedonic models, travel demand surveys, or other methods should use this subset of households as the starting point for their analysis. Market penetration studies that include households that face significant physical barriers to EV recharging will most likely provide erroneous results.

The findings of this paper agree with other analyses of potential EV markets that conclude that driving range, beyond a relatively short distance, is largely irrelevant to whether people could use an EV on a daily basis (*8,9,11*). However, our analysis says nothing about whether those who *could* use an EV, as per our criteria, *would* actually buy one.

Our analysis does suggest that EV costs could have profound consequences on the success of EVs. The market potential rapidly diminishes if lower-income households are excluded, which suggests that reducing EV cost could be more effective at enticing a larger market share than increasing EV driving range. EV research and development efforts should consider this possibility and focus attention on reducing the cost of EVs.

Implications

In this analysis, the near-term potential EV market is defined by four constraints that are used to indicate if a housing unit has the capability to recharge an EV and whether or not a household's commuting demands would preclude the use of an EV. However, these constraints could eventually be overcome by institutional, technological, and behavioral changes.

Institutional changes could overcome some of the market-limiting effects of our selected criteria. One problem discussed in this study is that investments in recharging stations are risky for landlords and renters. However, if utilities are allowed to include recharging station costs in rates charged for electricity (rate-basing), they may be more than willing to pay for recharging facilities in rental units. The cost of this part of the recharging infrastructure could be spread over a larger population that would enjoy the air quality benefits of EVs. Alternatively, utilities could earn emissions credits for subsidizing recharging stations.

Technological advances could also mitigate one or more of the constraints used in this study. The most significant increase in market potential may come from freeing EVs of the home recharging requirement. One possibility is to recharge EV batteries away from home: however, we do not believe that away-from-home recharging will be practicable until battery-powered EVs are ubiquitous. Another technological alternative is to replace or complement the battery with a fuel cell—an electrochemical device that converts stored methanol or hydrogen into electricity and that can be refueled in a few minutes. Should fuel cell technology progress and a hydrogen or methanol retail network for the fuel cell vehicle develop, then our home recharging constraints may not be applicable. However, any solution to the constraint of home recharging should be cognizant of the fact that those who *can* recharge at home may consider the convenience a significant advantage of battery-powered EVs (*12,25*).

Finally, changes in travel behavior may provide a means of overcoming the constraints presented in this analysis. The marketability of EVs is dependent not only on how close their performance characteristics are to conventional vehicles, but also on the willingness of households to adapt their travel behavior to EVs. Scientists and engineers continue to strive for greater driving ranges, but some households will be learning to adapt to shorter-range vehicles. Incentives that motivate changes in travel behavior may expand the potential EV market more effectively than technological advances.

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