CONCLUDING REMARKS

The computer-aided method and the CMS simulation program discussed in this paper can be used to develop

1. Efficient CMS strategies for urban transportation networks, including vehicle assignment (demand responsive, fixed schedule, and mixed), stopping and routing, empty vehicle management, and failure management for vehicle, station, and guideway link failures;
2. Network geometry details, such as station capacities, location of bypasses and turnarounds, and storage and maintenance areas; and
3. Optimum vehicle fleet size consistent with the desired level and quality of service.

Although the simulation program was developed with reference to an AGRT system that uses 12-passenger automated vehicles, it is highly modular. Those few modules that are unique to a particular system can be easily modified and used to evaluate alternative CMS strategies for other types of transportation systems, such as bus systems or other forms of automated guideway transit systems.

The simulation program was used to develop several CMS strategies for a test network and O/D data provided by UMTA. The test results indicate that CMS strategies are readily adjustable so that 80-90 percent of trips can be accomplished within a mean wait time of 5 min. The generally held notion that fixed-schedule service is superior to demand-responsive service during high-demand periods was found to be incorrect. Some demand-responsive strategies developed and tested for the test network for peak demand periods also gave extremely good results—that is, high vehicle load factors and very short mean wait times. In addition, the demand-responsive strategies were found to be more adaptive to failures and dynamic variations in demand than fixed-schedule strategies.

CMS strategies, particularly for transportation systems that use small vehicles on complex routes, require further research and experimentation so that basic guidelines can be established for the development and refinement of algorithm parameters for planners of future systems. The simulation program developed is a powerful tool with which to test various CMS strategies. It can be improved further, however, to expand its capabilities.

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Electric Cars for Urban Transportation

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Within 10 years rapid technological advances will make the production of electric cars by a major manufacturer a likely possibility. Widespread use of electric cars would drastically reduce the amount of petroleum consumed for urban transportation and also cut automotive air pollution and noise significantly. Under current conditions and trends, however, sales of electric cars are likely to be relatively modest, unless a larger role is deliberately planned for them in order to reap their potential benefits for conservation and environmental quality. This paper is a summary of an investigation of the effects of large-scale use of electric cars on energy, the environment, and the economy.

Electric cars offer major potential advantages for urban transportation: the convenience and mobility of the internal-combustion automobile without its dependence on petroleum or its major environmental problems. Recent electric cars have had very limited appeal, primarily due to the short range between recharges and high overall costs. New batteries that will substantially relieve both range and cost disadvantages are expected soon. With these batteries and more efficient automotive technology, today's electric car ranges (up to 120 km in urban driving) may be doubled or even quadrupled in a few years, and the cost of battery depreciation may be reduced by as much as 70 percent. A federal program plans to demonstrate up to 10 000 improved electric vehicles by the mid-1980s, and General Motors has announced intentions to market urban electric cars in less than a decade (1-3). Thus an important new option may soon become available to transportation planners.

This paper summarizes a study of electric cars made for the Division of Transportation Energy Conservation of the U.S. Department of Energy by General Research Corporation (4). The study investigated the effects of large-scale use of electric cars on energy, the environment, and the economy. It also projected the performance and cost of future batteries and cars, together with their applicability in urban areas. The major beneficial impacts of electric car use are first quantified; then the capabilities and limitations of future electric cars and their potential use in urban areas are summarized.

BENEFITS

Electric cars do not necessarily require petroleum for fuel, but some of their recharge power may be generated in oil-fired power stations. Figure 1 shows that resultant petroleum use is expected to be a minor factor. Figure 1 indicates that if all automobiles in the United States were electrified in the year 2000, petroleum requirements for automotive travel would be reduced by 83 percent. Possible petroleum savings at intermediate levels of electrification would depend on the location of electrified cars. The band at the bottom of the figure is the projected petroleum use for recharging electric cars. If electric cars were distributed uniformly throughout the United States, the amount of petroleum they use would be at the upper edge of this band. However, if they were first distributed to geographic areas that do not rely on petroleum for generating electricity, almost no petroleum would be necessary for recharge until some 60 percent of all atuomobiles are electrified. Figure 2 shows the fuels that would be used for recharge in each of the nine regions of the National Electric Reliability Council, if all automobiles were electrified in the year 2000. Petroleum use would be

Figure 1. Effect of electric cars on petroleum use by automobiles, 2000.

