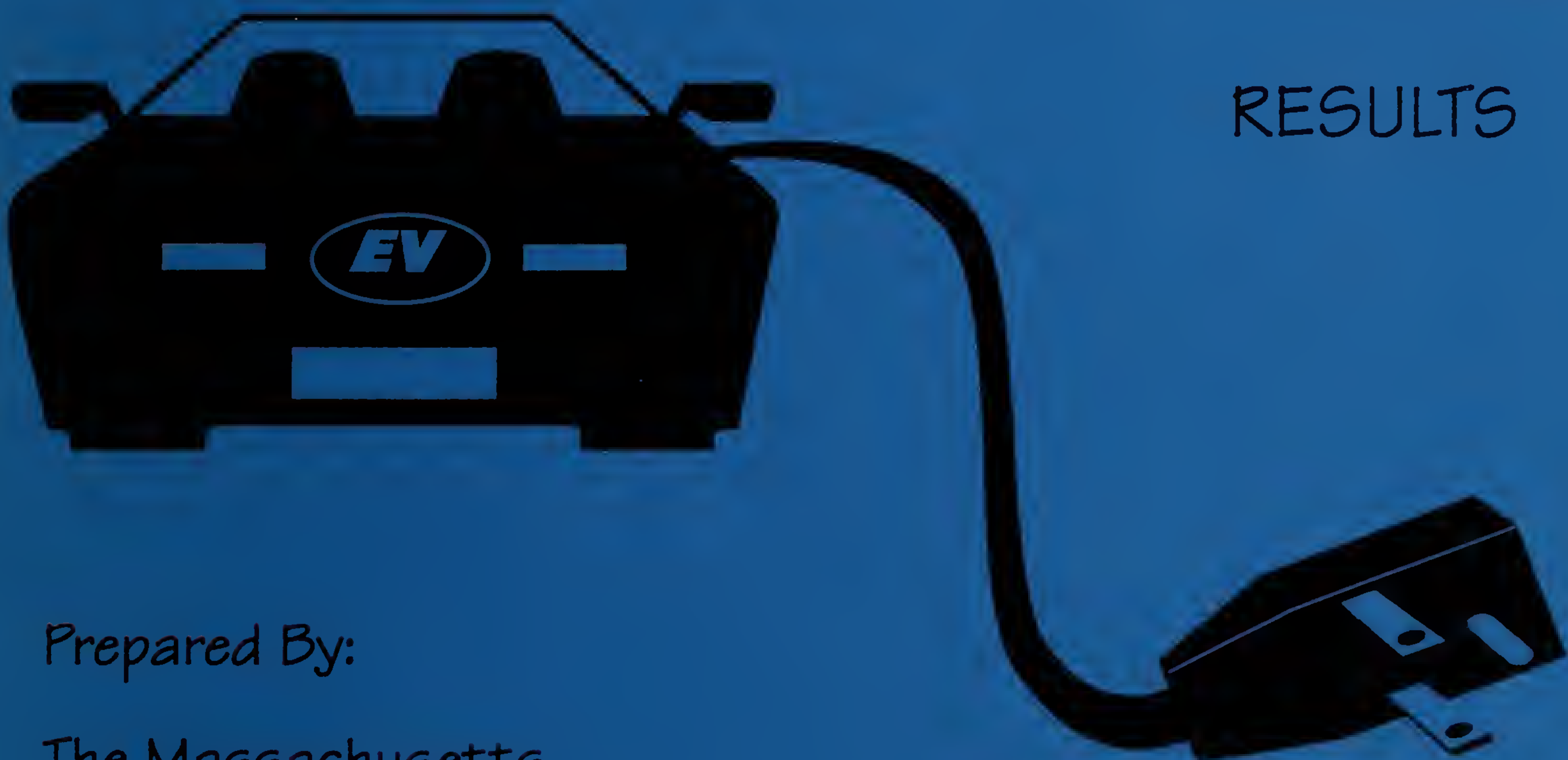
THE MASSACHUSETTS ELECTRIC VEHICLE DEMONSTRATION PROGRAM

FIRST YEAR PROGRAM RESULTS



Prepared By:
The Massachusetts Electric Vehicle Demonstration Program Steering Committee

AUGUST 1995

A Program of the Massachusetts Division of Energy Resources
100 Cambridge Street, 15th Floor • Boston, MA 02202 • 617-727-4732

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MASSACHUSETTS ELECTRIC VEHICLE DEMONSTRATION PROGRAM STEERING COMMITTEE

The Massachusetts Division of Energy Resources

The Massachusetts Highway Department

The Boston Edison Company

The New England Power Company

Commonwealth Electric Company/Cambridge Electric Light Company

Northeast States for Coordinated Air Use Management

The Metropolitan Area Planning Council

The Massachusetts Department of Environmental Protection

The Massachusetts Department of Procurement & General Services

The Northeast Alternative Vehicle Consortium

The Massachusetts Bay Transportation Authority

The EVSC would like to acknowledge the Federal Highway Administration for funding a substantial portion of this program through the Intermodal Surface Transportation Efficiency Act (ISTEA) Congestion Mitigation Air Quality (CMAQ) provisions.

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I. EXECUTIVE SUMMARY

The Massachusetts Electric Vehicle Demonstration Program

In 1992, the Division of Energy Resources (DOER) and several other public and private organizations developed the "Electric Vehicle Demonstration Program" (Program), a five-year effort to show the congestion mitigation and air quality benefits offered by electric vehicles (EVs) when incorporated into an intermodal transportation mix. In the first phase of the $2.7 million Program, the DOER purchased 20 EVs that it leases to commuters who travel from home to three intermodal locations where they park and take public transportation to work. The Program provides vehicle recharging equipment at two of the intermodal sites, powered in part by on-site photovoltaic arrays, as well as home recharging capability. A second phase of the Program will begin shortly with the purchase of additional EVs and advanced EV components. An EV Steering Committee (EVSC), chaired by the DOER, has guided implementation of the Program.

Phase I of the EV Demonstration Program has been a success. The vehicles have consistently exceeded the range requirements specified in the 1993 vehicle procurement, attaining an average range of approximately 37 miles per charge, and they are able to accelerate to and maintain normal highway speeds. The vehicles used in this Program have faced the challenges of winter in New England and have provided safe, reliable, and comfortable transportation. The lessees have stated and demonstrated their continuing satisfaction with the EVs made available to them. Monthly surveys indicate an average driver satisfaction level of 7.6 out of 10, and lend support to the project's premise that, even with the range limitations of the now-surpassed EV technology used in this Program, these vehicles meet the needs of many commuters in the northeast. The majority of drivers have opted to renew the vehicle lease for a second year.

In the two years since the specifications for the EVs in the Demonstration Program were first developed, there have been significant technical advances in EVs and battery technology. Although the vehicles in this Program are only about a year old, they are now regarded as being a generation behind the "state of the art" electric vehicles currently available. Therefore, the results of this Program, although positive, lag well behind what would occur using the latest electric vehicle and battery technologies.

Half of the vehicles in the Program were outfitted with sensors, on-board computers, and communications equipment to upload operating data to a central computer, from which the DOER has developed an extensive data base and analytical reporting process that has received national recognition. In the first year of the Program, the lessees have driven a total of nearly 120,000 miles under a wide variety of road and weather conditions. Although the Program has been designed primarily for commuting needs, the data indicate that many of the drivers are using the vehicles for normal household purposes as well as commuting.

At a retail price of 10 cents per kilowatt-hour, the electricity cost to operate a typical EV in the Program is approximately 3.5 cents per mile. This is comparable to the fuel cost per mile to drive a similar size internal combustion engine vehicle (ICEV) at current gasoline prices of $1.30 per gallon. This comparison reflects the fact that, although EVs are three times as efficient as ICEVs in distance traveled per British Thermal Unit (BTU) of energy supplied to the vehicle, the average retail price of electricity (at $.10 per kilowatt-hour) is three times the BTU-equivalent price of gasoline (at $1.30 per gallon).

The EV Demonstration Program has proven to be an effective stimulus for technological improvement in the electric vehicle industry. Aggressive specifications used in the vehicle procurement process hastened the introduction of such key EV features as thermal management systems for batteries and more convenient and safer retractable charging cords. In addition, feedback from the Demonstration Program has also encouraged the commercial introduction of more powerful electric motors and quieter direct drive systems that are now in use. The Program has also received significant attention from the automotive trade press, the news media, and the general public. This type of exposure has done a great deal to inform the public about the readiness of electric vehicles and the environmental and energy benefits relating to their use in the northeast.

At this juncture, DOER and the EVSC recommend the following plan for Phase II to continue the Program's ability to demonstrate advanced EV technology:

- Purchase up to ten new "state of the art" EVs with monitoring instrumentation.

- Retrofit up to ten of the Phase I vehicles with advanced batteries and charging systems.

This approach to Phase II of the Demonstration Program will ensure that the Program is evaluating the latest and most promising EV technologies in this rapidly evolving field.

II. PROGRAM BACKGROUND

A. Regulatory Context

For more than two decades, air quality in Massachusetts has failed to meet the standards prescribed by the Clean Air Act. Under the Clean Air Act Amendments of 1990 (CAAA), Massachusetts was designated as being in "serious non-attainment" of the ground level ozone (smog) standard on a statewide basis, with a resulting requirement to reduce emissions of volatile organic compounds (VOCs) and oxides of nitrogen (NOx) in order to attain the standard by 1999.

As part of a comprehensive strategy to comply with the CAAA, Massachusetts has focused a considerable amount of attention on reduction of emissions from motor vehicles—a significant source of the state's ozone air quality problems.[1] Shortly after passage of the CAAA, the Massachusetts Legislature adopted Chapter 410 of the Acts of 1990 requiring adoption of the California Low Emission Vehicle (LEV) standards, which include a requirement for a zero emission vehicle (ZEV). In the near term, electric vehicles operating on batteries are anticipated to be the only vehicles capable of meeting ZEV certification requirements, as established by the California Air Resources Board (CARB). The Massachusetts Department of Environmental Protection (DEP) adopted regulations implementing the LEV program in 1991.[2]

Under the LEV Program, large automobile manufacturers must produce a number of ZEVs equal to two percent of the manufacturer's prior year sales in Massachusetts of new passenger cars and light-duty vehicles (with a gross vehicle weight of 3,750 pounds or less). This figure rises to five percent in 2001 and ten percent in 2003. These percentage requirements translate into an expected 2,507 ZEVs to be marketed in Massachusetts in model year 1998, increasing to 6,268 in 2001 and 12,536 in 2003.

In 1991, the federal Intermodal Surface Transportation Efficiency Act (ISTEA) was signed into law to facilitate the continued development of the nation's highway and transit systems and other forms of transportation, with an emphasis on "intermodal" travel linking together various forms of transportation. Among its numerous provisions, ISTEA established a pool

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1 According to the Massachusetts Department of Environmental Protection, on-road motor vehicles are responsible for 29 percent of total VOC emissions and 40 percent of total NOx emissions in Massachusetts.

2 In 1991, the Commonwealth was sued by the Motor Vehicle Manufacturers of America (MVMA) regarding the state's adoption of the California LEV program. At this point in time, the federal courts have allowed the LEV program to go forward while the court case proceeds.

of funds available for "Congestion Mitigation and Air Quality" (CMAQ) improvements, designed to assist compliance with State Implementation Plans (SIP) under the CAAA.

B. Electric Vehicle Demonstration Proposal

With the ZEV mandate and the goals of ISTEA in mind, the Northeast States for Coordinated Air Use Management (NESCAUM) and the Massachusetts Division of Energy Resources (DOER) responded favorably in 1991 to a project proposal by Sheila Lynch & Associates to develop an Electric Vehicle Demonstration Program in the greater Boston area. The basic design of the Program would be for the Commonwealth to procure 50 EVs through competitive bid and lease them to ordinary commuters who typically drive to intermodal sites outside Boston, park, and then take public transportation to Boston. EV battery recharging facilities would be provided at some of the parking lots adjacent to the intermodal site locations to be selected, and these facilities would be supplemented with on-site photovoltaic (PV) power during daytime hours. Battery recharging would also occur at the homes of the participating motorists.

The proposal called for a demonstration fleet of at least 20 vehicles for Phase I and 30 additional vehicles in Phase II. The second phase would be an opportunity for the Program to take advantage of anticipated technological improvements in EVs and EV components. The proposal noted that Massachusetts is a leading producer of electric vehicles and that this project could strengthen the prospects of this fledgling industry. Further, to the extent that the project could make use of local high technology firms involved in renewable energy technologies, such as photovoltaic cells, the project would also help strengthen this sector of the Massachusetts economy.

After endorsing the proposal, NESCAUM/DOER approached a number of companies and organizations to encourage their interest and financial support for the Program. At an early stage, the Metropolitan Area Planning Council provided crucial support in convening discussions with various transportation agencies and other parties. In addition to the DOER, organizations providing funding for the proposal included Boston Edison Company, New England Power Company, and Commonwealth Electric Company/Cambridge Electric Light Company. NESCAUM/DOER submitted the EV Demonstration proposal to the Boston Metropolitan Planning Organization and the Massachusetts Highway Department, and it was subsequently approved as part of the State Transportation Improvement Program and budgeted $2.1 million in CMAQ funds from the Federal Highway Administration as part of the total $2.7 million budget for the Program.

The objective of the EV Demonstration Program, first and foremost, is to demonstrate the user readiness of battery-powered electric vehicles in year-round operation. In addition, the EV Demonstration Program is intended to:

- ➤ Encourage EV manufacturers to design vehicles that best meet the challenges of New England weather and terrain.

- Improve readiness in Massachusetts for ZEV implementation by addressing important technical issues such as battery/charger design, recharge site availability, and EV service infrastructure.

- Emphasize the need for cooperation among government, utilities, and the private sector in Massachusetts to achieve these goals and encourage investment in future EV technologies and infrastructure.

C. Funding Sources and Participants

As noted earlier, funding for the EV Demonstration is primarily provided by the Federal Highway Administration (FHWA) through the CMAQ portion of ISTEA, which is ultimately transferred to the Program through the Massachusetts Highway Department. Other public and private sources of funding, sufficient to meet the 20 percent CMAQ match requirement, were also obtained. The funding sources and amounts are as follows:

➤ Federal Highway Administration	$2,128,000
➤ Division of Energy Resources (includes $200,000 of in-kind support)	400,000
➤ Boston Edison Company	100,000
➤ New England Power Company	75,000
➤ Commonwealth Electric Company/ Cambridge Electric Light Company	25,000
TOTAL BUDGET	$2,728,000

D. Formation of the EVSC

In order to guide the overall execution of the EV Demonstration Program, and to gain the expertise and perspective of other organizations, DOER set up an Electric Vehicle Steering Committee (EVSC) consisting of 11 representatives from organizations listed in the front of this report. The EVSC includes representatives of electric utilities, state government agencies, regional planning agencies, and air quality groups. The EVSC meets monthly to review all aspects of the Program and make recommendations to DOER. To date, the EVSC has focused much of its time on developing specifications for the EVs, charging stations, and data collection procedures, as well as addressing other ongoing program management issues. The combined resources and expertise of the EVSC have been invaluable in the implementation of this Program.

E. Significance of the EV Demonstration Project

In a recent report on the EV market, the U.S. General Accounting Office (GAO) found that a significant weakness in public and private efforts to develop an EV industry in the United States is the small number of EVs on the road, and the lack of rigorous field demonstrations and evaluations. In its research, the GAO found that the Massachusetts EV Demonstration Program is one of the most ambitious demonstration programs undertaken to date in the United States, both in terms of numbers of vehicles involved and the program budget. The only project larger than the Massachusetts EV Demonstration is the Sacramento Municipal Utility District EV Program which includes 30 vehicles, all leased to company employees. A distinguishing feature of the Massachusetts EV Demonstration Program is that its participants are motorists from the general public rather than drivers in corporate or organizational fleets. This enhances the relevance of the field results from this project.

According to the GAO, there are about 270 cars, vans, and buses involved in other EV demonstration programs around the country. Many EV demonstration program officials have reported that it is very difficult to obtain a sufficient number of EVs for a meaningful demonstration program—they are simply not available. Fortunately for the Massachusetts EV Demonstration Program, there was sufficient interest and manufacturing capability within the emerging EV industry to supply all vehicles solicited through a competitive procurement process described in III.A below.

III. PROGRAM DESIGN & IMPLEMENTATION

A. Vehicle RFP and Delivery

In May 1993, the Commonwealth released a Request for Proposals (RFP) for electric vehicles. The award criteria provided for multiple vendor awards. Three vendors responded, but only one was deemed fully responsive. Solectria Corporation of Wilmington, Massachusetts was awarded a contract to provide the Commonwealth of Massachusetts with 20 Solectria Force vehicles which are Geo Metro automobiles converted to EVs by: (1) the removal of the gasoline engine, fuel tank, and other internal combustion-related equipment, and (2) the installation of an electric motor and drive system, batteries, and various electronic controls. See **Attachment 1** for a picture of the Solectria Force. The mandatory performance specifications in the RFP included:

1. 0-40 mph in 15 seconds with all auxiliary loads (e.g. heater, radio, lights, etc.) on.
2. 0-60 mph in 25 seconds with all auxiliary loads on.
3. 30 to 50 mph at 6% road gradient.
4. Cruise at 55 mph under normal conditions.
5. Night range of 30 miles at ambient temperature of 10° F.
6. Cabin climate control of 65° F under normal operating conditions.
7. Meet all Federal Motor Vehicle Safety Standards (FMVSS) or have waiver from certification.
8. Must be designed for structural integrity by not exceeding original specifications for Gross Vehicle Weight Rating (GVWR) or the Gross Axle Rating (GAR).
9. Thermal management system for battery banks.
10. On-board retractable charging cords.
11. Minimal maintenance requirements.

In addition to the mandatory requirements, the specifications included several desirable features. Solectria provided two of them: emergency back-up power for hazard lights, and automatic pre-heating timer controls.

