Idaho
National
Engineering
Laboratory

INEL-96/0080-Qtr 2

August 1996

Electric and Hybrid Vehicle Program
Site Operator Program
Quarterly Progress Report for
January through March 1996)
(Second Quarter of Fiscal Year 1996)

J. Francfort

LOCKHEED MARTIN

INEL-96/0080-Qtr 2

Electric and Hybrid Vehicle Program

Site Operator Program

Quarterly Progress Report for January through March 1996 (Second Quarter of Fiscal Year 1996)

J.E. Francfort[1]
R.R. Bassett[2]
S. Briasco[3]
W. Culliton[4]
E.F. Duffy[5]
R.A. Emmert[6]
J.R. Hague[7]
R. Hobbs[8]
B. Johnson[9]
I.J. Kakwan[10]
R. Miller[11]
S. Neal[12]
L. Stefanakos[13]
T.G. Ware[14]

Published August 1996

Idaho National Engineering Laboratory
Lockheed-Martin Idaho Technologies Company
Idaho Falls, Idaho 83415

Prepared for the
U.S. Department of Energy
Assistant Secretary for Energy Efficiency and Renewable Energy (EE)
Under DOE Idaho Operations Office
Contract No. DE-AC07-94ID13223

[1] INEL/Lockheed Martin Idaho Technologies
[2] Sandia National Laboratories
[3] Los Angeles Department of Water and Power
[4] Orcas Power & Light Company
[5] Potomac Electric Power Company
[6] Platte River Power Authority
[7] Kansas State University
[8] Arizona Public Service
[9] Potomac Electric Power Company
[10] Texas A&M University
[11] U.S. Navy
[12] Pacific Gas & Electric Company
[13] University of South Florida
[14] Southern California Edison Company

Executive Summary

Program Overview

The U.S. Department of Energy (DOE) Site Operator Program was initially established to meet the requirements of the Electric and Hybrid Vehicle Research, Development, and Demonstration Act of 1976. The Program has since evolved in response to new legislation and interests. The goals of the Site Operator Program include the field evaluation of electric vehicles (EVs) in real-world applications and environments; the advancement of electric vehicle technologies; the development of infrastructure elements necessary to support significant electric vehicle use; and increasing the awareness and acceptance of EVs by the public.

The Site Operator Program currently consists of eleven participants under contract and two other organizations that have data-sharing agreements with the Program (Table ES-1). The participants (electric utilities, academic institutions, and Federal agencies) are geographically dispersed within the United States and their vehicles see a broad spectrum of service conditions. The current electric vehicle inventories of the site operators exceeds 250 vehicles.

Several national organizations have joined DOE to further the introduction and awareness of electric vehicles, including:

- EVAmerica (a utility program) and DOE conduct performance and evaluation tests to support market development for electric vehicles
- DOE, the Department of Transportation, the Electric Transportation Coalition, and the Electric Vehicle Association of the Americas are conducting a series of workshops to encourage urban groups in Clean Cities (a DOE program) to initiate the policies and infrastructure development necessary to support large-scale demonstrations, and ultimately the mass market use, of electric vehicles.

The current focus of the Program is the collection and dissemination of EV operations and performance data to aid in the evaluation of real-world EV use. This report contains several sections with vehicle evaluation as a focus, including:

Electric Vehicle Testing Results

An examination of the DOE and EVAmerica sponsored 1994, 1995, and 1996 performance testing of thirteen electric vehicles. Performance indicators such as acceleration, braking, range, and energy efficiency are examined on a per vehicle basis and as trends. The tested vehicles range from conversions to the most recently tested EV, the Toyota RAV4. (The GM EVI has just completed testing and the results will be reported in the next quarterly report.)

Table ES-1. Site Operator Program Participants.

Entity	Principal Thrusts of Program Effort
Arizona Public Service Co.	a, b, d
Kansas State University	a, b, c, d
Los Angeles Dept. of Water & Power	a
Orcas Power and Light Co.	a, b, d
Pacific Gas and Electric Co.	a, b, d
Platte River Power Authority	a, b, d
Potomac Electric Power Co.	a, b, d
Sandia National Laboratory*	a
Southern California Edison Co.	a, b, d
Texas A&M University	a, c, d
University of South Florida	a, b, c, d
U.S. Navy,* Port Hueneme, CA	a
York Technical College	a, b, c, d

a. Fleet evaluation, vehicle test
b. Infrastructure development
c. Technical education
d. Public awareness

* Sandia and the Navy are not Site Operators, but they do share information with the Site Operator Program, and this information is provided to the reader of this report.