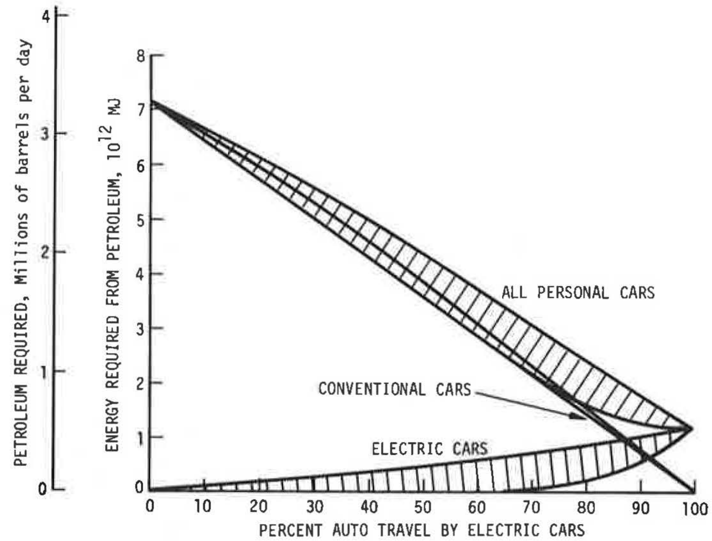
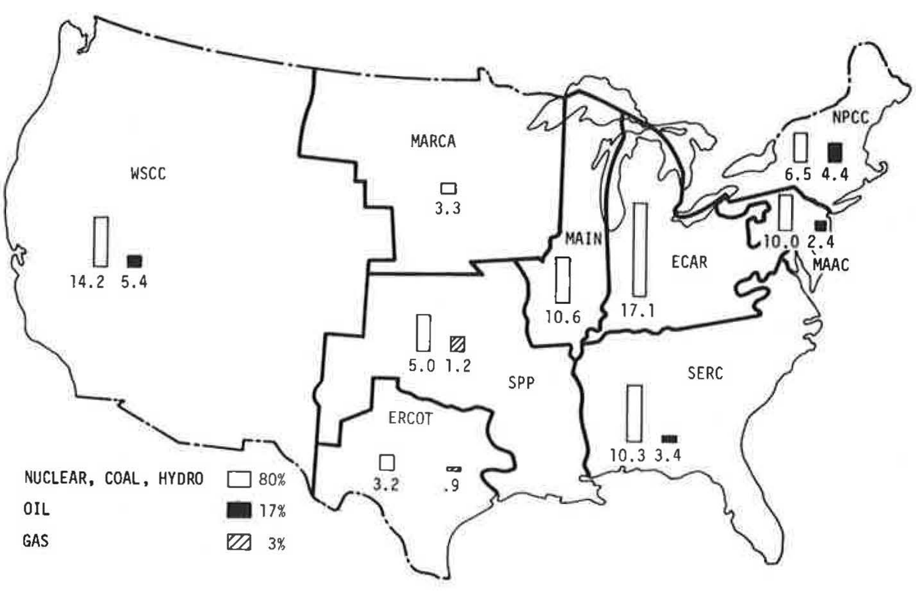


Figure 2. Fuel mix by region for electrifying all cars, 2000.



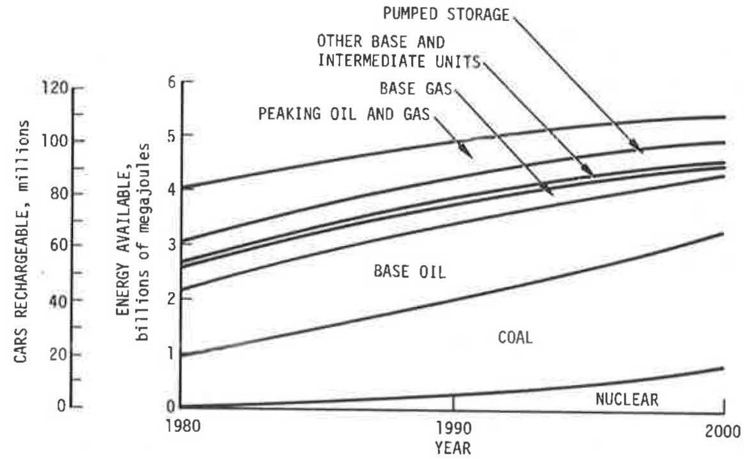


Figure 3. Energy available on peak days for recharging electric cars, 1980-2000.