The vehicles ordered included both two-and four-seat Solectria Force models. Fifteen of the vehicles were ordered with maintenance-free sealed lead-acid batteries (made by three companies: GNB, Sonnenschein, and Gates) and five with nickel cadmium (Ni-Cad) batteries (made by SAFT). All vehicles use AC induction motors, controllers, and chargers manufactured by Solectria Corporation. Delivery of vehicles under the contract began in April 1994. The inspection and approval of the final vehicle delivered under phase I took place in August 1994. The average delivered vehicle cost was $36,331[3]. **Attachment 2** provides a further description of each vehicle procured in the Program.

B. Recharging Equipment RFP and Delivery

An RFP for recharging equipment was issued in November 1993. Diversified Technologies Incorporated (DTI) of Lexington, Massachusetts received the contract award to provide: (1) the design and installation of thirteen daytime commercial grade 120 volt, 15 & 30 ampere charging stations for EVs, (2) twenty residential grade 120 volt, 15 & 30 ampere charging stations for EVs, and (3) 16 kilowatts of commercial grade photovoltaic cells to offset a potion of the energy consumed by the EVs during daytime recharging. The recharging stations include meters to record the on-site energy consumption for vehicle recharging and the energy output from the photovoltaic arrays. The inspection and approval of final installations took place in September of 1994.

Under DTI's contract, the company installed recharging facilities at the Alewife and Braintree intermodal stations and at the home of each Program participant. Because the Solectria vehicles used in this Program came equipped with on-board recharging units capable of operating on normal 110 volt alternating current, the recharging facilities procured from DTI are essentially metered electrical outlets.

C. Data Retrieval Specification RFP and Delivery

Because of the limited amount of field data available on EV performance, particularly with regard to driving in New England conditions, the EVSC concluded that it would be valuable to collect a variety of performance data on the EVs in this project. The EVSC decided that outfitting 10 of the 20 vehicles with data collection gear would be sufficient and constitute a reasonable sample given the high costs involved with automated data collection equipment. In August 1993, the Commonwealth issued an RFP for data collection equipment and data base management services, which was awarded to Science Applications International Corporation (SAIC) of San Diego, California. SAIC installed all the necessary

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3 It should be noted that the vehicles procured in this Program, as is currently true throughout the electric vehicle industry, are ICEVs that are converted to EVs on a very small scale and in a labor-intensive manner. It is widely believed that, with the advent of mass-produced vehicles designed and built as EVs from the "ground up," the costs of EV manufacturing will fall dramatically as will EV prices.

hardware and software, including cellular phones in each vehicle to permit daily data uploading to a central computer system. Inspection and acceptance of the last data acquisition system installation took place in August 1994. **Attachment 3** depicts the location and number of sensors in each of the ten vehicles. SAIC and the DOER checked all raw data uploaded by telephone for accuracy prior to its use. Much of the data contained in this report is a result of SAIC's raw data collection, and subsequent analysis by the DOER.

The data collection system consists of the Campbell CR10 programmable datalogger—essentially an on-board computer—and modems and cellular phones for nightly uploading of information.

The data collection system measures a variety of data, and also provides several calculated values:

Measured Data:

1. Vehicle status (off without charging; off with charging; in operation).

2. Date and time.

3. Miles driven in trip.

4. Volts.

5. Amps consumed by the vehicle during operation.

6. Amps consumed by the battery during charging.

7. Amount of time vehicle is charging.

8. Front battery compartment temperature.

9. Back battery compartment temperature.

10. Passenger compartment temperature.

11. Ambient temperature.

Calculated Values:

1. Time vehicle operated in charging/driving/off mode.

2. Kilowatt-hours (KWH) consumed during trip.

3. KWH consumed per mile during trip.

4. Average speed for the trip in mph.

5. Average acceleration for the trip.

6. Average KWH demand during a trip.

7. Average KWH demand during charging.

8. Average KWH capacity during regeneration for a trip.

The objective of the data collection process is to assess vehicle performance and other operating conditions on a daily and monthly basis. Data are collected every two seconds for all parameters except energy used to charge the vehicle (collected every 30 minutes). For ease of use and subsequent analysis, the data collection system averages the data every 15 seconds.

D. Transportation Management Service RFP and Delivery

The RFP for Transportation Management Service was issued in December 1992. Under this RFP, the Commonwealth sought a vendor who could provide a variety of program management services including:

1. Soliciting and screening EV lessees, with DOER's approval.

2. Providing 24-hour emergency road service such as towing.

3. Coordinating the purchase by DOER of insurance for each vehicle to protect the lessees and the Commonwealth from collision and liability damages.

4. Facilitating training and certification of local automobile repair shop personnel with regard to Demonstration Program EVs.

5. Managing communication regarding service and insurance issues with lessees and EV service personnel.

The American Automobile Association (AAA) of Massachusetts won the contract for this service and offered to provide the service at no cost. As part of its service offering, AAA provides each lessee with a AAA Plus Membership, which includes free towing, roadside repairs, and other travel-related services.

E. Selection of Demonstration Project Participants

As part of its contract for Transportation Management Service, AAA was assigned the task of soliciting EV lessees through an advertisement in its member magazine. Criteria for participation as a lessee included:

1. The lessee must currently use one of the specified intermodal parking sites (Commuter Rail/Rapid Transit parking garages at Alewife and Braintree MBTA stations or at the Massachusetts Highway Department park and ride lot in Newburyport).

2. The lessee must live within 25 miles of the site.

3. The lessee must be willing to satisfy DOER standards for a driver record safety check.

4. The lessee must be willing to pay $200 per month to lease the EV (includes insurance) and complete a driver survey form monthly. In addition, the driver must be willing to pay the MBTA for a reserved monthly parking space, which includes access to and free use of the recharging equipment.

The selection of drivers was more difficult than initially anticipated. The initial solicitation for drivers was made through the use of AAA's member magazine and leafleting at the three intermodal stations targeted for EV use by the EVSC. This solicitation received a warm reception by interested individuals. However, many potential drivers declined to participate because of lease and parking costs or the required release of driving records from the Registry of Motor Vehicles. Boston Edison Company helped complete the lessee recruitment process by soliciting lessees through bill inserts to customers in the target areas.

F. Data Collection, Analysis, and Uploading by DOER

After the data are transmitted from the EVs to SAIC's central computer, the data are compiled in a data base and downloaded to DOER for further analysis. On a monthly basis, DOER prepares several regular reports which track items such as estimated vehicle range, energy efficiency, and raw data provided by SAIC that require follow-up. Based on this work, and in conjunction with DOER's participation in the Advanced Research Program Agency (ARPA) project with the Northeast Alternative Vehicle Consortium (NAVC), DOER then uploads EV Demonstration Program data to the National Data Center Site on the Internet World Wide Web.

IV. FIRST YEAR PROGRAM RESULTS

A. Vehicle Use Data

To date, the EV lessees have driven the EVs almost 120,000 total miles. Consistent with the intended design of the Program, a substantial amount of the EV use appears to be related to transit station commuting and follows a recognizable pattern. However, there are also indications that some drivers are using EVs for other household purposes as well. For these drivers, the EV use pattern resembles that of a "first car" rather than a commuter car. For example, as shown in **Attachment 4**, some lessees use the cars intensively, driving 800 or more miles per month and taking 130 or more monthly trips, with frequent weekend or evening usage. It is not unusual for "heavy" users to drive their EVs 25 or more hours monthly.

Attachment 5, which depicts velocity and acceleration data for vehicles, indicates that the EVs in the Program travel at a wide range of speeds in daily driving, and are therefore being used for both highway and city driving. Maximum speeds of 65 miles per hour have been recorded. Average speeds recorded for drivers in the Program are 26.3 mph. **Attachment 6** shows that the monthly average trip distance ranges between 3.4 and 8 miles. **Attachment 6** also shows that the average distance traveled between recharges ranges from a low of 6.1 miles to a high of 16.2 miles, and that the average monthly vehicle use ranges between 14 and 22 hours.

B. User Satisfaction Information

As part of the EV lease agreement, each lessee agreed to answer a monthly questionnaire about his or her vehicle's performance. As shown in **Attachment 7**, the questions are in the form of a one-page checklist of vehicle features that can be documented as "OK," or "not OK" with room for comments if so desired. In addition, the questionnaire seeks the lessee's rating of the vehicle's overall monthly performance from 0 (poor) to 10 (ideal). The DOER has recorded the data on a monthly basis and has used it to track EV driver satisfaction levels over time. **Attachment 8** is the monthly average of user satisfaction levels since the Program began. As shown, the average monthly user satisfaction level varies between a low of 7.12 and a high of 8.22, averaging 7.6.

Additional information about user satisfaction can be inferred from the leasing process itself. To date, lease payments have been uninterrupted and timely. In addition, 8 of 12 lessees have opted to renew the EV lease for another year without any marketing activities being undertaken to accomplish this result.

Although there were instances where the vehicles did not always perform up to driver expectations, the survey data indicate that the lessees were generally satisfied with the vehicle, and that they were eager to continue leasing the vehicles. This information lends support to the Program premise that, even with range limitations of the now-surpassed EV technology used in the Program, these vehicles can satisfactorily meet the needs of many commuters in the northeast.

Attachment 9 provides a sampling of comments made by drivers during the first year of the Program.

C. Vehicle Performance

1. Reliability

During the first year of this Program, the Solectria vehicles were generally reliable and met the performance specifications required in the purchase agreement. Although warranty and non-warranty repairs and maintenance were needed for all vehicles in the Program, most repairs were of a minor nature and were rendered promptly by Solectria, which provided responsive and flexible service. There were no catastrophic failures of any major vehicle components.

One useful indicator of reliability is the number of vehicle breakdowns. As part of its Transportation Management service, AAA provides 24-hour emergency road service (ERS) via an 800 telephone number accessible through the cellular phone in each vehicle. Since the Program began in April 1994, AAA has logged a total of 11 ERS calls. Six of these calls ultimately required battery maintenance. All other calls were due to a variety of minor repair requirements to the controller, the charger, or auxiliary systems. **Attachment** 10 lists the nature of the calls. Most work was covered by warranty except labor for battery maintenance and replacement.

In the first year of the Program, the average cost of repairs and maintenance per vehicle was $492. These charges were incurred for repairs and maintenance work performed by Solectria outside of normal warranty coverage. A significant portion of this cost relates to battery maintenance and replacement work. As noted below in IV.D, six of the 20 vehicles required full or partial battery replacement (at no cost for the parts) due to manufacturing defects or unexplained failures.

2. Safety

The Solectria vehicles delivered to DOER meet federal motor vehicle safety standards. While the EV Demonstration Program was not established to perform explicit tests on vehicle safety (e.g. crash tests or avoidance tests), the safety-related anecdotal information is positive. On the monthly lessee survey, drivers are asked to evaluate “overall safety” as well as “steering and handling” and “brakes”—all important indicators of safe vehicle operation. All comments regarding “overall safety” and “steering” were “ok.” With regard to “brakes” a small number of drivers indicated that the vehicle did not stop quickly enough in emergency situations. This may be due to the absence of power brakes in the Solectria vehicles, to which some drivers were most likely unaccustomed. Overall, however, the data suggest that lessees felt the vehicles to be safe.

3. Energy Efficiency

There are two ways to describe the energy efficiency of electric vehicles: (1) charging efficiency which compares the number of miles traveled per KWH of energy drawn from the plug; and (2) discharge efficiency which compares the number of miles traveled per KWH drawn from the battery. For both measures, higher efficiency leads to lower operating costs. Efficiency (along with battery energy storage capacity) is also the key determinant of vehicle range, with higher efficiency leading to higher range.

Efficiency data collected from July 1994 through May 1995 are profiled in the lower portion of **Attachment 11**. It is clear from this graph that both charging efficiency and discharge efficiency follow a seasonal pattern suggesting that efficiency is at a maximum in the spring and fall months, somewhat decreased in the summer, and at a minimum in winter. Discharge efficiency decreased from 6.6 miles per KWH in September to 4.3 miles per KWH in February, a decrease of 35 percent. A similar decrease in charging efficiency occurred as well.

There are several possible explanations for this decrease in efficiency during colder months: vehicle heating (both pre-travel heating and travel heating), window defrosting, greater use of headlights, high lubricant viscosity, tire deflation, greater wind resistance in colder, denser air, and diminished battery performance in cold weather as battery temperature drops below the optimal minimum temperature of 70° F. It is not possible at this time to identify the relative contribution of each factor above in the observed energy efficiency decrease.

Attachment 12 presents energy efficiency data for each of the 10 instrumented vehicles in the Program. The energy efficiency data in this graph are expressed on a kilowatt-hour per mile basis, meaning that the *lower* the ratio, the *higher* the efficiency. The graph also shows energy losses, that is, the difference between the KWH per mile used to charge the battery and the KWH per mile drawn from the battery. High energy losses imply inefficiency in the battery charging process.

Attachment 12 shows that while discharge efficiency varies only moderately among the 10 vehicles, the charging efficiency varies dramatically, with the energy losses varying to an even greater degree. These data suggest that Ni-Cad equipped vehicles 21E and 23E, are experiencing some problems during the charging process and that these vehicles should be tested thoroughly to determine the problem.

4. Range

The purchase agreement with Solectria and the Program's technical specifications required that the EVs delivered to the Commonwealth achieve a minimum nighttime range of 30 miles at 10° F. Vehicle range is calculated by multiplying the discharge efficiency by the battery's kilowatt-hour capacity.

In its first year, the EV Demonstration fleet's estimated average vehicle range is 37 miles per charge. The highest estimated monthly range for an individual vehicle is 53 miles per charge and the lowest estimated range is 24 miles per charge. As shown in the top of **Attachment 11**, the average monthly range for the overall EV fleet has a high of 47 miles and a low of 31 miles. The longest recorded actual trip thus far in the Demonstration Program has been 47 miles. Overall, the range data suggest that all but one of the vehicles are able to consistently achieve the minimum of 30 miles per charge as required in the vehicle procurement specifications.

As noted above, the estimated range is the product of discharge efficiency and battery kilowatt-hour capacity. In this analysis, it is assumed that the battery capacity does not vary from the battery's rating. Therefore, the variation in estimated range is directly proportional to the variation in discharge efficiency, as shown on **Attachment 11.** It is possible however, that the calculated range may be upwardly biased, if, in fact, the battery capacity is less than the manufacturer's rating.

Recent advances in battery technology suggest that increased range in EVs can be achieved in Phase II of the Demonstration Program. A Solectria vehicle equipped with a nickel metal hydride battery recently logged 238 miles on a single charge in an EV road race. Advanced lead-acid batteries are now available that can reportedly provide up to 100 miles or more per charge. While the costs of these breakthrough technologies may be higher than those for conventional lead-acid batteries, larger scale production will be the key to reducing the unit costs for a new generation of batteries.

5. Comfort and Convenience

In designing the RFP specifications for the vehicle, the EVSC intended to procure a vehicle with comfort comparable to ICEVs on the market today. In addition to the sticker price paid for such convenience and comfort features as a heater, air conditioning, rear defrosters, cassette radios, and cellular telephones, there is also a price paid in reduced vehicle range, as these devices increase power consumption. Still, comfort and convenience items in the car proved popular with the lessees who gave the Solectria EV high marks for these features. One feature that was especially well received is the pre-trip heating by which the heating system can be placed on a timed operation so that the vehicle is warm prior to the trip, making it more comfortable. The other advantage of this feature is that the electricity required to pre-heat the vehicle is drawn from the utility grid, helping to conserve battery power for the trip.

6. Operating Costs

As noted above, the data collection system used in the monitored EVs allows a determination of each vehicle's charge efficiency, that is the kilowatt-hours drawn from the plug per mile traveled. As shown in **Attachment 12**, the average charging efficiency for the ten instrumented vehicles (measured between July 1994 and April 1995) was 0.351 KWH per mile. The variation in EV charging efficiency reflects a number of potential factors such as variation in the performance of the batteries, charger, and thermal management systems; route and terrain differences faced by the vehicles; and driver behavior (such as use of the power saver control, heating, and other auxiliary options, etc.). Further analysis is required to differentiate between these factors.

A driver's energy cost per mile can be determined by multiplying the charging efficiency by the retail cost of a kilowatt-hour of electricity. Unlike the retail price of gasoline, the retail price of electricity can vary widely, depending on the utility company from which it is purchased, a customer's rate classification, and the time of day the energy is obtained. Because of these factors, there is no single benchmark cost per KWH that can be used to accurately calculate the energy costs of driving EVs in this Program. Therefore, in **Attachment 13** this report presents the energy cost per mile for each of the ten instrumented vehicles given electricity prices ranging from $0.05 per KWH to $0.15 per KWH—a rough approximation of the range of prices currently offered to residential and commercial electricity customers.

Another useful way to evaluate the energy costs of the EVs used in the Program is to compare them to ICEV fuel costs. In **Attachment 14**, a matrix is presented that can be used to determine the miles per gallon an ICEV would need to achieve to have energy costs equivalent to those of an average EV in this Program (given user-specified prices for a kilowatt-hour of electricity and a gallon of gasoline). For example, the matrix indicates that at an electricity price of $0.10 per KWH and a gasoline price of $1.30 per gallon, an ICEV would need to get 37.0 miles per gallon to have equivalent energy costs for the average EV used in this Program. Other combinations of electricity and gasoline price can be used in the same manner.

At a price of 10 cents per kilowatt hour, the electricity cost to operate a typical EV in the Program is approximately 3.5 cents per mile. This is comparable to the fuel cost per mile to drive a similar size internal combustion engine vehicle (ICEV) at current gasoline prices of $1.30 per gallon. This comparison reflects the fact that, although EVs are three times as efficient as ICEVs in distance traveled per British Thermal Unit (BTU) of energy supplied to the vehicle, the average retail price of electricity (at $.10 per kilowatt-hour) is three times the BTU-equivalent price of gasoline (at $1.30 per gallon).