Energy Economics of Electric Vehicles

This section compares the energy cost per mile of an internal combustion vehicle at gasoline prices ranging from \$1.10 to \$1.90 per gallon; to the energy cost per mile for three electric vehicles that have energy efficiencies of 4, 5, and 6 miles per kWh, and per kWh energy costs ranging from \$0.02/kWh to \$0.40/ Wh.

Site Operators Activities

This section provides details of the activities at each site operator, including EV operations, maintenance, energy use, public awareness and education efforts. More that a dozen different types of EVs are in use, with a variety of battery types, and vehicle applications.

This report and the results of DOE/EVAmerica performance testing are available electronically over the Internet. The World-Wide-Web (WWW) site also includes operations data captured by an on-board data acquisition system, and a user-friendly interface that allows point-n-shoot plotting, and custom and canned queries of the operations, performance, and specifications database. The WWW home page is located at http://spiderman.inel.gov

Acknowledgment

The principle author thanks each of the Site Operator participants for their input, active participation, and timely comments in the form of their quarterly reports. The Site Operator Program report incorporates text and data from the quarterly reports that each of the Site Operator participants submit. Because of the significant amount of text that is draw from each of the individual Site Operator's reports, each of the individual Site Operators are listed as co-authors. However, any errors, emissions, or inaccuracies are the singular responsibility of the principle author.

J.E. Francfort

Contents

Introduction

The Site Operator Program was initially established by the Department of Energy (DOE) to incorporate the electric vehicle activities dictated by the Electric and Hybrid Vehicle Research, Development and Demonstration Act of 1976. In the ensuing years, the Program has evolved in response to new legislation and interests. The Program currently includes eleven sites located in diverse geographic, meteorological, and metropolitan areas across the United States. Information is shared reciprocally with two additional sites (U.S. Navy and Sandia National Laboratory) that are not under Program contract.

The goals of the Site Operator Program include the field evaluation of EVs in real-world applications and environments; the advancement of electric vehicle technologies; the development of infrastructure elements necessary to support significant electric vehicle use; and increasing the awareness and acceptance of EVs by the public.

The current participants in the Site Operator Program and their locations are shown in Figure 1. In previous quarterly reports, a table provided detailed information on several EVs that have been performance tested. (This testing is a cooperative effort between the U.S. Department of Energy and EVAmerica). The table has been eliminated and the reader is directed to the Site Operator World-Wide-Web (WWW) Internet Home Page for EV performance testing information. Additional information on the WWW site includes past quarterly reports, EV specifications, operations data captured by on-board data acquisition equipment, and database queries. The WWW address is http://spiderman.inel.gov

The Site Operator Program is managed by personnel of the Electric and Hybrid Vehicle Program at the Idaho National Engineering Laboratory (INEL). The current principal management functions include:

- Technical and financial monitoring of programmatic activities, including periodic progress reports to DOE.
- Data acquisition, analysis, and dissemination. The data from the Site Operators are made available to users through the INEL Site Operator Database at the WWW site and through this report.
- Coordination of Site Operator efforts in the areas of public awareness and infrastructure development (program-related meetings, and educational presentations).

This issue of the Site Operator Program Quarterly Report contains the following sections:

- A brief perspective of the Program history and goals

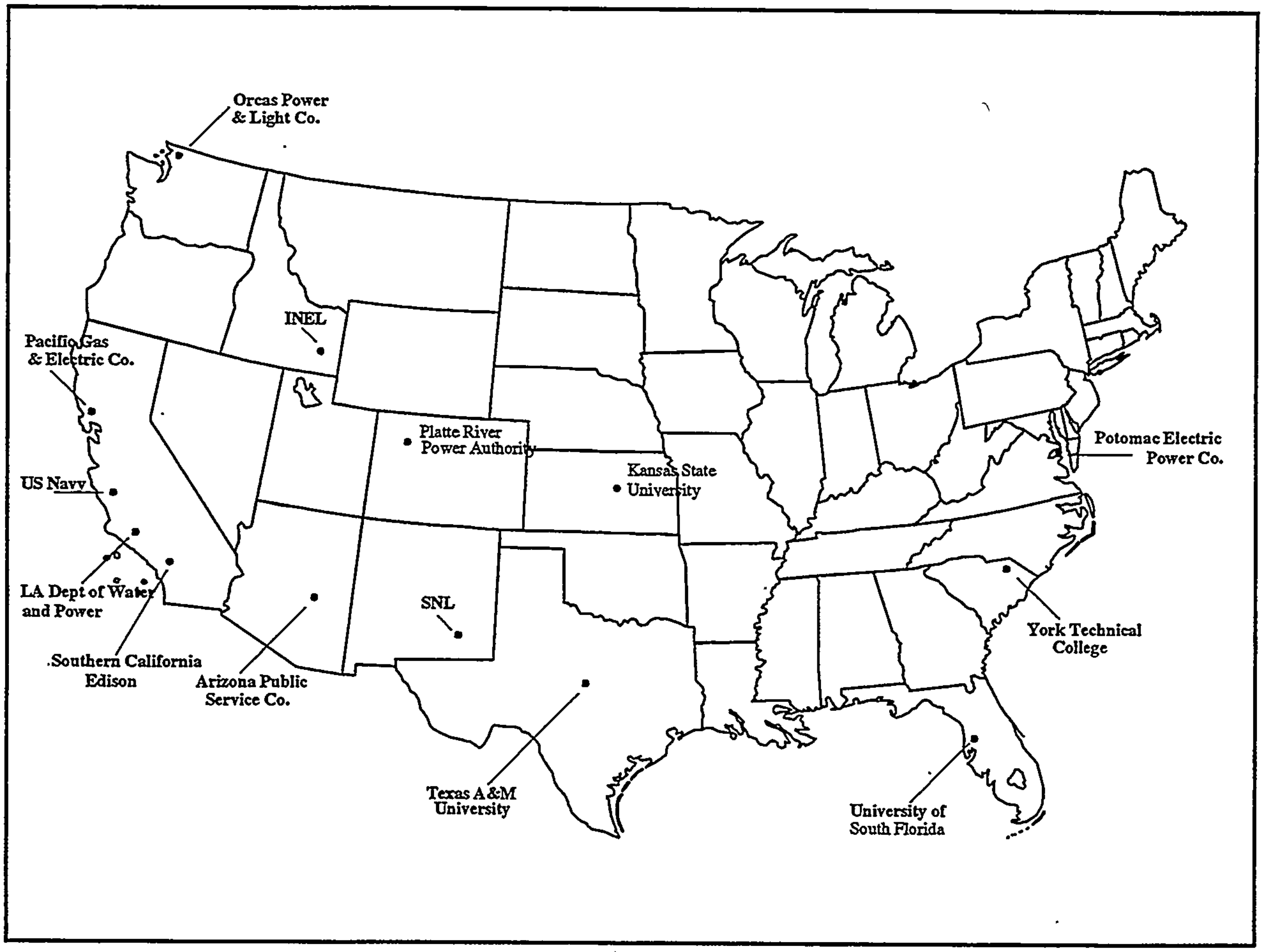

Figure 1. Site Operator Program participant locations.

- A general discussion of EV performance testing results and an indication of performance testing trends over the years 1994, 1995, and 1996.
- A discussion about the Energy Economics of EVs in comparison to internal combustion vehicles
- The Site Operator Activities provide more specific information concerning the Program participants and their overall interests, their programmatic activities, and their experiences with EVs and accompanying problems. Detailed information on EV activities at each Site Operator include operations, maintenance, and EV tests of components.

Program Experience Overview

The Site Operator Program has evolved substantially since its inception in response to the Electric Vehicle Research and Demonstration Act of 1976. In its original form, a commercialization effort was intended but this was not feasible for lack of vehicle suppliers and infrastructure. Nonetheless, with DOE sponsorship and technical participation, a few results (primarily operating experience and data) were forthcoming.

In the early 1980s, DOE emphasis shifted to data collection and interpretation. A mechanism was set up to support participating sites. However, several problems soon became apparent:

- Too much data was required
- Data collection methods were primitive
- Data quality was suspect
- Database operation was ineffective.