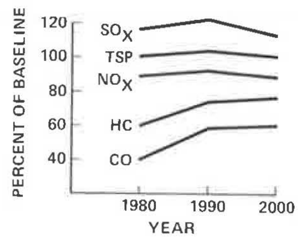


Figure 4. Effect of 100 percent electrification of cars on regional emissions of air pollutant (population-weighted averages).

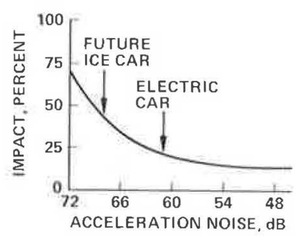


Figure 5. Impact of future urban traffic acceleration noise versus future level of automobile acceleration noise (percentage of 1974 level of impact).

significant only in New England, the Middle Atlantic States, and the Far West.

These findings are based on detailed projections for over 220 major utilities in the United States (4). Most new capacity planned by utilities will be coal-fired or nuclear, so the relative importance of oil-fired plants will decline. Typically, utilities expect to have sufficient capacity for the annual peak demands in their service areas. In most parts of the country these peaks occur during hot summer afternoons. During the late night hours, even on a peak day, demand is expected to be far below the peak level, so much capacity that would otherwise be idle could be used to recharge electric cars. Figure 3 shows the projected amount of energy that could thus be provided from various fuels, together with the approximate number of electric cars that this energy could recharge. Electric cars are assumed to require 1 MJ of recharge energy per kilometer of travel and a little less than 50 MJ for the average day's driving. Even on the peak-demand day, enormous numbers of cars could be fully recharged; and on other days of the year, much more recharge energy would be available. Utilities are rapidly moving toward peak and off-peak pricing and to direct load management by remote control. These would concentrate electric car recharging during the late evening hours, when available capacity and petroleum savings would be greatest.

Electric cars emit no air pollutants. The power plants that recharge them may, however, emit pollutants if they burn fossil fuels, and these pollutants may be discharged in the same air quality control region as that in which the cars operate. To some extent, the increased emissions from utilities would offset the decreases due to replacement of conventional automobiles by electric cars. Figure 4 assumes that all automobiles will be electrified (4) and shows projected changes in emissions for the 24 largest urban United States Air Quality Control Regions (AQCRs). This is an upper bound on effects that might be expected from electric cars. Results are shown as a percentage of baseline emissions (i.e., total emissions from all sources projected in the absence of electric cars). Figure 4 indicates that electric cars would substantially reduce the regional emissions of pollutants primarily due to vehicles—hydrocarbons (HC) and carbon monoxide (CO). This benefit would be offset, however, by increases of up to 20 percent in emissions of sulfur oxides (SO_x) due to fossil-fueled power plants that generate recharge power. Emissions from conventional automobiles were assumed to decline in line with standards imposed by the Clean Air Act Amendments of 1977. Thus, the benefits of electric cars for HC and CO emissions are less in 1990 and 2000 than in 1980. The overall air quality analysis indicates that sources other than personal automobiles will dominate urban air pollution in future years. This is the reason why the benefits shown in Figure 4 for electric cars are relatively modest.

Traffic noise, the principal noise problem in the United States, was estimated in 1974 to affect adversely almost 100 million people. Noise emissions standards have already been promulgated for trucks, buses, and motorcycles—the noisiest motor vehicles. Standards for automobiles are under development. In urban cruise, where tire noise dominates, electric cars offer little potential advantage. During acceleration, however, engine-related noises predominate for conventional automobiles, and even after considerable improvement, they are expected to be much noisier than electric cars during acceleration. About 15 million people were adversely affected by traffic-acceleration noise in 1974. Required reductions in truck, bus, and motorcycle noise will reduce this to about 70 percent of the 1974 level in future years, even if automobile acceleration noise remains at its present 72 dB level (5). This is shown at the left of Figure 5. Acceleration noise of future internal-combustion engine automobiles is assumed to be reduced to the 68 dB level, which will lower impacts to about 45 percent of the 1974 level (4). The acceleration noise of future electric cars could probably be lower still—about 61 dB (4).