D. Battery and Charging System Performance

Based on manufacturer data, the expected useful lives for the sealed lead-acid batteries and Ni-Cad batteries used in the Program should be about 8,000 and 32,000 miles, respectively. During the first year, there have been six vehicles in the Program that have required individual battery replacements (all lead acid) well before reaching the 8,000 mile mark. See **Attachment 15** for details. Two of these failures were due to defective batteries from a manufacturer who acknowledged the problem and indicated that it stemmed from initial factory production methods. These batteries have since been replaced and the replacements are functioning normally. At this time, DOER has not been able to determine the cause of the other four premature battery failures.

The specifications for the vehicles in this Program required a "thermal management system" to keep the operating temperature of the batteries within an optimal range. The concern about battery temperature is that, at very low temperatures, lead-acid batteries have diminished output, while at very high temperatures, battery components can be damaged. Maintaining optimal battery temperature requires a sophisticated thermal management system that provides initial warming of the battery, controls waste heat buildup, and insulates the system. **Attachments 16.1 and 16.2** show high and low ambient temperature and battery bank temperature (front and rear) on four vehicles during August 1994 and January 1995. A battery bank temperature of between 70° and 90° F is considered an optimal range in which lead-acid systems perform well with minimal degradation, and is depicted on the graph as dotted lines. All four vehicles analyzed have lead-acid batteries with battery bank thermal management systems.

These graphs show several important trends: In August, measurements show that all battery banks (front and back) exceeded the maximum optimal range temperature, in one case by 63° F. In addition, all but one battery bank fell slightly below the minimum optimal range temperature. In January, all but two battery banks exceeded the maximum optimal temperature, in one case by 88° F. All but one battery bank fell below the minimum temperature by up to 30° F. In both hot and cold weather, there is a substantial swing in both front and back battery bank temperatures from minimum to maximum. There is, however, fairly close uniformity between front and back battery temperatures on each specific vehicle.[4]

The ideal situation would be for all battery temperatures to be within the designated optimal temperature range at all times. It is likely that accelerated thermal degradation has occurred in most of the systems as a result of the high temperatures experienced. One result of this could be shorter battery life due to accelerated internal corrosion. Another result could be an imbalance in individual battery charge rates causing either overcharging, additional thermal stress and cell failure, or undercharging and depressed vehicle range. In Phase II, the Program should seek improved battery thermal management systems that can more closely regulate battery temperatures.

As noted earlier, several of the Ni-Cad battery equipped vehicles have been experiencing very high energy losses during the recharging process. This is shown in **Attachment 12** where the energy losses for Ni-Cad equipped vehicles 21E and 23E are significantly higher than for the other vehicles

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4 Solectria has indicated that the extreme temperature readings may be the result of faulty temperature sensors, and that the equipment should be checked for accuracy.

Attachment 17.1 sheds further light on the relatively inefficient charging of the Ni-Cad batteries. As shown in this graph, as the number of hours the Ni-Cad batteries are charged increases in a given month, so do the energy losses. The solid line through the plotted points is a regression line showing a positive relationship between energy losses for the Ni-Cad batteries and hours of charging. On the other hand, **Attachment 17.2** , which is the same type of graph for the vehicles equipped with lead-acid batteries, does not show such a relationship. In addition, it should be noted that the lead-acid batteries generally have 300 or fewer hours of charging per month, while some of the Ni-Cad batteries are being charged for up to 600 hours per month. At this time, the EVSC does not have a conclusive explanation for the inefficient Ni-Cad charging performance. It is possible that the frequency of battery watering may be a factor. Another possible problem could be some source of incompatibility between the on-board charging unit and the Ni-Cad battery. These and other possible explanations are now being investigated fully. It should be noted, however, that the Ni-Cad equipped vehicles have no apparent problems regarding discharge efficiency, which is actually higher than that for the vehicles with lead-acid batteries.

Another concern regarding the electric supply in the EVs used in the Program has been with the operation of the charger. It is unclear why for some of the vehicles there are significantly more charging cycles than vehicle trips. In addition, charging data indicate that even when battery packs are fully charged, some chargers are continuing to cycle on and off. It is possible that this type of charger operation may be reducing charging efficiency and contributing to early degradation of the battery.

In Phase II of the Demonstration Program, it would be prudent to test alternative charging equipment and controllers (such as inductive chargers) that can monitor battery temperature, state of the battery charge and voltage, and provide feedback. Specifications for such equipment should require that the charger, charge controller, and battery must work together to maximize efficiency, life span, and range of the vehicle.

Another unresolved question about the charger/battery system concerns identifying the best recharging approach to increase battery longevity and efficiency. According to Solectria and the battery manufacturers, opportunity charging—that is plugging in whenever possible—is the best recharging strategy for lead-acid batteries. However, there have been some test results from other demonstration programs showing that waiting until the battery reaches an 80 percent discharge before recharging is the best approach for Ni-Cad batteries. This remains an open question that should be evaluated further in Phase II.

E. Charging Station Performance

As mentioned earlier, drivers in the Program were provided with recharging facilities for home use as well as use of those at the Alewife and Braintree stations. The results of the Program indicate that when fully depleted, the batteries used in this Program take between six and eight hours to recharge fully, and fewer hours if the battery is not fully depleted.[5] Data collected from the instrumented vehicles includes both the KWH used for recharging and the time of use. This information is presented in **Attachments 18.1, 18.2**, and **18.3**

Attachment 18.1 shows the 24-hour distribution of energy use (for both home and station charging) in May 1995 (selected as a representative month) to charge the five instrumented vehicles using the Alewife intermodal station.

Attachment 18.2 is the same for the Braintree intermodal station, and **Attachment 18.3** aggregates the data for the Alewife and Braintree stations. The graphs all show a peak demand for power during the heart of the business day, when the vehicles are assumed to be recharging at the parking garage. At approximately 3 pm, the load bottoms out as the batteries reach capacity (or the EVs are driven out of the parking lot). The load begins rising after 3 pm, peaks around midnight, and tapers off to a low point in the early morning hours. This pattern appears to reflect commuters returning home and plugging in their vehicles for evening recharging. **Attachment 18.3** shows that approximately 37.6 percent of the electricity consumed for recharging occurs between 8 am to 5 pm, when the vehicles are likely to be at the central charging facilities.

Attachment 19 depicts the electricity used through June 30, 1995 to charge all vehicles while parked at Alewife and Braintree stations, relative to the amount of electricity generated by the photovoltaic (PV) arrays installed at each site. COM/Electric managed the collection of these data. The PV arrays have produced 5,117 KWH more electricity than has been used for charging at Alewife station. Braintree, which has only one PV array instead of three[6], has consumed 3,185 KWH more than its PVs have generated. When combined, the two stations have generated 1,932 KWH of electricity beyond the EV charging requirements at the two stations.

A more detailed examination of the benefits provided by the PV arrays is shown in **Attachments 20.1, 20.2**, and **20.3** in which the hourly generation of electricity from the PVs during May 1995 is compared to the hourly energy demand for EV recharging at the Alewife and Braintree stations. As shown in **Attachment 20.1**, the PV-generated electricity at Alewife station in May 1995 fully offsets the energy demand for recharging during all hours, except for some minor usage during the period 7 pm through 5 am. At Braintree station, the situation is different. The peak demand for recharging at Braintree station occurs from 8 am through 12 noon. PV generation is substantially less than electrical demand for recharging during this period, indicating that a major portion of the energy used at Braintree is coming not from the PV arrays, but the power grid. However, in the afternoon, the PV output at Braintree

5 These recharge times were accomplished using the vehicle's on-board 110 volt chargers, designed to operate on normal household current with standard three-prong outlets. More rapid charging is possible using higher voltage outlets.

6 The initial engineering plan called for two photovoltaic arrays to be installed at both Alewife and Braintree stations. However, due to locational constraints at the Braintree site, DOER subsequently arranged for three of the arrays to be placed at the Alewife station and one at the Braintree station.

station is equal to or slightly greater than the electrical demand for recharging. **Attachment 20.3** combines the results for Alewife and Braintree stations. The results noted here are for May 1995, and can be expected to vary monthly based on changing daylight patterns.

The use of the PV installations certainly brings the electric vehicles in this Program much closer to fulfilling the full promise of a zero emission vehicle: no tailpipe emissions and no "elsewhere" emissions on the power grid.

F. Public Awareness and Education Results

As noted in this report, the EV Demonstration project has succeeded in many technical areas, and most importantly, in satisfying the needs of the lessees. The project has also produced a substantial benefit in assisting public education about the energy and environmental benefits of EVs. Since the inception of the Demonstration Program, the EVs in this Program and the lessees using them have been profiled in numerous newspaper and journal articles. The vehicles in the Program are all clearly marked as being EVs and further contribute to public awareness of this new technology. As a direct result of this public exposure to the EVs, there are now more inquiries coming to DOER from the public and fleet operators about EVs than ever before. This is an important contribution of the EV Demonstration Program.

The EV Demonstration Program has also proven to be an effective stimulus for technological improvement in the electric vehicle industry. Aggressive specifications used in the vehicle procurement process hastened the introduction of such key EV features as thermal management systems for batteries and more convenient and safer retractable charging cords. In addition, feedback from the Demonstration Program has also encouraged the commercial introduction of the more powerful electric motors and quieter direct drive systems that are now in use.

V. RECOMMENDATIONS FOR PHASE II

A. Phase II Overall

As noted in the prior sections of this report, there are several areas where Phase II of the EV Demonstration Program can continue to make progress in obtaining the most effective and efficient EV technology. The pace of technological development surrounding EVs is very brisk, and the following list of recommendations for Phase II of the Program needs to be reassessed as circumstances may warrant. The suggested recommendations reflect technical analyses performed by the EVSC as well as suggestions proffered by lessees in the Program.

The second phase of the Program was originally intended to acquire an additional 30 vehicles. However, the costs incurred in the first phase for vehicle purchase, instrumentation, and charging systems installation preclude a purchase of this scale. At this juncture, DOER and the EVSC recommend the following overall plan for Phase II[7]:

1. Purchase eight to ten new advanced electric vehicles. This procurement activity will be undertaken in conjunction with the EV America procurement program, a national effort led by utilities and other organizations to help build the EV market.

2. Retrofit up to ten of the Phase I vehicles with advanced batteries and charging systems.

3. Target Phase II monitoring and data collection efforts toward Phase I retrofitted vehicles and new EVs; additional data collection on unmodified Phase I vehicles will not yield information of sufficient value.

4. Broaden the use of existing and new EVs in the Program by leasing new and existing EV to workplace carpool drivers, as well as intermodal station commuters.

If fully implemented, these four recommendations will enable Phase II of the EV Demonstration to examine the readiness of EVs in a broader range of commuter uses. Phase II of this five-year project will last from 1995 to 1997, and will result in a Phase II final report in December 1997.

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7 These recommendations will be presented to the Federal Highway Administration for formal review and approval.

In addition, EVSC and DOER make the following detailed recommendations relating to three action areas: (1) Programmatic Implementation; (2) Phase I Vehicle Improvements/Retrofits; and (3) Procurement Recommendations.

B. Recommendations for Programmatic Implementation

1. Ensure that preventative maintenance procedures are followed for all vehicles in the Program by educating Program participants about vehicle maintenance needs.

2. Encourage EV vendors and suppliers to actively assist the EVSC in data collection and Program results analysis.

3. Collect and analyze time-of-use recharge and photovoltaic data to determine the precise environmental and energy benefits associated with EVs in the Program.

4. Investigate and define the best recharging strategy for battery performance and longevity.

5. Broaden eligible Program participants to include workplace carpool drivers.

C. Recommended Phase I Vehicle Improvements/Retrofits

1. Explore the feasibility of upgrading key components (battery, charger, charge controller, fuel indicator, thermal management system, etc.) of Phase I EVs where technology has improved.

2. Improve the data available regarding battery condition by conducting periodic discharge tests, or installing battery diagnostic devices.

3. Add additional data sensors to record the use of auxiliary devices (e.g. heater) and use of the "power saver" control.

4. Add vehicle safety devices, such as the following:

   - Pedestrian warning beeper for backing up.
   - Luminescent power cord for safe operation at night.
   - Improved weather-proof plug assembly.
   - Seat/shoulder belts that attach to door pillar frame, not door.

- Improved electric vehicle insignia on vehicle.

- Dashboard warning message to turn wheel toward curb when parking.

D. Procurement Recommendations

The EV Demonstration Program should work closely with the EV America consortium to incorporate EV specifications in Phase II procurements that will help the EV industry standardize products, achieve economies of scale, and bring more efficient and effective technologies to market.

As part of Phase II procurement activities and collaboration with EV America, the Program should make sure that RFP specifications for EVs and components provide options for:

1. Advanced batteries with greater energy density and durability so vehicle range can be increased to serve a broader potential market.

2. Improved charger designs that include more precise control of charge operation and communication with the battery. Revised charger/charge controller specifications should require closed loop monitoring of temperature, voltage, impedance, and state of charge so that optimal battery voltage and temperature are maintained.

3. Improved thermal insulation of battery bank so desirable temperature is achieved and maintained with minimal energy consumption.

4. Improved hill climbing.

5. Improved illumination of the dashboard instruments to improve legibility.

6. Fuel gauge that performs comparably to gauge in conventional automobiles.

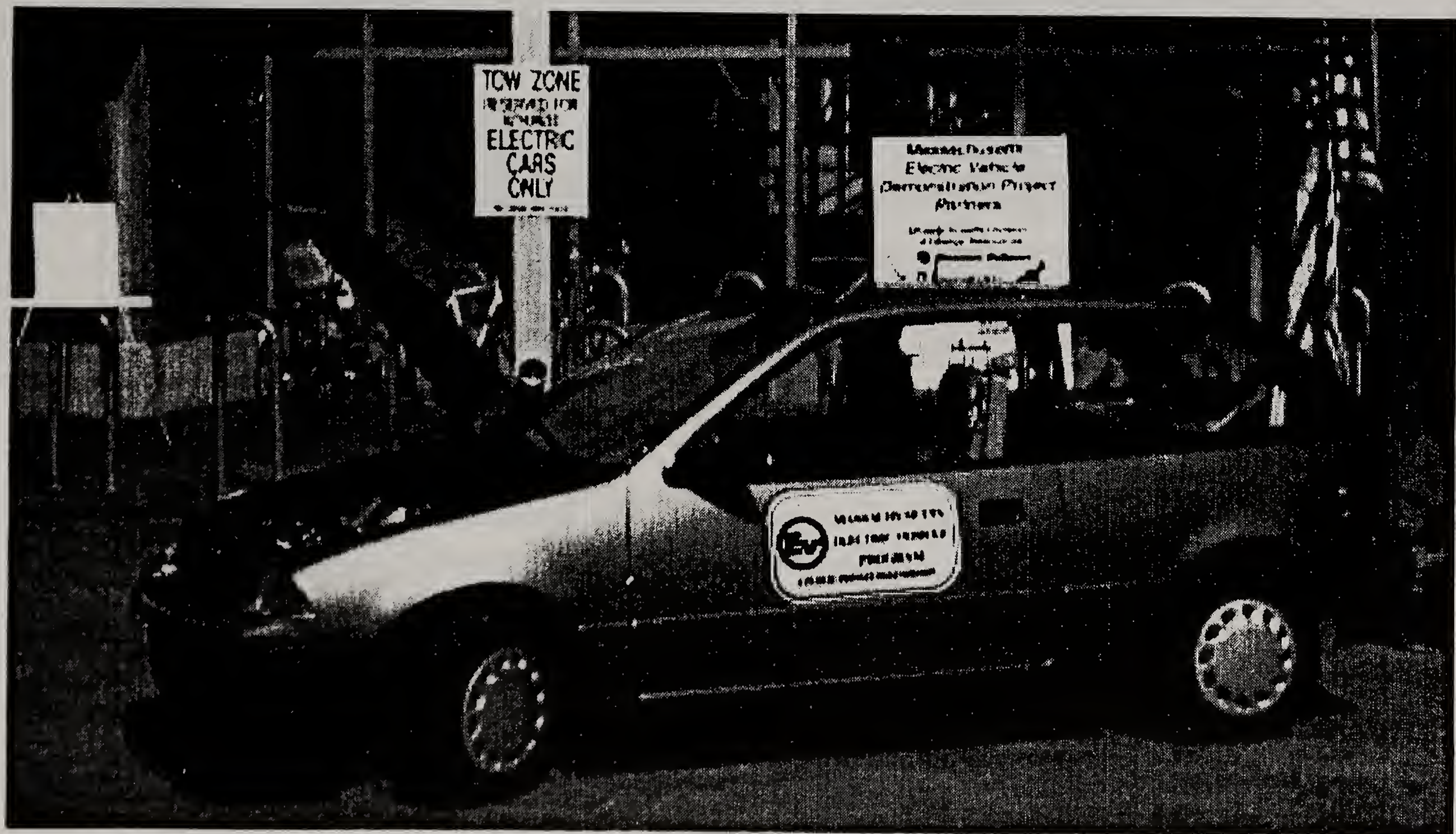
7. EV vendors should be required to identify a network of maintenance facilities and provide a two to three year bumper-to-bumper maintenance package as part of the bid price on the vehicles.