The contract for the Program was transferred to the INEL in 1987 and the basic premises of the Program were refined subsequent to the INEL takeover, to emphasize the following efforts:

- Operating and maintenance data collection, analysis, and dissemination
- Public demonstrations to promote general awareness of this developing technology.

Both of these efforts have been fruitful. In particular, practical methods and equipment now exist for acquiring and handling operating data, with increasingly broad distribution of relevant information.

The current Program comprises eleven sites and over 250 vehicles, of which about 50 are latest generation vehicles. DOE partially funds the Program participant expenditures and the INEL receives operating and maintenance data.

As noted elsewhere in this report, participants represent several widely differing categories: electric utilities, academic institutions, and federal agencies. While both the utilities and the academic institutions tend to establish beneficial relationships with the industrial EV community. Program participant efforts reflect varying combinations of day-to-day use, laboratory testing and evaluation, and successful promotion of public awareness by demonstrations, exhibits, and media dissemination of related activities and information.

The utilities have been concerned with infrastructure needs for electric vehicle operation, particularly those required for battery recharging. Several candidate technologies have been investigated and developed for commercial use. In addition, the problems associated with operating and maintaining an EV fleet have been scoped and workable solutions devised and implemented.

The academic institutions and electric utilities have been productive beyond the original Program scope in the areas of:

- Charging methods, both curbside and solar
- EV performance testing results
- Vehicle operating data acquisition, via mobile data acquisition systems (MDAS)
- Training courses and related materials for maintenance personnel and operators
- Field testing of experimental or prototype vehicles and components.

The INEL has worked closely with Program participants to improve acquisition methods and data quality. The INEL has also established a central database and arranged for the dissemination of a spectrum of EV-related information. Through Program reports, INEL also gains a broad picture of the state of EV technology and accompanying public awareness.

Some tentative conclusions can be drawn about the current state of EV technology and operation:

- The industry is evolving as product offerings are becoming more technologically advanced.
- Product prices should decrease and the technology continue to increase as most of the major automakers have announced product offering schedules.
- The effects of climate are adequately documented by inputs from widely differing locations.
- Battery technology is a major limitation in achieving range and vehicle cost goals.
- Conversion of vehicles originally designed for internal combustion engine power can frequently severely reduce payload capability and the service life of key components.
- Production of <u>useful</u> data may be limited where up-to-date equipment is not available. Some of the operating units monitored by the program are approaching a 20-year service life.

Several states (notably, California and Massachusetts) have or are considering regulatory mandates or voluntary agreements to increase the use of EVs for environmental benefit. Their eventual effectiveness is dependent upon establishing a viable EV manufacturing industry and an adequate infrastructure for vehicle operation and service.

In the context of these requirements, several national organizations have joined DOE and the major auto manufacturers in promoting EV use, including:

- EVAmerica is a utility-led program intent on accelerating the development and introduction of EVs into the marketplace. A key effort is performance and field test evaluation.

- DOE, the Department of Transportation, the Electric Transportation Coalition, and the Electric Vehicle Association of the Americas are conducting a series of workshops in ten Clean Cities (Atlanta, Boston, Detroit, Ft. Lauderdale, Los Angeles, New York, Phoenix, Richmond, Sacramento, and Washington DC) to encourage urban groups to initiate the policies and infrastructure development necessary to support large-scale demonstrations, and ultimately the mass market use, of electric vehicles.

- The Partnership for a New Generation of Vehicles (PNGV) in America has been established as a joint Federal-Industrial-Academic effort to identify and evaluate vehicular transportation alternatives, including energy storage devices and alternative fuels.

Another organization, the Electric Vehicle Research Network, is an EPRI-sponsored group of 11 electric utilities who field test EVs, but are not Program participants.

A change of Program direction in the future is expected. Probable candidates for operator testing and data acquisition are hybrids, advanced EVs (i.e., designed as such rather than conversions), add-on or replacement key components (i.e., energy storage devices, system control, and driveline), and devices resulting from PNGV findings.