Substitution of electric cars for all internal-combustion automobiles would then reduce noise impacts by almost one-half, to a little over 20 percent of the 1974 level.

LIMITATIONS

Despite their potential benefits for petroleum conservation and the urban environment, the probable usage of electric cars is likely to be quite modest. Figure 6 shows two recent projections of the percentage of the United States automobile fleet that may be electric in future years (6, 7). Both projections are under 10 percent in the year 2000, due primarily to the higher expected cost for electric cars despite the major improvements in batteries projected for the coming decade. Even with these improvements, electric cars are expected to cost somewhat more and do somewhat less than competing conventional automobiles. This assumes energy prices similar to those of today. If gasoline prices were doubled or tripled (to levels prevalent now in Europe), the cost disadvantage would disappear. The range limitation would remain, however, and even though it might entail travel sacrifices on only a few days of the average year, it would probably be a significant deterrent to the purchase and use of electric cars. Furthermore, the acceleration performance of electric cars will probably remain inferior.

The basic problem in electric cars has been (and will remain) the battery, which is heavy and expensive in relation to a gasoline tank. Today's lead-acid batteries are roughly 85 times heavier than a tank of gasoline that stores the same effective propulsion energy. Moreover, today's batteries must be replaced, at considerable cost, after 300 or 400 discharges. Major innovations (nickel-zinc and lithium-sulfur battery systems, for example) are expected to double, triple, or even quadruple both energy stored per kilogram and cycle life. Nevertheless, extra weight and extra cost relative to the gasoline tank will surely remain.

Future electric cars will generally be heavier and more expensive than their conventional counterparts. Figure 7 assumes the weight-conscious and efficient automotive technology appropriate to 1980 and after and compares the weights of future electric and internal-combustion-engine four-passenger subcompact automobiles (4). Passenger compartments in the two automobiles are identical in size and weight. The big difference between them is the weight assigned to energy storage: in the electric car, it is almost 15 times greater than in the internal-combustion automobile. The structure and chassis weight of the electric car is substantially greater than that of the conventional automobile in order to support this additional weight. The propulsion weights are about equal and provide roughly equal amounts of power output. The acceleration capability of the electric car is much less, however, because the car is much heavier.

The electric car in Figure 7 is designed for a long range between recharges, which necessitates a relatively large battery. Weight and the associated costs can be reduced if driving range is sacrificed. The trade-off between range and life-cycle cost is shown in Figure 8 for electric cars that have improved technology similar to that illustrated in Figure 7 (4). Figure 8 also shows the trade-off between range and life-cycle cost for electric cars with technology like that widely used one or two years ago and for advanced electric cars with lithium-sulfur high-temperature batteries. In every case, reduction in design range reduces costs substantially. The minimum ranges shown are those at which battery power output is barely sufficient to meet an assumed acceleration requirement. This requirement, 0 to 64 km/h in 10 s, is the minimum considered acceptable for safe entry into

Figure 6. Projected percentages of electric cars in the U.S. automobile fleet, 2000.

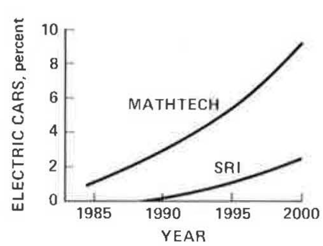
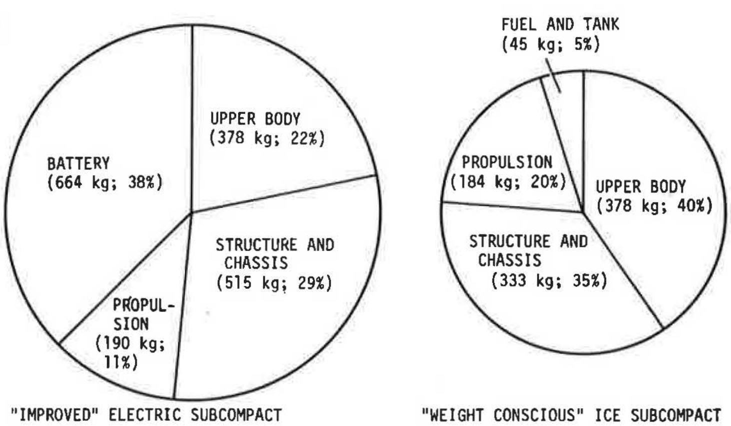


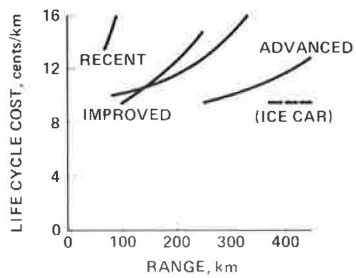
Figure 7. Comparison of electric cars and conventional subcompact automobiles.