ATTACHMENT 1

MASSACHUSETTS ELECTRIC VEHICLE DEMONSTRATION PROGRAM

DEMONSTRATION PROGRAM ELECTRIC VEHICLE

SOLECTRIA FORCE



MASSACHUSETTS ELECTRIC VEHICLE DEMONSTRATION PROGRAM

DESCRIPTION OF PHASE I VEHICLES

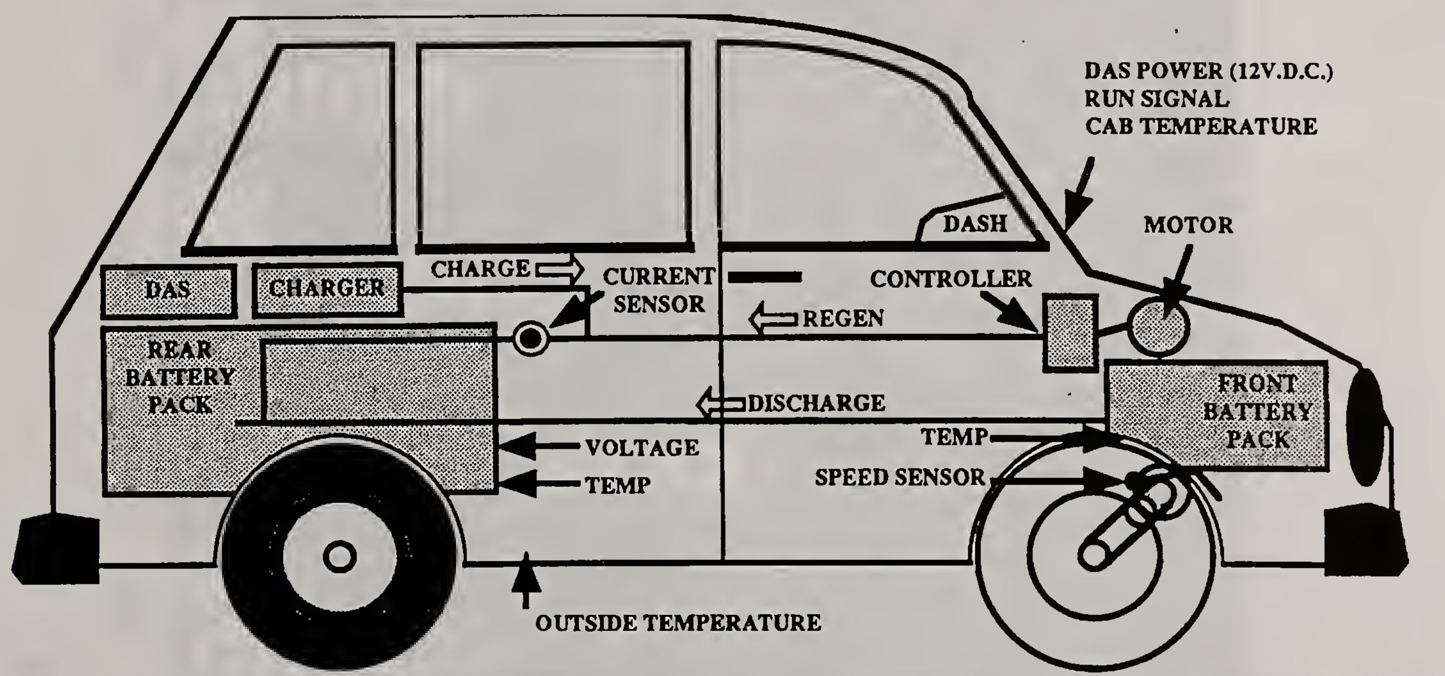
VEHICLE ID#	MODEL	BATTERY TYPE	BATTERY MAKER	VEHICLE COST
10E	Force 2-Seat	Sealed L-A	Gates	$36,090
11E	Force 4-Seat	Sealed L-A	Gates	$32,756
12E	Force 2-Seat	Sealed L-A	Gates	$36,090
13E	Force 4-Seat	Sealed L-A	Gates	$32,756
14E*	Force 4-Seat	Sealed L-A	Gates	$32,756
15E*	Force 4-Seat	Sealed L-A	Gates	$32,756
16E	Force 4-Seat	Sealed L-A	Sonnenschein	$32,756
17E*	Force 4-Seat	Sealed L-A	Gates	$32,756
18E*	Force 4-Seat	Ni-Cad	Saft	$44,710
19E	Force 4-Seat	Ni-Cad	Saft	$44,710
20E*	Force 4-Seat	Ni-Cad	Saft	$44,710
21E*	Force 4-Seat	Ni-Cad	Saft	$44,710
22E	Force 4-Seat	Sealed L-A	Gates	$32,756
23E*	Force 4-Seat	Ni-Cad	Saft	$44,710
24E	Force 4-Seat	Sealed L-A	Gates	$32,756
25E	Force 4-Seat	Sealed L-A	Gates	$32,756
26E*	Coupe 2-Seat	Sealed L-A	Sonnenschein	$34,020
27E*	Coupe 2-Seat	Sealed L-A	Sonnenschein	$34,020
28E	Force 2-Seat	Sealed L-A	Sonnenschein	$36,090
29E*	Force 2-Seat	Sealed L-A	Sonnenschein	$36,090

**Asterisk denotes vehicle with data collection equipment*

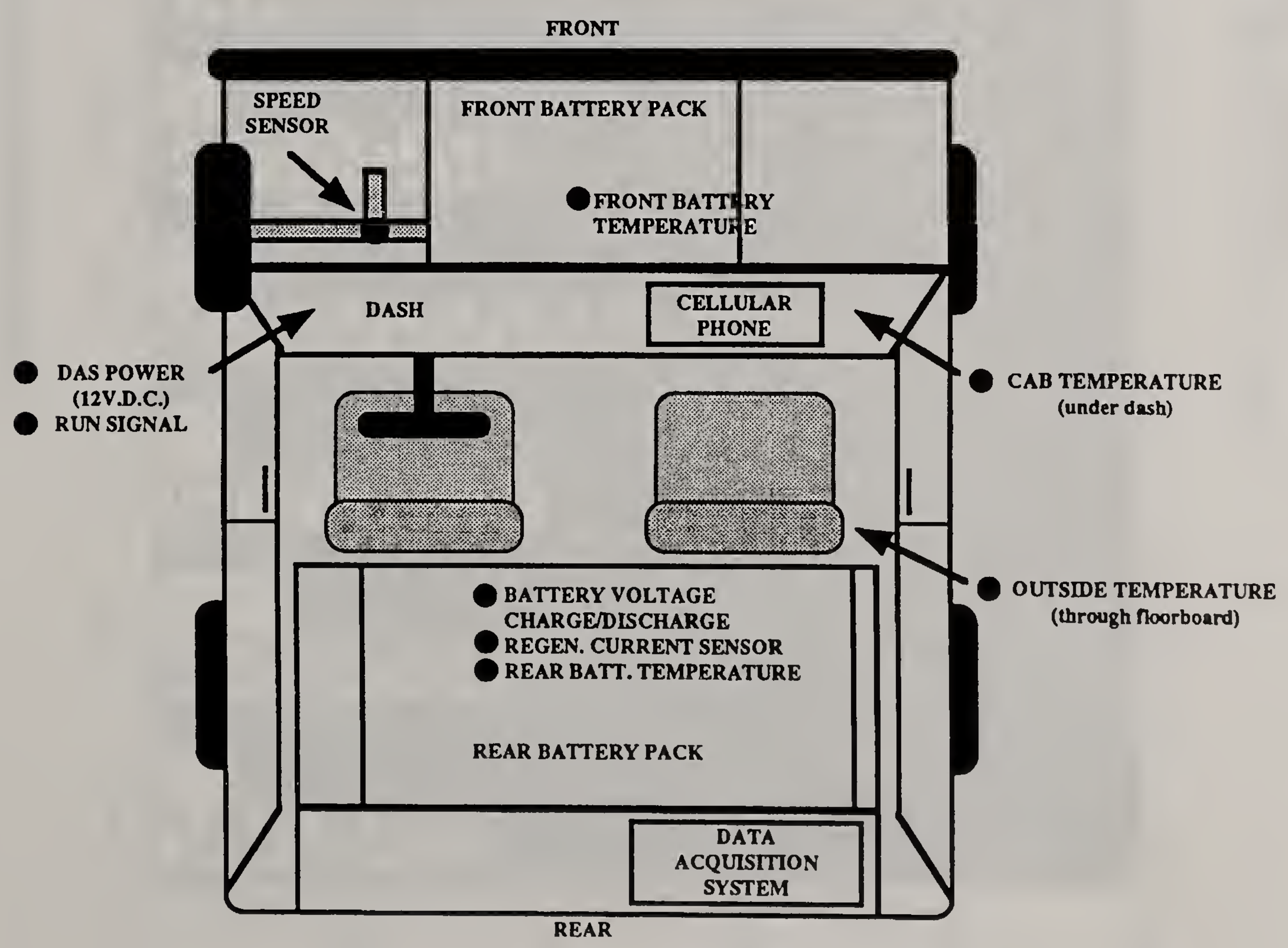
Sealed L-A = Sealed Lead-Acid Maintenance Free Battery
Ni-Cad = Nickel Cadmium Battery

Massachusetts Electric Vehicle Demonstration Program

Location of Data Acquisition Sensors



SOLECTRIA ELECTRIC VEHICLE SENSOR LAYOUT

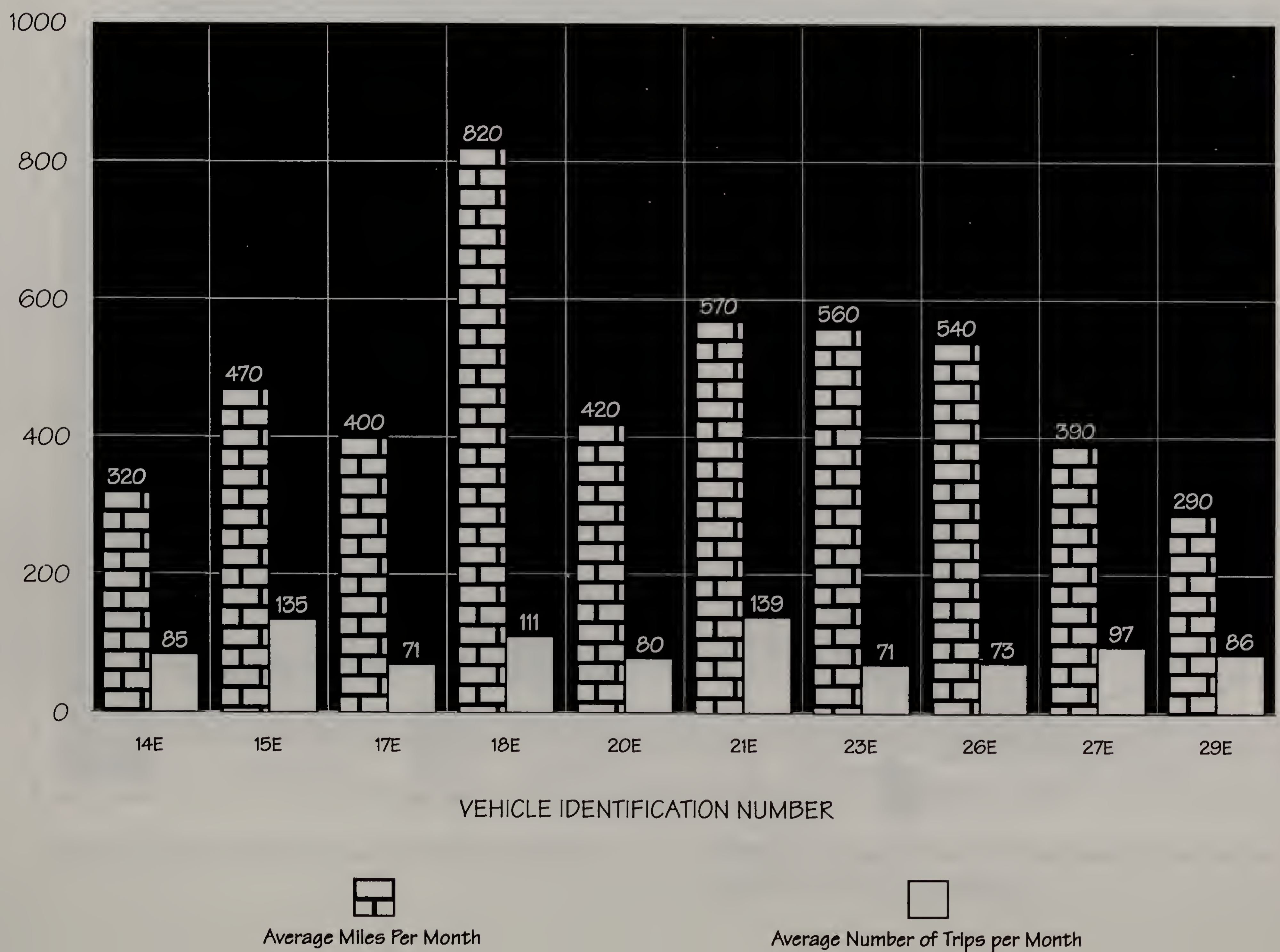


Original drawing prepared by SAIC for MDOER - see mmdas.doc for description. saicsl.doc

MASSACHUSETTS ELECTRIC VEHICLE DEMONSTRATION PROGRAM

VEHICLE TRAVEL PROFILE I

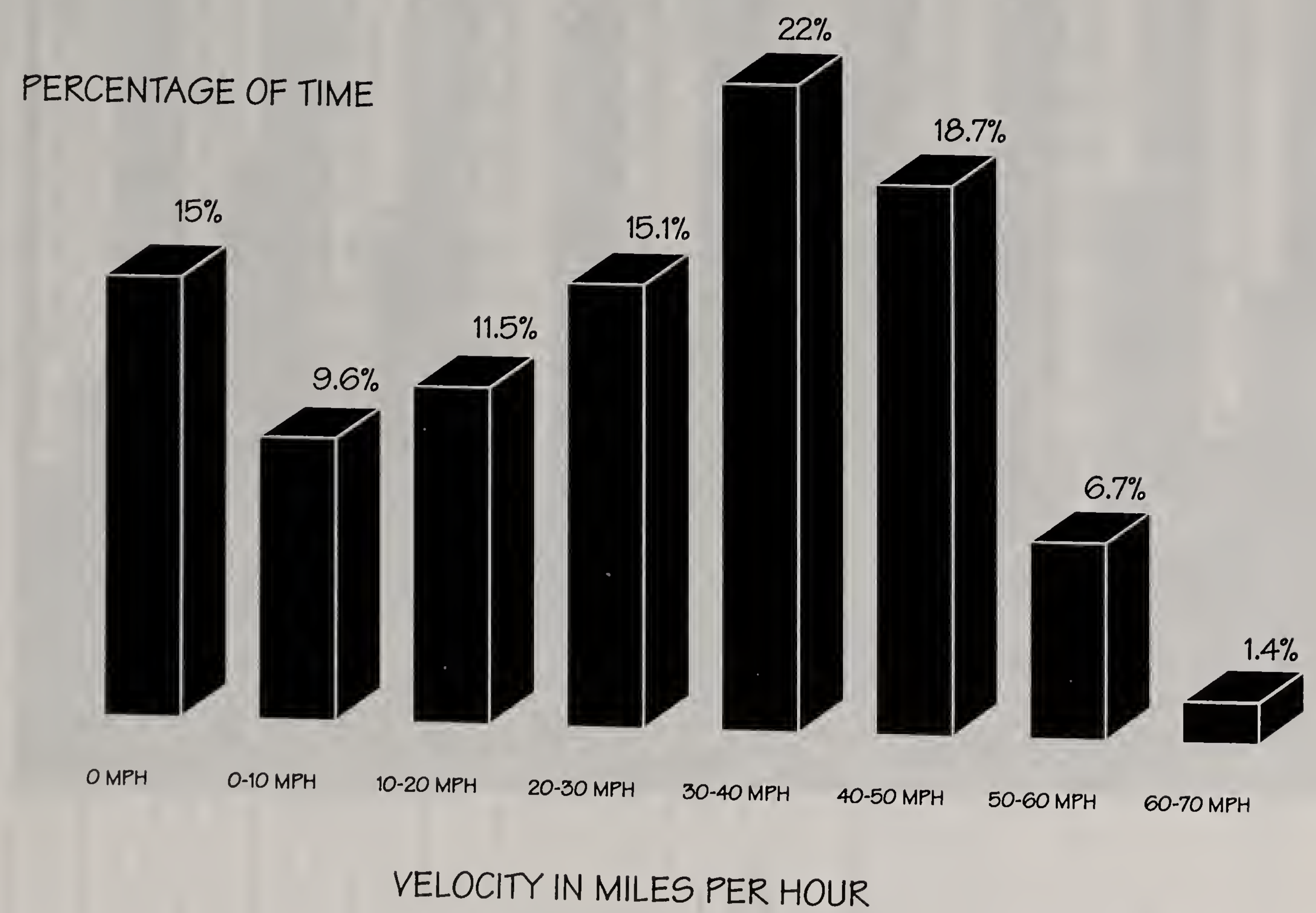
(July 1994 - April 1995)



MASSACHUSETTS ELECTRIC VEHICLE DEMONSTRATION PROGRAM

VEHICLE VELOCITY DISTRIBUTION, MAY 1995

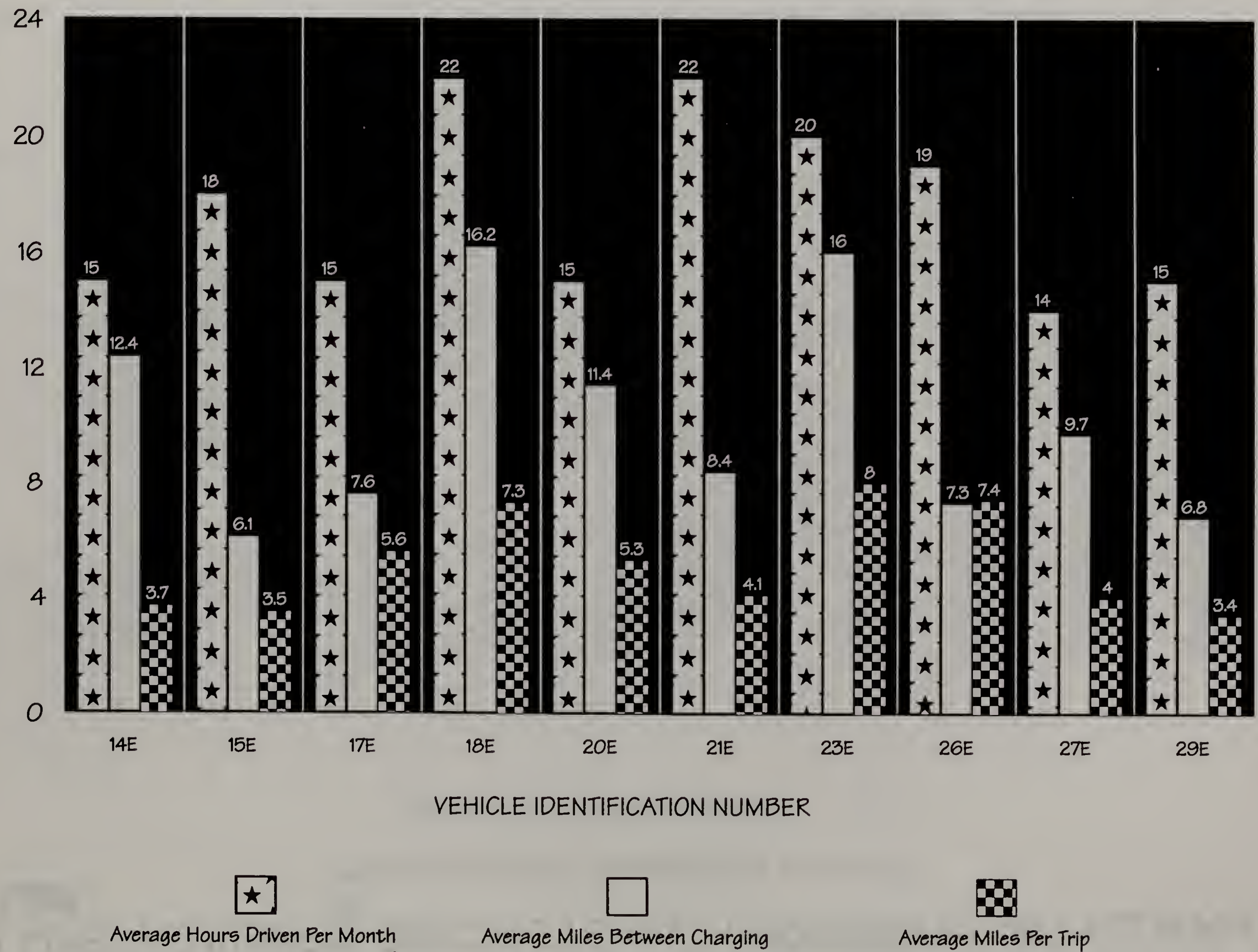
(for all instrumented vehicles)



MASSACHUSETTS ELECTRIC VEHICLE DEMONSTRATION PROGRAM

VEHICLE TRAVEL PROFILE II

(July 1994 - April 1995)



ELECTRIC VEHICLE USER RESPONSE

DRIVER FORM
Vehicle ID No.___
Odometer Reading____________

Driver Name: ____________________

Month:______________ Phone: ________________________________

Overall opinion of vehicle:

Poor				OK				Ideal		
0	1	2	3	4	5	6	7	8	9	10

(circle one)

What's the main reason for your score? ____

____

For each of the following features of the electric vehicle please check OK or not OK and comment where appropriate.

		OK	NOT OK	WHY NOT?
Ride smoothness	a.			
Quietness or noise	b.			
Driver comfort	c.			
Steering and handling	d.			
Brakes	e.			
Air conditioner	f.			
Heater	g.			
Range between charges	h.			
Instrumentation and layout	i.			
Range meter (accuracy)	j.			
Acceleration (pickup)	k.			
Top speed (cruising)	l.			
Hill or grade-climbing	m.			
Battery charging operations	n.			
(Is this done by you? Y/N)				
Battery watering operations	o.			
(Is this done by you? Y/N)				
Overall dependability	p.			
Overall safety	q.			
Overall usefulness	r.			
Other (specify)	s.			

Please mail this form once a month to:

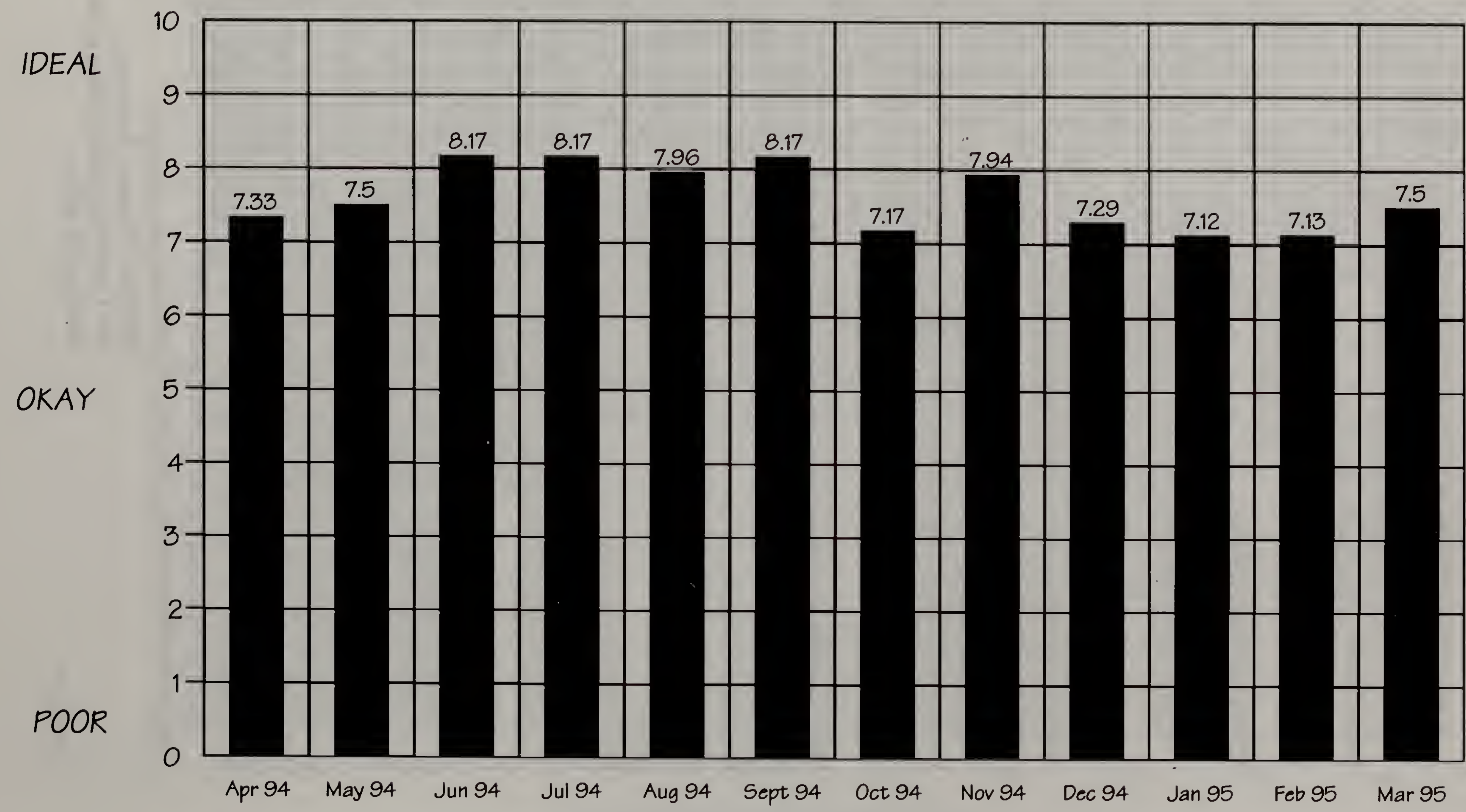
EV Program Manager
Division of Energy Resources
100 Cambridge Street, Suite #1500
Boston, MA 02202

p: \doer\wp\drs

ATTACHMENT 8

MASSACHUSETTS ELECTRIC VEHICLE DEMONSTRATION PROGRAM

USER SATISFACTION SURVEY RESULTS



MASSACHUSETTS ELECTRIC VEHICLE DEMONSTRATION PROGRAM

A SAMPLING OF DRIVER SURVEY COMMENTS

☺ “Driving a pollution-free car around town is wonderful.”
☺ “It starts cold when others don’t.”
☺ “No maintenance is fantastic.”
☺ “The pre-programmed heater is out of this world.”

☹ “Faster acceleration would be nice.”
☹ “The belt drive is too noisy.”
☹ “I can barely read the LCD power gauge.”
☹ “I’d like an on-board coffee maker.”

MASSACHUSETTS ELECTRIC VEHICLE DEMONSTRATION PROGRAM

AMERICAN AUTOMOBILE ASSOCIATION

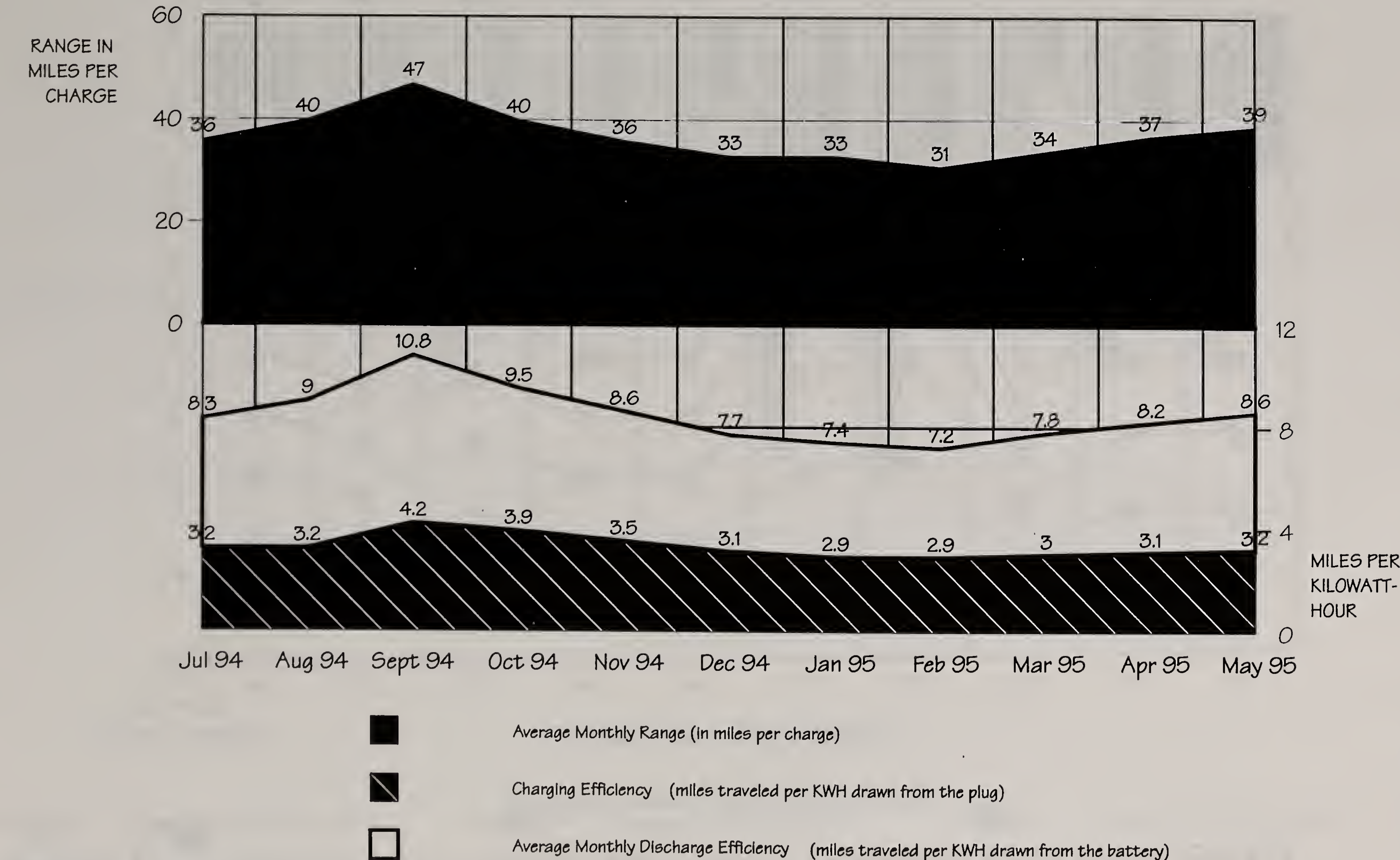
EMERGENCY ROAD SERVICE

VEHICLE ID#	# OF ERS CALLS	NATURE OF CALL
10E	2	TOWING REQUIRED - LACK OF POWER; MECHANICAL PROBLEM- TOWED TO SOLECTRIA
11E	1	TOWING REQUIRED - LACK OF POWER
12E	0	
13E	2	TOWING REQUIRED - LACK OF POWER; MECHANICAL PROBLEMS
14E	1	TOWING REQUIRED - LACK OF POWER
15E	1	TOWING REQUIRED - LACK OF POWER
16E	1	TOWING REQUIRED - LACK OF POWER
17E	0	
18E	0	
19E	0	
20E	1	TOWING REQUIRED - LACK OF POWER
21E	0	
22E	0	
23E	0	
24E	1	TOWING REQUIRED - LACK OF POWER
25E	0	
26E	1	TOWING REQUIRED - LACK OF POWER
27E	0	
28E	0	
29E	0	

MASSACHUSETTS ELECTRIC VEHICLE DEMONSTRATION PROGRAM

AVERAGE MONTHLY RANGE & DISCHARGE EFFICIENCY

(for all instrumented vehicles)