- 1747 kg CURB WEIGHT
- 43.3 kW PEAK POWER AVAILABLE (23 W PER kg OF TEST WEIGHT)
- 250 km RANGE (NICKEL-ZINC BATTERY)
- 150 km RANGE (LEAD-ACID BATTERY)

- 940 kg CURB WEIGHT
- 53 kW CONTINUOUS POWER AVAILABLE (49.3 W PER kg OF TEST WEIGHT)
- UNLIMITED RANGE (WITH REFUELING)

Figure 8. Life-cycle costs of electric cars versus internal-combustion engine (ICE) automobile design range.



freeways via typical uphill on-ramps. In all cases, the electric cars can cruise at speeds in excess of the legal limit. The internal-combustion engine automobile costs in Figure 8 are based on those published regularly by the U.S. Department of Transportation (8). The electric car costs are intended to be comparable. They do, however, reflect an assumption of 20 percent longer life (12 years instead of 10) due to the inherent durability and reliability of electric motors and controllers. Battery lifetimes were assumed to be much longer than at present—up to 1000 deep-discharge cycles, or a maximum of 8 years of operation. Average annual driving of 16 000 km/year was also assumed. Further improvements in battery performance and cost would have relatively little effect on these results. Increases in gasoline prices to levels now prevailing in Europe, however, would eliminate most of the disadvantage of the electric cars, even for long-design ranges.

Whether the shorter-range, lower-cost designs of Figure 8 are desirable depends on the intended application. For the most part, urban driving seldom requires long daily ranges. The table below shows driving range requirements sufficient for 95-98 percent of the driving days in Washington, D.C., and Los Angeles (4). These ranges were derived from analyses of trips reported by some 30 000 households in the origin-destination surveys made of the two areas in 1967-1968. The requirements are stated separately for the three principal groups of automobiles identified in the analysis.

	Range Required for Daily Urban Driving	
Automobile Group	95th Percentile (km)	98th Percentile (km)
Secondary	55-75	70-105
Only	85-150	115-210
Primary	110-220	140-290

About one-third of the automobiles in each region were secondary automobiles at multiautomobile households. By definition, these automobiles were driven less than the primary automobile of each multiautomobile household. Another third of the automobiles were only automobiles of single-automobile households. The remaining automobiles were primary automobiles (those driven farthest) of multiautomobile households. Among two dozen other groupings of automobiles investigated, none showed requirements as low as for secondary automobiles nor as high as for primary automobiles. Comparison of these requirements with the ranges illustrated in Figure 8 shows that current electric cars could handle much of today's urban travel and, with expected future improvements, could handle almost all urban travel. If designed to be secondary cars for short-range use, electric cars would be competitive in cost with conventional automobiles. This may nevertheless be undesirable because (a) few secondary automobiles are purchased new, (b) motorists may prefer extra costs to sacrifices of travel mobility, and (c) nonurban travel capability may also be desired, even of second automobiles.

As improved technology increases the range of electric cars, they will become adequate for the needs of most urban drivers. Facilities for overnight recharge at residences will generally be required. Although battery-exchange stations and battery-recharging outlets on street or in parking lots are technically possible, they appear economically unattractive. Generally, overnight recharging will be easiest at single-family housing units that have off-street parking, where electric outlets with sufficient capacity can be easily accessible. The table below gives the percentage of single-family units in various areas that have garages or carports, estimated from the Annual Housing Survey of the Bureau of the Census (4, 9, 10).