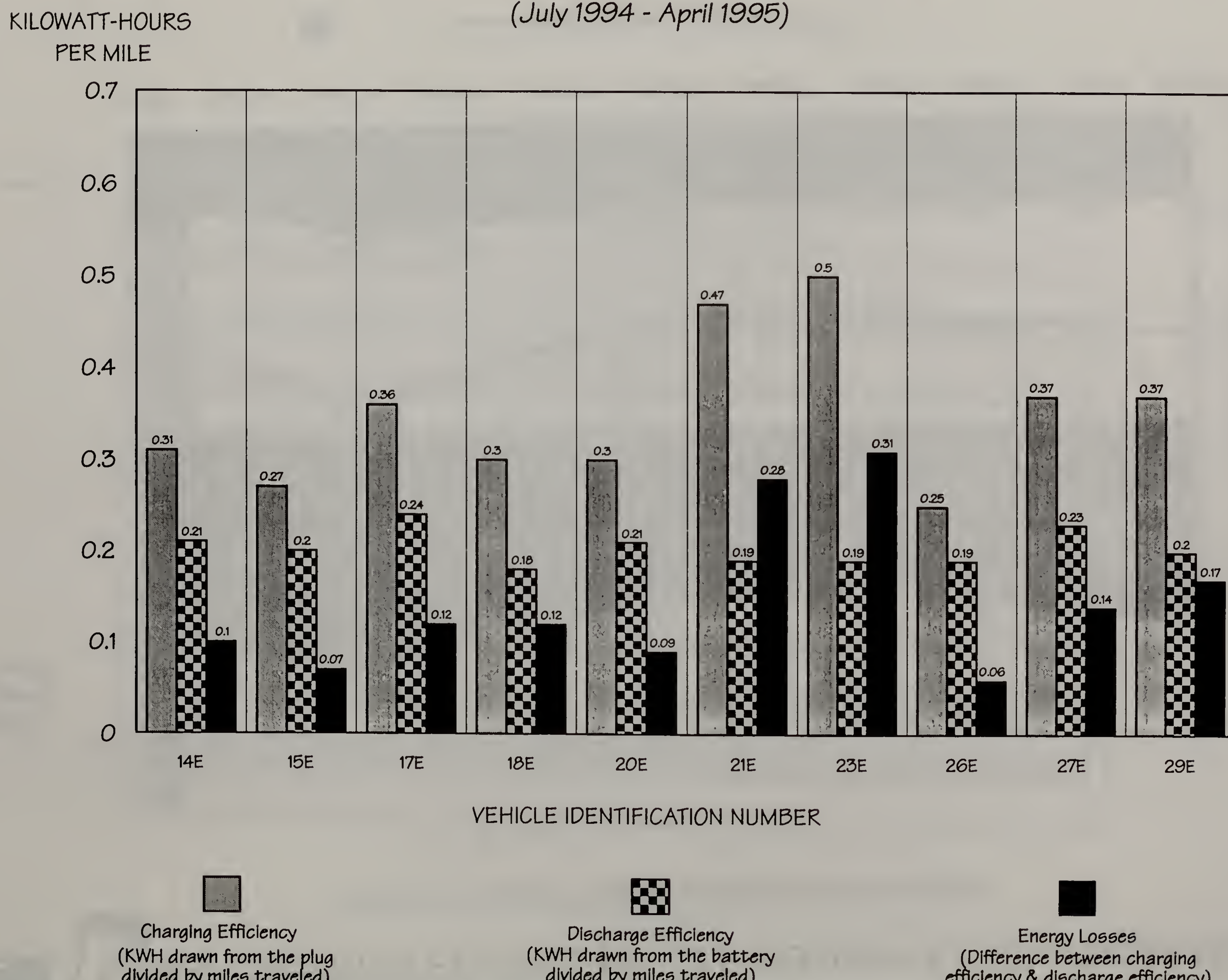


ATTACHMENT 12

MASSACHUSETTS ELECTRIC VEHICLE DEMONSTRATION PROGRAM

VEHICLE EFFICIENCY COMPARISONS

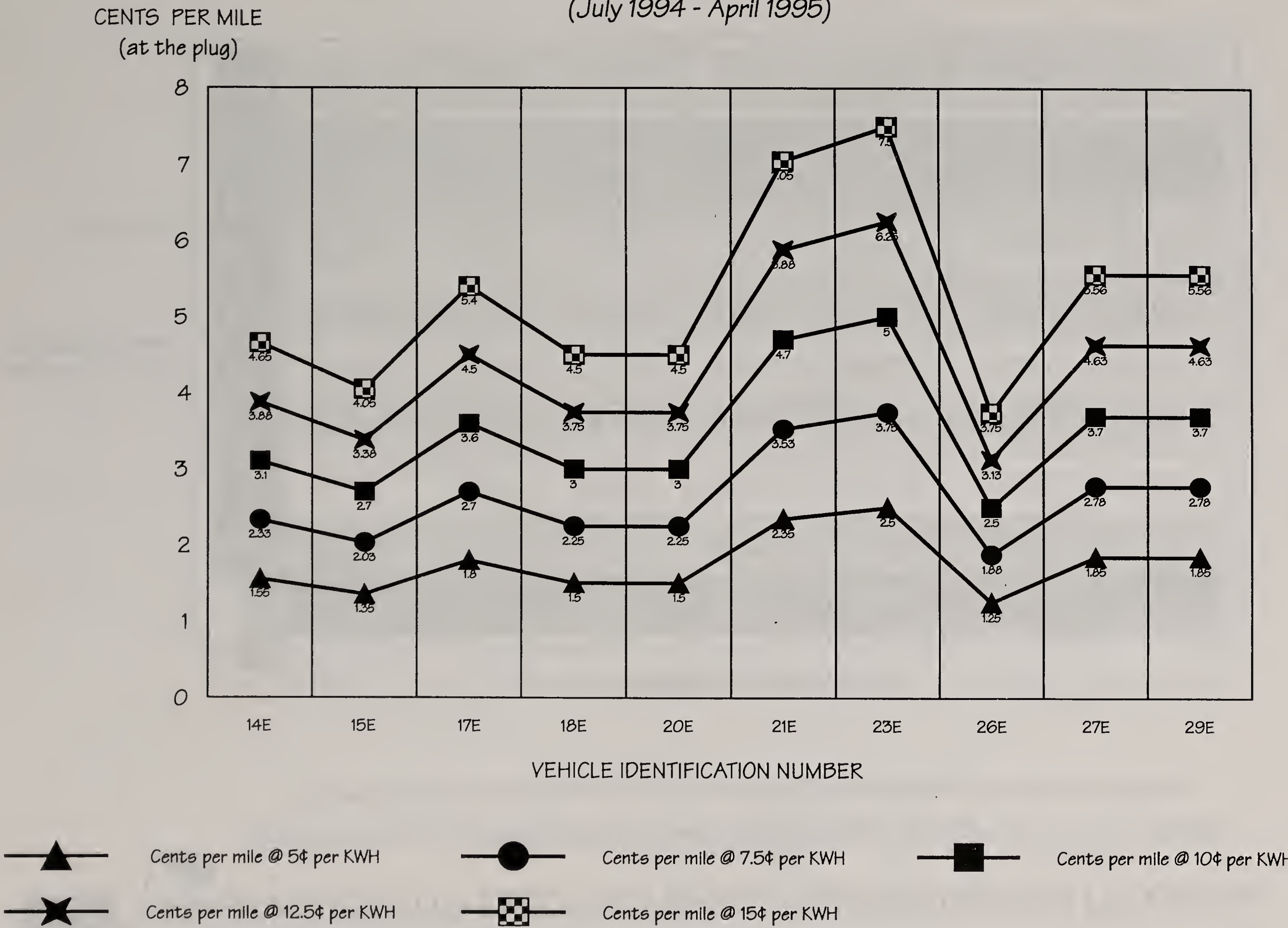
(July 1994 - April 1995)



MASSACHUSETTS ELECTRIC VEHICLE DEMONSTRATION PROGRAM

ELECTRIC COST PER MILE

(July 1994 - April 1995)



MASSACHUSETTS ELECTRIC VEHICLE DEMONSTRATION PROGRAM

MILES PER GALLON REQUIRED TO ACHIEVE EQUIVALENT ENERGY OPERATING COSTS RELATIVE TO AN AVERAGE ELECTRIC VEHICLE IN DEMONSTRATION PROGRAM

GASOLINE COST (PRICE PER GALLON)

ELECTRICITY COST (PRICE PER KWH)

	$1.00	$1.10	$1.20	$1.30	$1.40	$1.50	$1.60
2¢	142.50	156.70	170.90	185.20	199.40	213.70	227.90
4¢	71.20	78.30	85.50	92.60	99.70	106.80	114.00
5¢	57.00	62.70	68.40	74.10	79.80	85.50	91.20
6¢	47.50	52.20	57.00	61.70	66.50	71.20	76.00
8¢	35.60	39.20	42.70	46.30	50.00	53.40	57.00
10¢	28.50	31.30	34.20	37.00	39.90	42.70	45.60
12¢	23.70	26.10	28.50	30.90	33.20	35.60	38.00
14¢	20.40	22.40	24.40	26.50	28.50	30.50	32.60
16¢	17.80	19.60	21.40	23.10	24.10	26.70	28.50

NOTE: This matrix depicts the miles per gallon necessary for an internal combustion vehicle to achieve equivalent energy operating costs with the average electric vehicle in the demonstration program. A unique result can be found at the intersection of the selected prices per KWH and per gallon of gasoline. This table is based on an average charging efficiency of .351 KWH per mile, as realized in this program over the period from July 1994 to April 1995 for the ten instrumented vehicles.

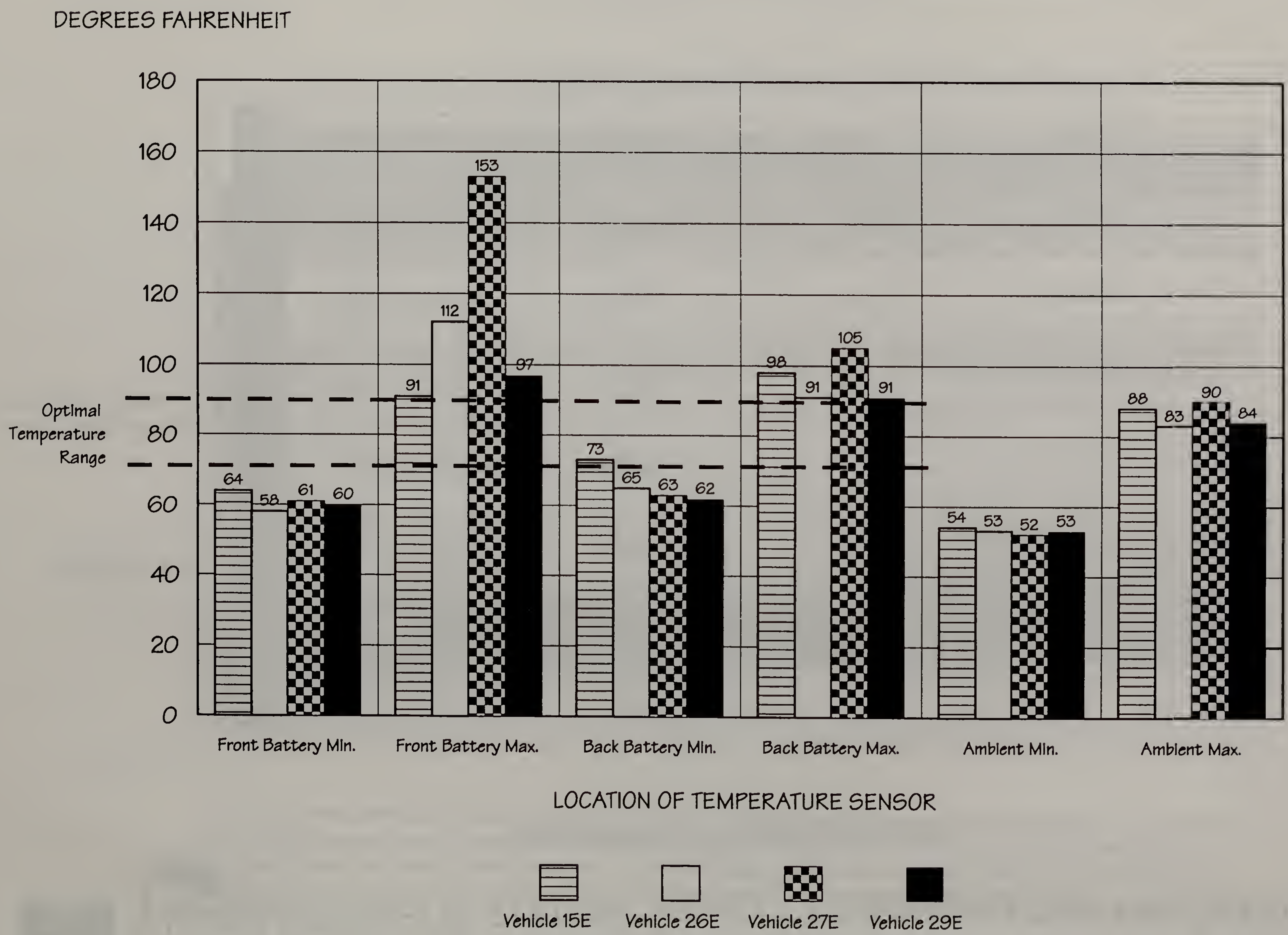
MASSACHUSETTS ELECTRIC VEHICLE DEMONSTRATION PROGRAM

DESCRIPTION OF BATTERY FAILURES

VEHICLE ID#	BATTERY TYPE	MILES DRIVEN	CELLS REPLACED	CAUSE OF FAILURE
10E	Sealed L-A/GNB	1,977	All	Manufacturing Defect
11E	Sealed L-A/GNB	3,400	All	Manufacturing Defect
12E	Sealed L-A/GATES	4,443	10 of 19	Unknown
13E	Sealed L-A/GATES	3,507	7 of 19	Unknown
14E	Sealed L-A/GATES	3,234	6 of 19	Unknown
24E	Sealed L-A/GATES	2,955	4 of 19	Unknown

MASSACHUSETTS ELECTRIC VEHICLE DEMONSTRATION PROGRAM

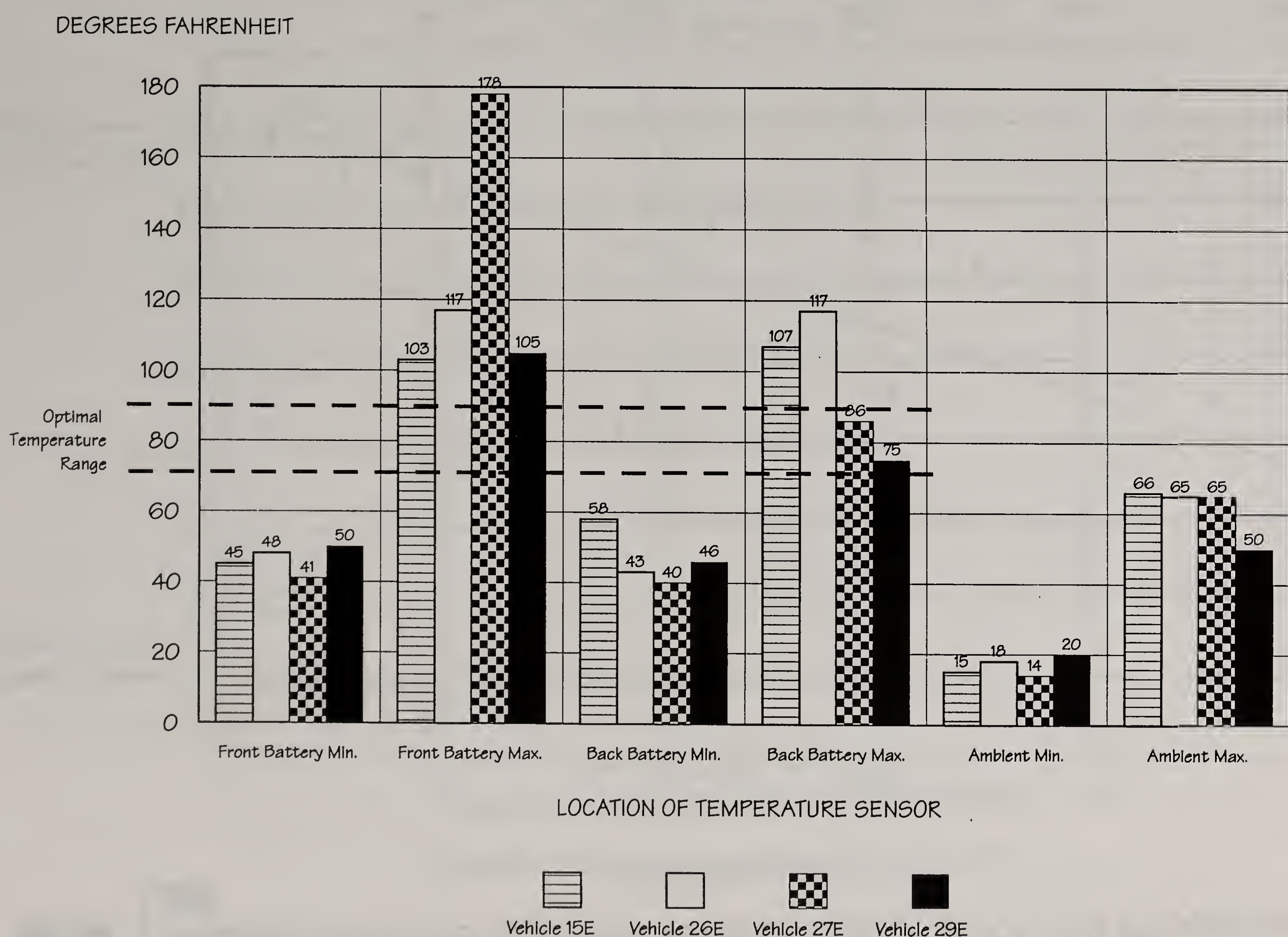
AUGUST BATTERY TEMPERATURE



ATTACHMENT 16.2

MASSACHUSETTS ELECTRIC VEHICLE DEMONSTRATION PROGRAM

JANUARY BATTERY TEMPERATURE

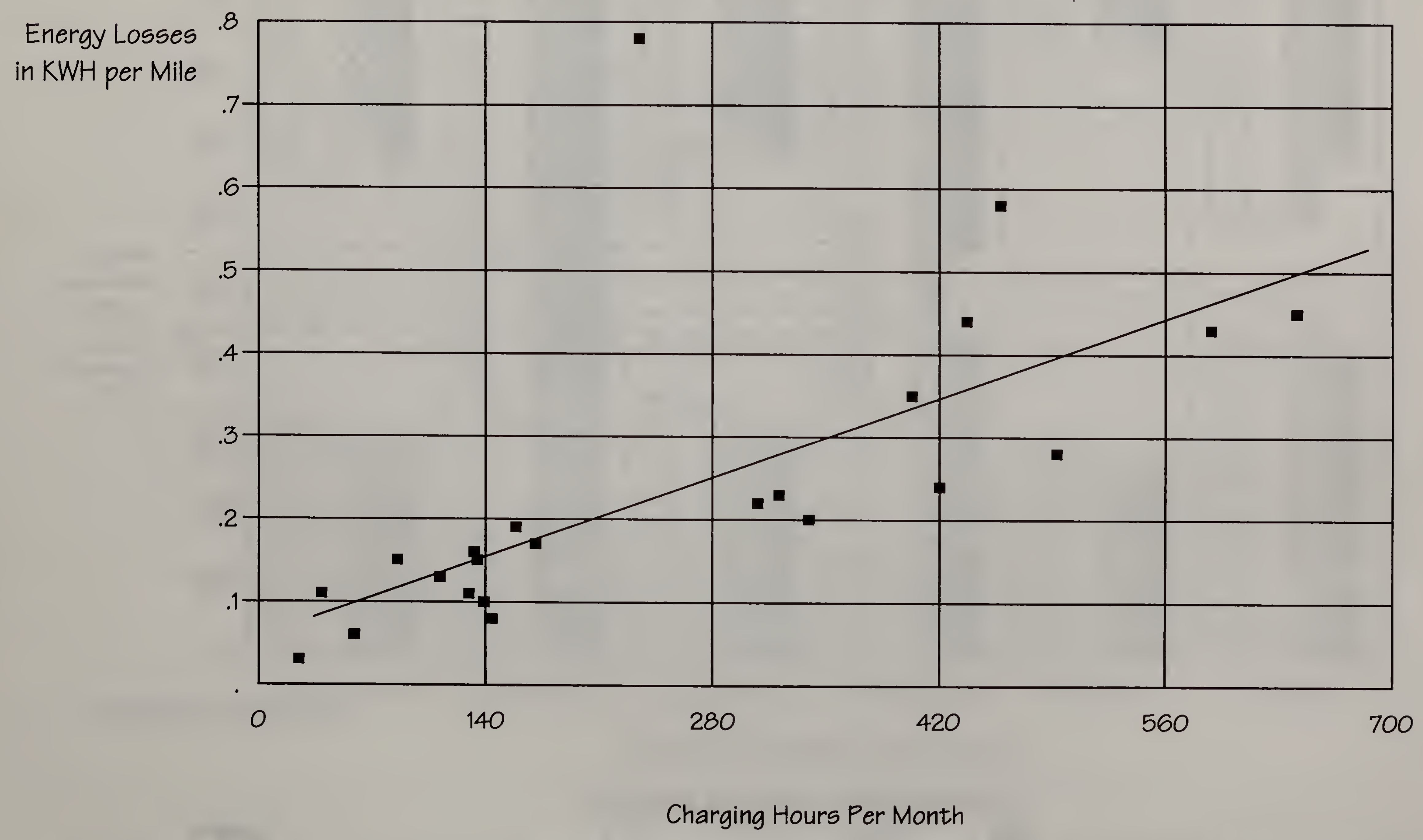


ATTACHMENT 17.1

MASSACHUSETTS ELECTRIC VEHICLE DEMONSTRATION PROGRAM

ENERGY LOSS ANALYSIS FOR NI-CAD VEHICLES

CHARGING HOURS RELATIVE TO ENERGY LOSSES
(December 1994 - May 1995)