	Available Off-Street Parking		
Place	Single-Family Housing Units (%)	Multifamily Housing Units (%)	All Housing Units (%)
Los Angeles	94	93	94
Washington	54	94	71
In all SMSAs	80	92	85
Outside SMSAs	73	87	77
Entire United States	78	91	83

The number is surprisingly low in such cities as Washington and Baltimore. The data do not include uncovered parking in driveways or yards, however, which might also be suitable. Off-street parking of some kind is usually available at multifamily housing units. Here, however, provision of secure outlets for recharging may be a serious problem, especially in basement parking garages, where installations might be difficult. Individual metering will probably be a necessary additional expense because an electric car may require as much energy as all other household uses combined.

CONCLUSIONS

Future use of electric cars on a large scale would cut petroleum consumption drastically for automotive travel and cause significant attendant reductions in air pollution and traffic noise. Despite their probable availability from a major manufacturer within a decade, sales of electric cars are expected to be relatively modest. Future electric cars will be capable and economical, but they will still cost somewhat more and do somewhat less than competing conventional automobiles.

This situation is not without precedent. Low-pollution conventional automobiles are more expensive and more troublesome than uncontrolled internal-combustion automobiles. They would not sell well either if their advantages had not been considered so important that a major role in United States transportation was planned and implemented for them. More recently, fuel-efficient automobiles have received the same treatment. In the future, electric cars may deserve similar treatment. Transportation planners in urban areas where petroleum use and pollution from internal-combustion automobiles remain important problems should give serious attention to electric cars.

Electric cars are, of course, only one of several technological options under development and evaluation at the federal level for the reduction of environmental pollution and petroleum consumption. Electric cars may be unique, however, in that existing federal and industry programs already promise to make them widely available in the marketplace within a relatively few years. Thus, where pollution, conservation, and continued high mobility are important considerations in transportation system planning, electric cars deserve to be considered along with such frequently proposed possibilities as parking restrictions, exclusive bus and carpool lanes, automobile-free zones, automobile taxation, transit subsidy, transit expansion, and land-use controls.

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Assessment of Market Potentials for Electric Vehicles

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The widespread use of electric vehicles within the transportation system is essential for improvement of environmental quality and reduction of the consumption of petroleum-based fuels. This paper describes the development and application of a market assessment model that is used to estimate the market potential for alternative electric vehicle technologies by relating service needs to range capabilities. The market assessment model uses stratified household travel data to simulate typical daily travel patterns over a period of a year. Alternative scenarios of vehicle use are introduced to relate the sensitivity of the market potentials to household travel behavior. An approach to analyzing commercial vehicle market potentials is also presented. The analysis results reveal the interrelationships among the market potentials, vehicle-range capabilities, and vehicle-use assumptions and indicate the application of these findings to identification of an effective electric-vehicle technology development program.

Gasoline- and diesel-powered vehicles are the single largest consumer of petroleum supplies. As a means of relieving the demand for petroleum within the transportation sector, the Electric and Hybrid Vehicle Research, Development, and Demonstration Act of 1976, as amended, was passed to foster the accelerated integration into the market of electric and hybrid vehicles. The act provides resources to encourage the early demonstration of the state-of-the-art technology and the long-range development and commercialization of improved vehicle technology. A total of $160 million has been appropriated to support these activities.

The passage of this act reflects the nation's concern over environmental degradation in urban areas caused by conventional petroleum-fueled vehicles and the need for substitute forms of energy to mitigate the adverse consequences of continued reliance on imported petroleum. Many consider that the key to resolution of these concerns, and the principal objective of the act, is in the large-scale commercialization and operation of electric vehicles (EVs) within the transportation sector. Numerous technical problems must be overcome before an EV system that is capable of replacing a significant share of the conventional and commercial vehicle fleet is available to the transportation consumer. In order to facilitate the early commercialization and marketability of EV technologies within resource constraints, a resource allocation strategy must be developed to guide technology development in an orderly and efficient manner (1).

A critical component of the allocation strategy, and the focus of this paper, is a dynamic market assessment model that identifies the market potential for alternative EV technology configurations. The market assessment model identifies the scale, composition, and requirements of potential EV markets and facilitates the application of an iterative procedure whereby alternative technology and market focus strategies can be analyzed and modified to maximize program objectives.

MARKET ASSESSMENT MODEL

The market assessment model analyzes the potential for the substitution of EVs for conventional vehicles by identification of generic vehicle type and user groups and determination of the compatibility of an EV to the travel and service requirements of the user groups. If a match can be established between the functional service needs of the user and the functional capabilities of the EV, this