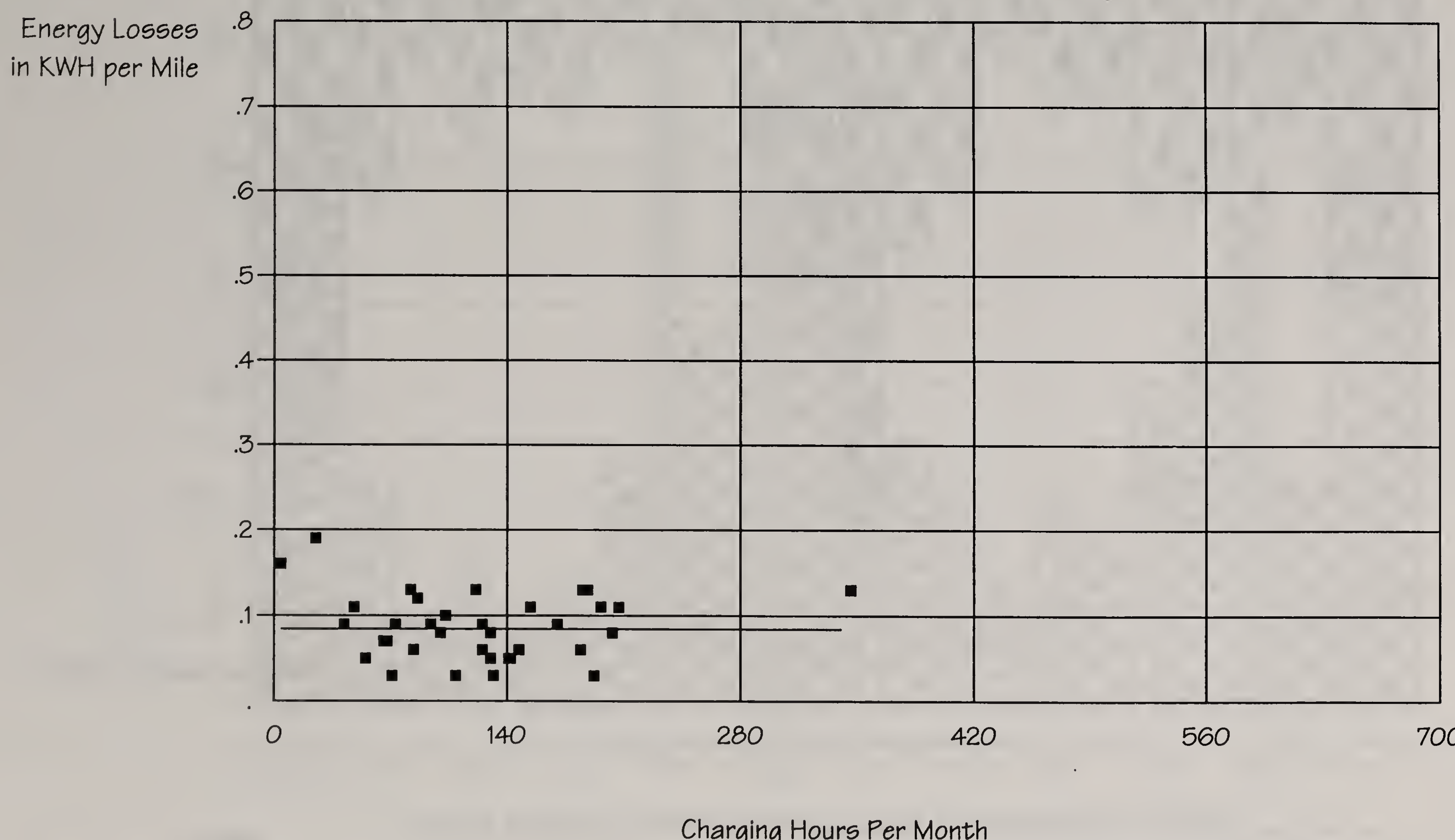


ATTACHMENT 17.2

MASSACHUSETTS ELECTRIC VEHICLE DEMONSTRATION PROGRAM

ENERGY LOSS ANALYSIS FOR LEAD-ACID VEHICLES

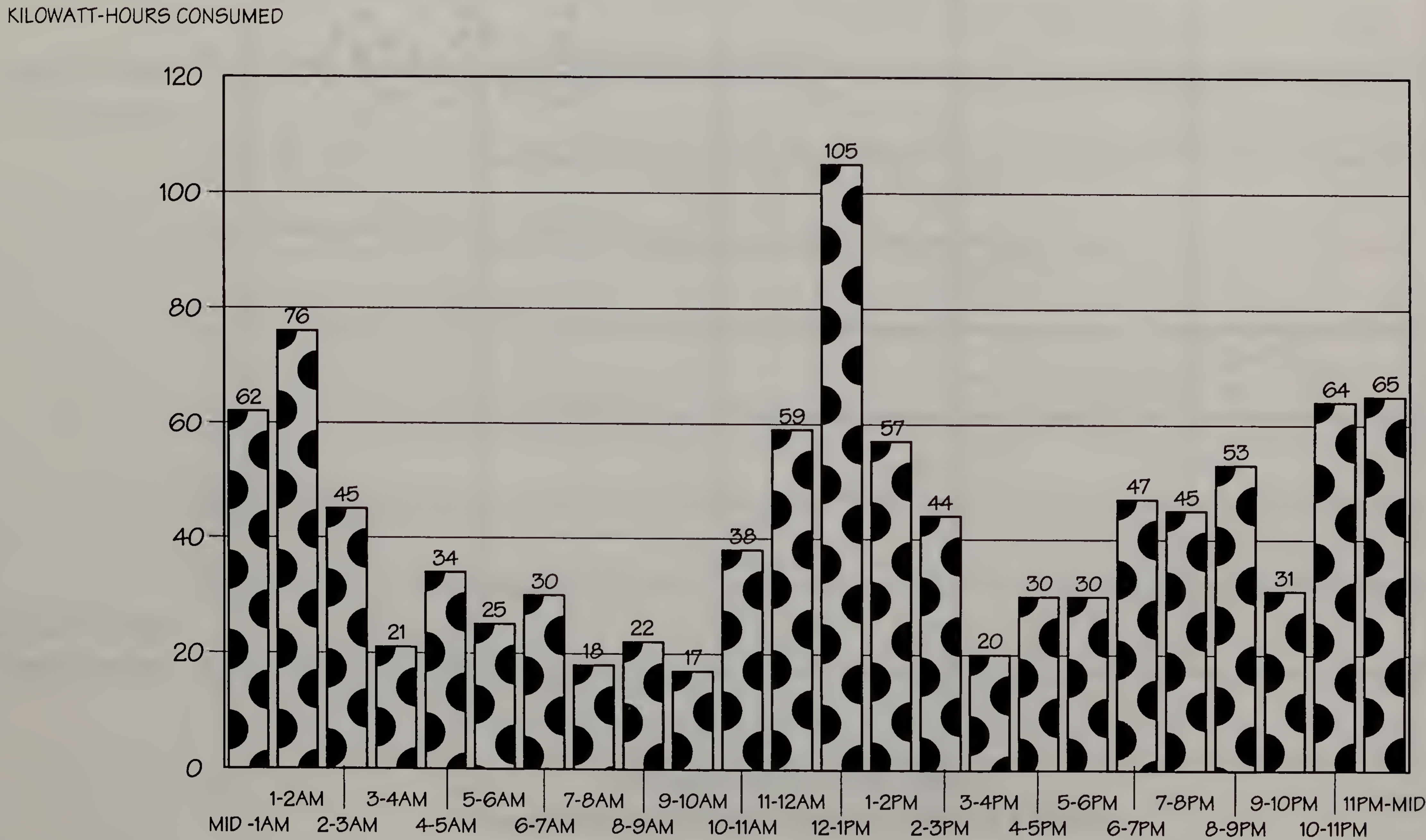
CHARGING HOURS RELATIVE TO ENERGY LOSSES
(December 1994 - May 1995)



MASSACHUSETTS ELECTRIC VEHICLE DEMONSTRATION PROGRAM

HOURLY ENERGY DEMAND FOR BATTERY CHARGING, MAY 1995

For vehicles using Alewife Station

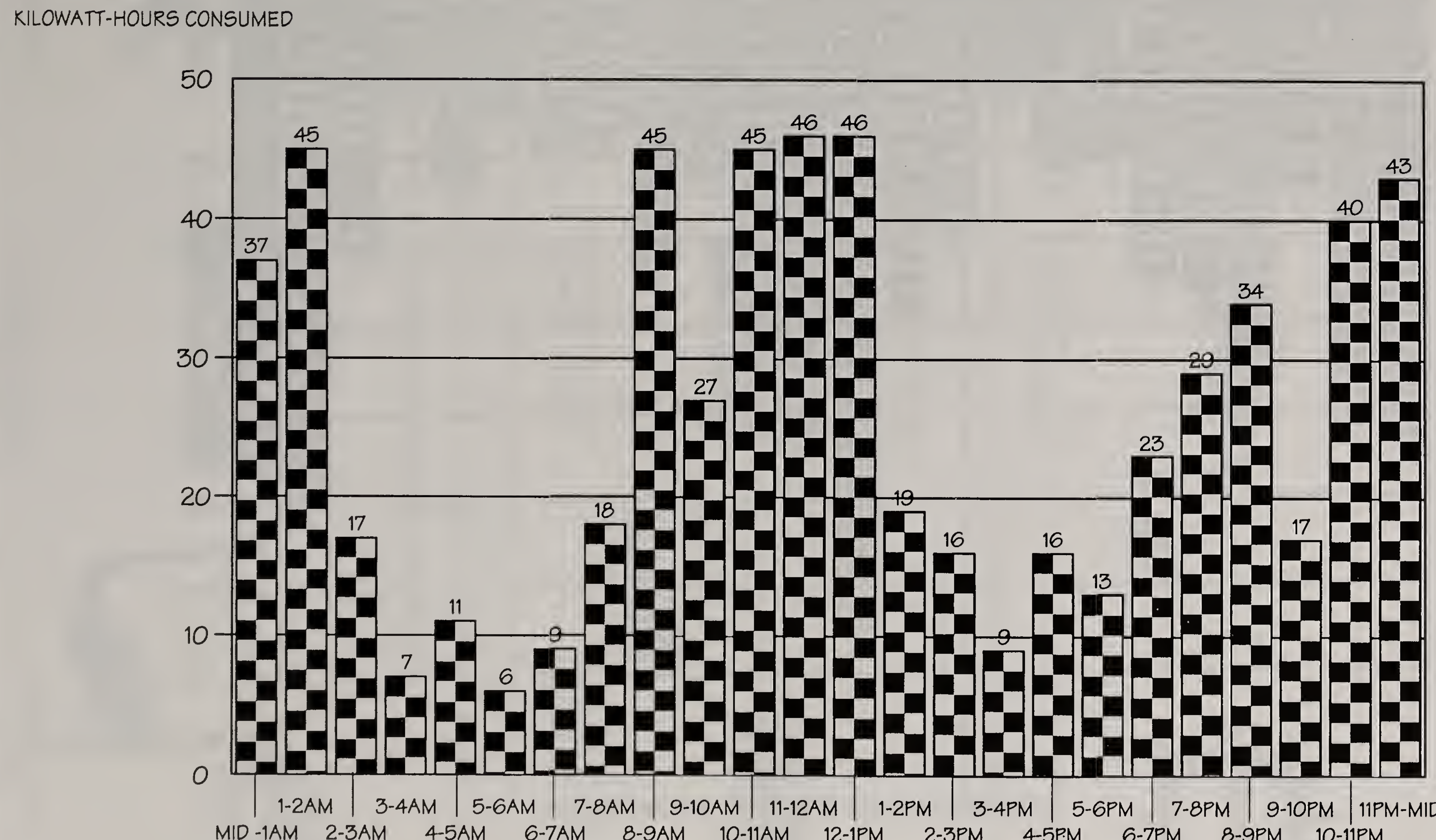


NOTE: This graph represents total hourly energy usage during May 1995 for the five instrumented vehicles using the Alewife charging station. Energy use includes home & station charging.

MASSACHUSETTS ELECTRIC VEHICLE DEMONSTRATION PROGRAM

HOURLY ENERGY DEMAND FOR BATTERY CHARGING, MAY 1995

For vehicles using Braintree Station



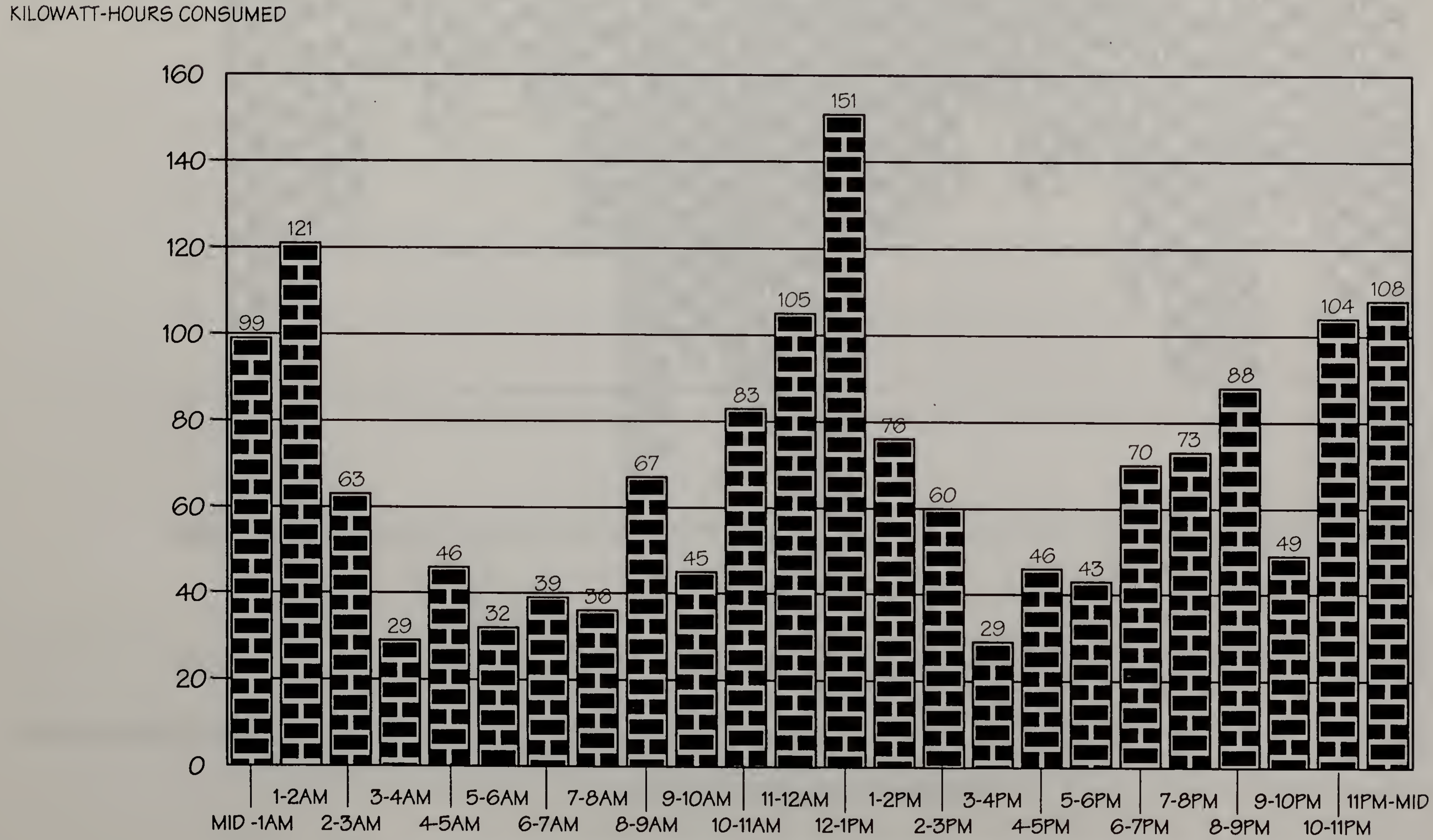
NOTE: This graph represents total hourly energy usage during May 1995 for the five instrumented vehicles using the Braintree charging station. Energy use includes home & station charging.

ATTACHMENT 18.3

MASSACHUSETTS ELECTRIC VEHICLE DEMONSTRATION PROGRAM

HOURLY ENERGY DEMAND FOR BATTERY CHARGING, MAY 1995

For vehicles using Alewife & Braintree Stations



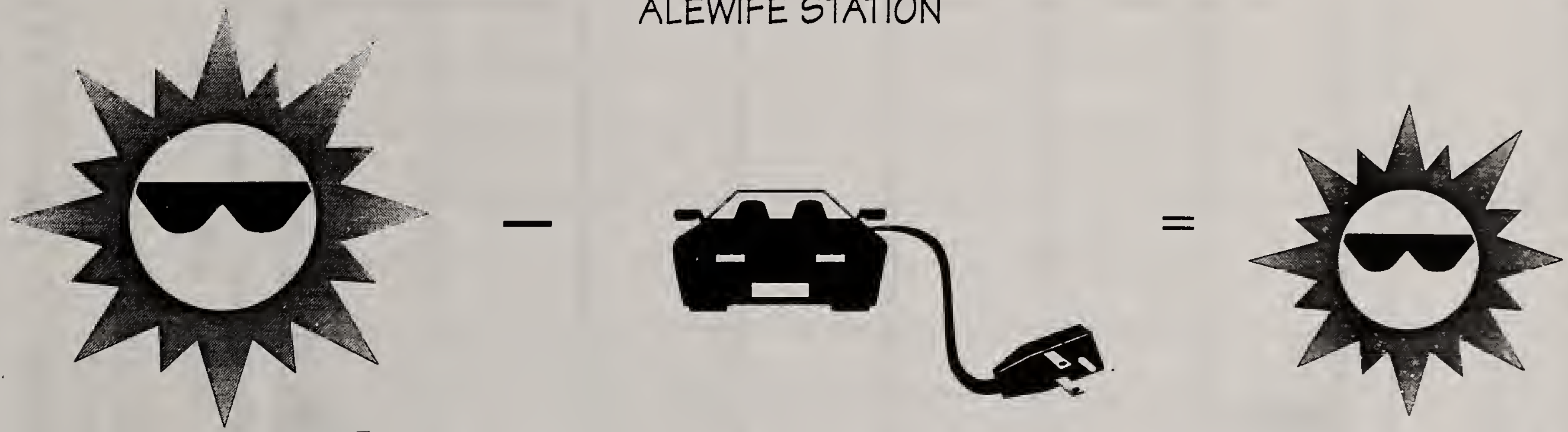
NOTE: This graph represents total hourly energy usage during May 1995 for the ten instrumented vehicles using the Alewife & Braintree charging stations combined. Energy use includes home & station charging.

MASSACHUSETTS ELECTRIC VEHICLE DEMONSTRATION PROGRAM

PHOTOVOLTAIC ELECTRICAL GENERATION & USE AT RECHARGE STATIONS

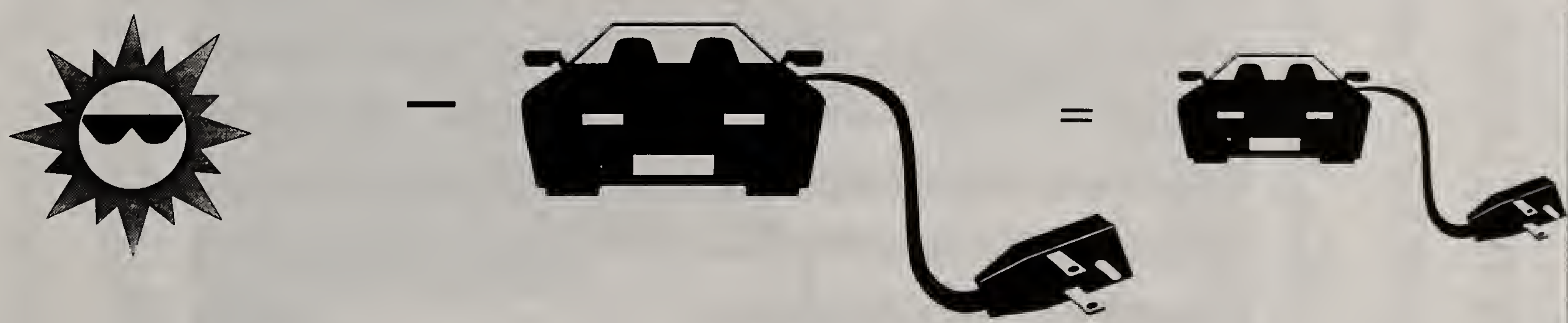
(Cumulative Program Results through June 30, 1995)

ALEWIFE STATION



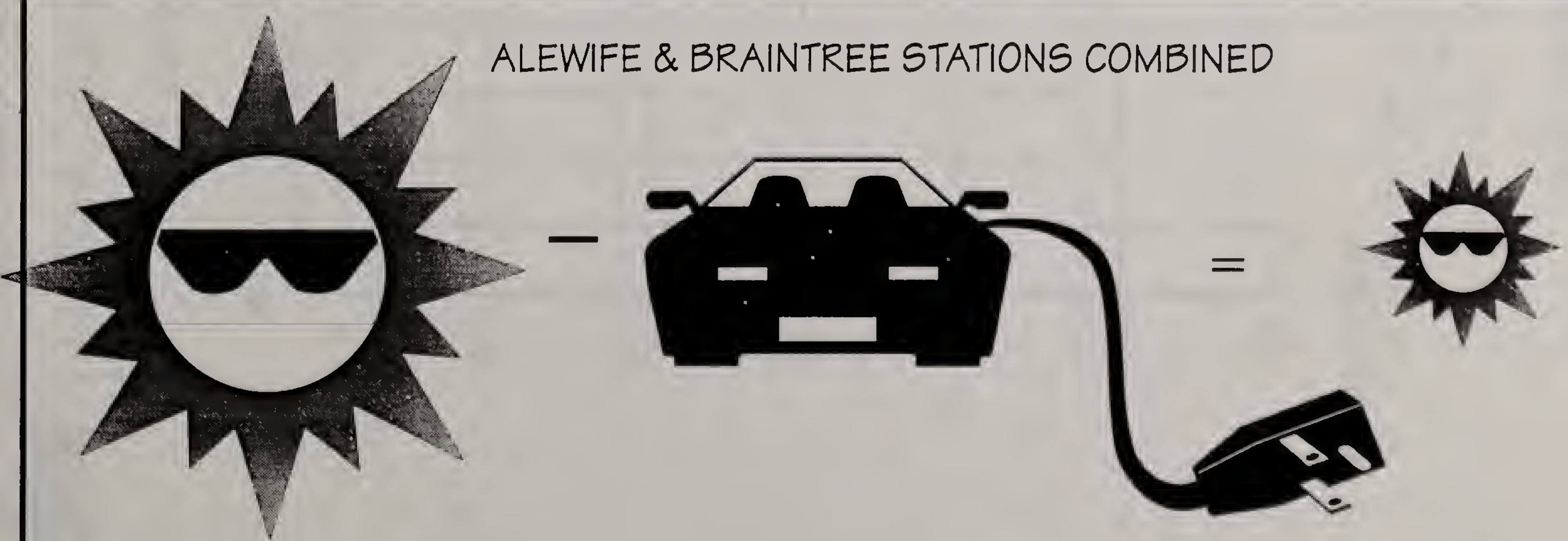
8,645 Kilowatt Hours Generated — 3,528 Kilowatt Hours Used for Recharging Vehicles = 5,117 Surplus Kilowatt-Hours Generated

BRAINTREE STATION



3,038 Kilowatt Hours Generated — 6,223 Kilowatt Hours Used for Recharging Vehicles = 3,185 Kilowatt-Hours Consumed in Excess of Generation

ALEWIFE & BRAINTREE STATIONS COMBINED

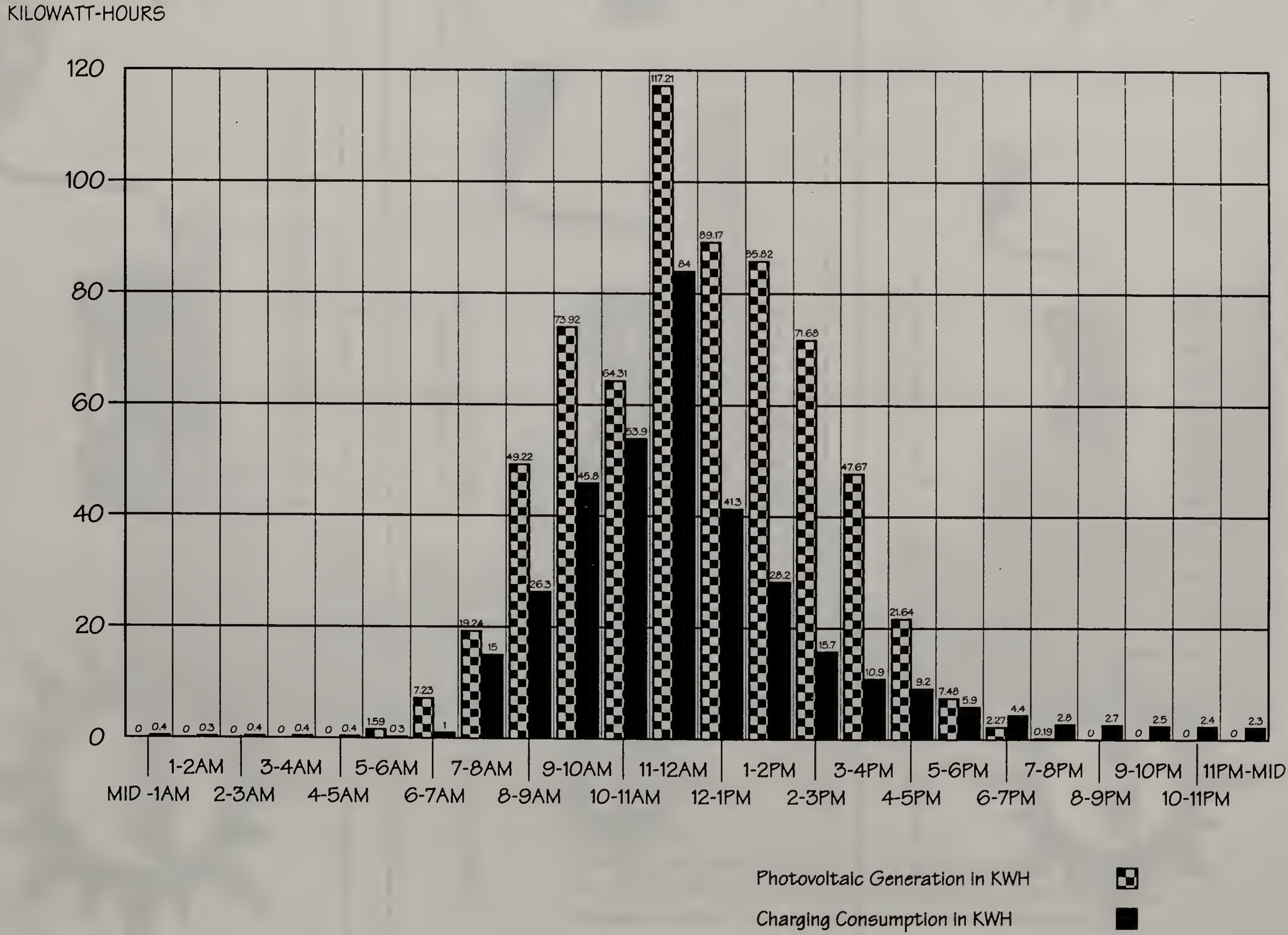


11,683 Kilowatt Hours Generated — 9,751 Kilowatt Hours Used for Recharging Vehicles = 1,932 Surplus Kilowatt-Hours Generated

MASSACHUSETTS ELECTRIC VEHICLE DEMONSTRATION PROGRAM

TIME DISTRIBUTION OF PHOTOVOLTAIC GENERATION & BATTERY CHARGING

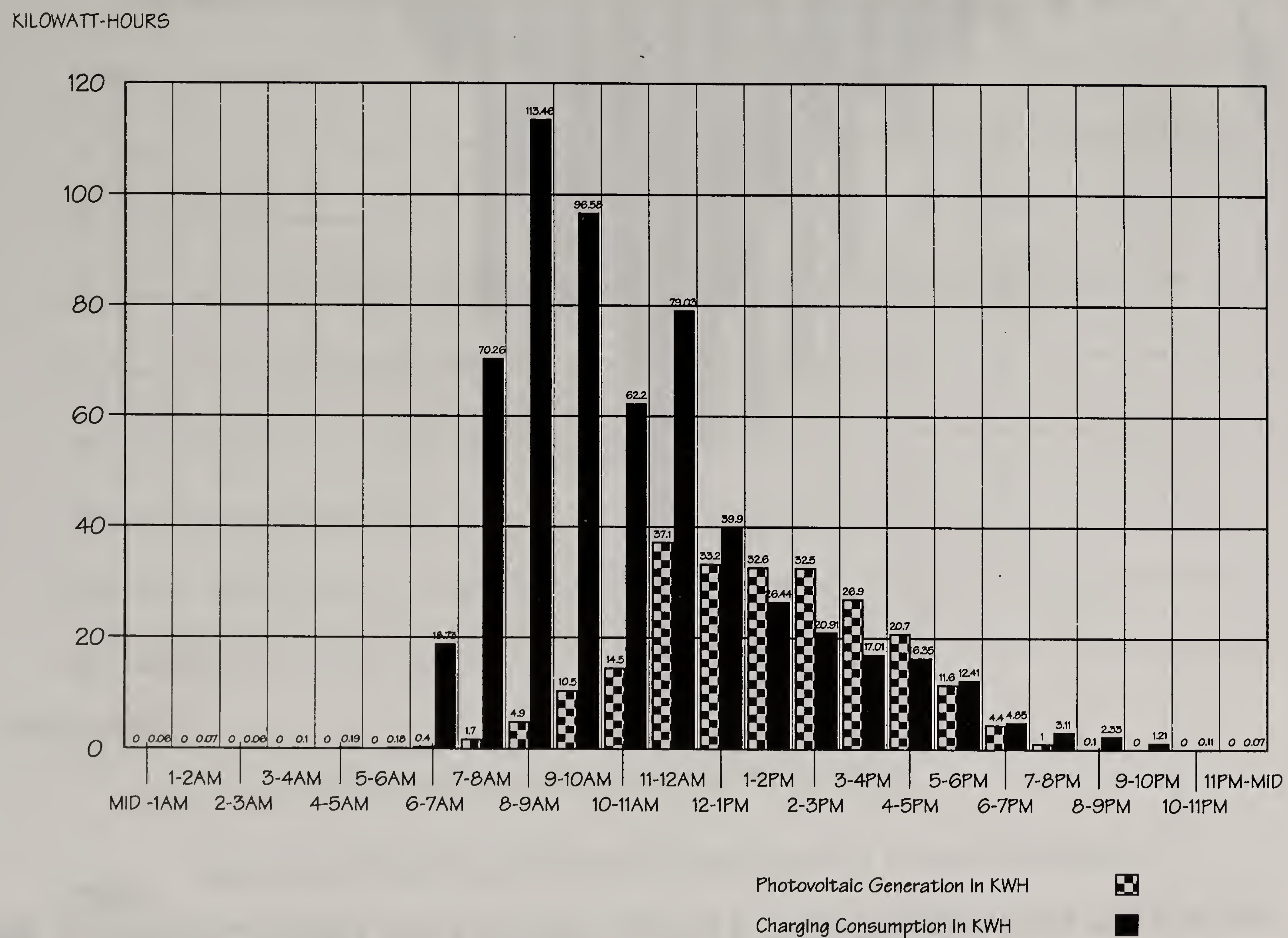
Alewife Station (May 1995)



MASSACHUSETTS ELECTRIC VEHICLE DEMONSTRATION PROGRAM

TIME DISTRIBUTION OF PHOTOVOLTAIC GENERATION & BATTERY CHARGING

Braintree Station (May 1995)

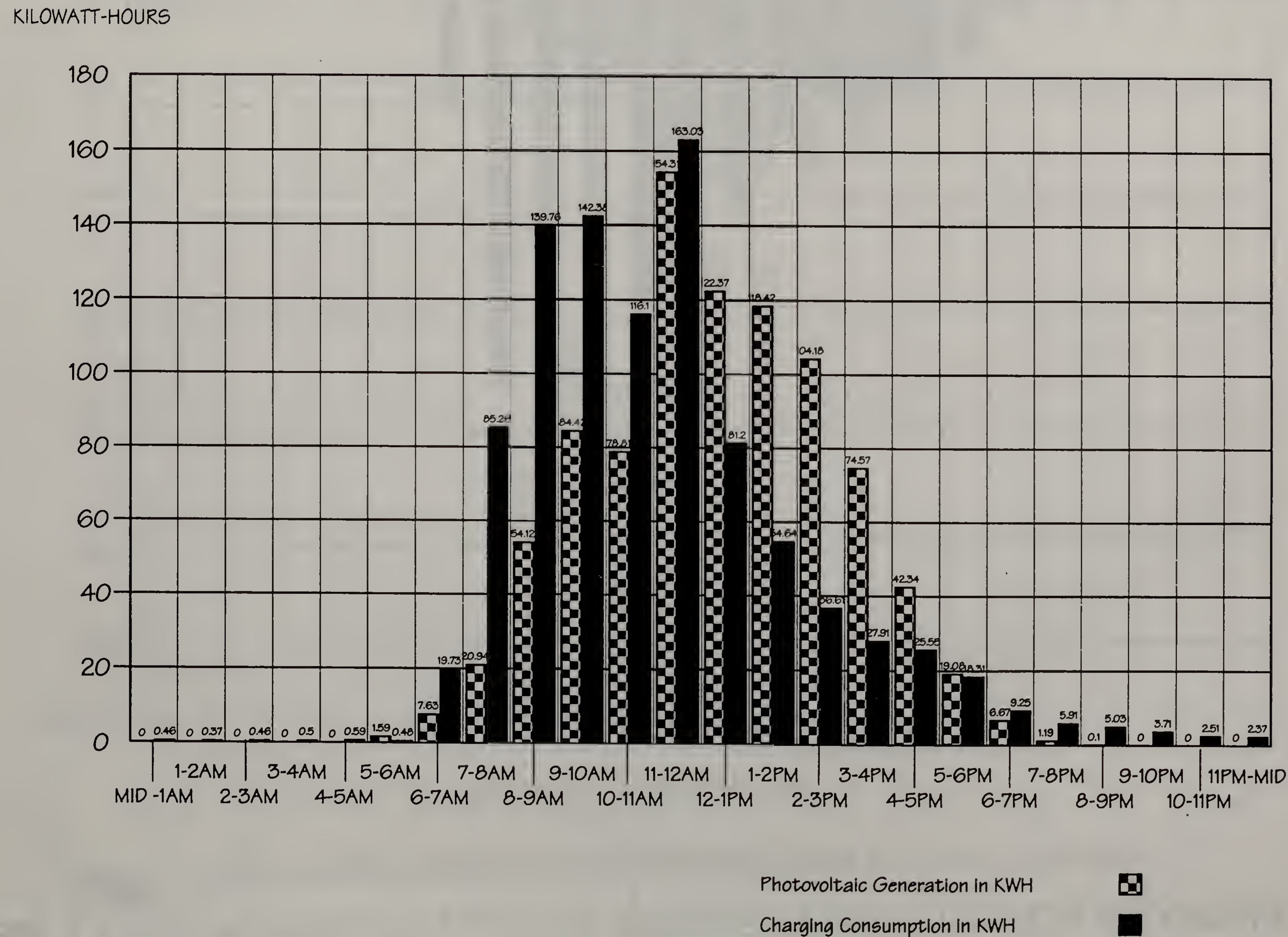


ATTACHMENT 20.3

MASSACHUSETTS ELECTRIC VEHICLE DEMONSTRATION PROGRAM

TIME DISTRIBUTION OF PHOTOVOLTAIC GENERATION & BATTERY CHARGING

Alewife & Braintree Stations Combined (May 1995)



ACKNOWLEDGMENTS

The Electric Vehicle Steering Committee would like to acknowledge the work of several individuals who have been instrumental in preparing this report.

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John G. Cosmas, P.E., The Division of Energy Resources

Irving Sacks, The Division of Energy Resources

Dan Fortier, Metropolitan Area Planning Council

Andrew G. Greene, Consultant to the Division of Energy Resources

Design & Production
Greene Energy & Environmental, Co.

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Boston, MA 02202
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