Electric Vehicle Testing Results

The DOE Site Operator Program, in conjunction with EVAmerica, has conducted EV performance testing during the current, as well as the previous two years (1996, 1995 and 1994). Thirteen vehicles (Table 1) have been tested to date. The testing has been performed with stringent testing procedures and minimum qualification standards that vehicles must meet to be accepted for testing. These standards and procedures are intended to allow a vehicle-to-vehicle and year-to-year comparison of vehicle performances. Not only are performance trends established by using a standardized testing methodology, but more importantly, based on the results of this testing, potential fleet purchasers of EVs can now have greater confidence that his or her expectations of vehicle performance will be met if a vehicle passes the performance tests.

While the test results for the 1996-tested Toyota are included in the graphs and tables, discussion of year-to-year performance trends are limited, as it is difficult to draw year-to-year conclusions for 1996 from a single test vehicle. If additional vehicles are tested during 1996, the results will be reported and discussed in future quarterly reports.

The performance attributes for the one vehicle tested during 1996, the average performance attributes for the three vehicles tested during 1995, and the nine vehicles tested during 1994 are plotted below in Figure 2. The deltas represent the annual increase or decrease in performance. For instance, the first group of bars represent the average miles achieved by the 1994 and 1995 test groups, and the mileage for the 1996-tested Toyota. The 1995 test group saw a 27% increase in average mileage compared to the 1994 test group, while the 1996-tested Toyota saw a 1% decrease in mileage compared to the 1995 test group. The average range (82.6 miles) for the 1995 vehicles, when driven at a constant speed of 45 mph, increased by 27% compared to the 1994 test group (64.8 miles). The decrease in range for the Toyota is partially a function of the type of battery used. The Toyota test vehicle used lead acid batteries while one of the 1995 vehicles used nickel metal hydride batteries, which increased the average range for the 1995 test group.

The single vehicle maximum range for the 1995 group was 106 miles and the maximum for the 1994 test group was 88 miles for a single vehicle (Figure 3). The average range (50.8 miles) for the 1995 group of EVs driven at a constant speed of 60 mph showed a 19% increase compared to the 1994 test group (42.8 miles). Within the 1995 test group, the maximum individual vehicle range at 60 mph was 71 miles, while the 1994 individual vehicle maximum range at 60 mph was 57 miles (Figure 4).

Table 1. Performance testing results from the Site Operator Program/EVAmerica 1996, 1995, and 1994 testing of electric vehicles. This is a partial list of testing results for the 13 vehicles tested during the three years. Some vehicles failed to complete some of the tests and this is noted. [Complete testing performance profiles and testing notes for all of the vehicles can be obtained by accessing the Site Operator Internet home page at http://spiderman.inel.gov SOC - (state-of-charge)].

	Constant speed range		Acceleration 0 to 50 mph	Maximum Speed	Battery		Time to Recharge
	@ 45 mph (miles)	@ 60 mph (miles)	@ 50% SOC (sec)	@ 50% SOC (mph)	Manufacturer	Type	Hrs:Min
Vehicles tested during 1996							
1996 Toyota RAV4 EV	81.7	54.7	13.3	78	Matsushita	Valve Regulated Lead Acid	8.47
Vehicles tested during 1995							
1995 Solectria E-10 (1995 Chev. S-10 P/U)	80.8	49.9	17.4	68	Hawker	Sealed lead acid	11.11
1995 Solectria Force (1995 Geo Metro)	105.9	70.9	18.5	70	GM Ovonic	Nickel metal hydride	8.57
1994 Baker EV100 P/U (GMC full size P/U)	61.2	31.5	14.9	71	GM Ovonic	Nickel metal hydride	7.50
1995 average performance	82.6	50.8	16.9	70			9.19
Vehicles tested during 1994							
Solectria S-10 Pickup (Chevrolet S-10)	72.8	39.5	21.7	66	Hawker Energy	Sealed lead acid	6.52
Solectria Force (Geo Metro)	49.5	26.6	21.5	70	Hawker Energy	Sealed lead acid	3.54
US Electricar Pickup (Chevrolet S-10 Pickup)	70.7	47.3	20.1	71	Hawker Energy	Sealed lead acid	15.40
US Electricar Sedan (Geo Prizm)	59.3	41.5	16.2	81	Hawker Energy	Sealed lead acid	8.12
BAT International Pickup (Ford Ranger)	55.4	44.0	not achieved	not achieved	Trojan	Flooded lead acid	not available
BAT International Metro (Geo Metro)	88.4	51.6	26.0	67	Trojan	Flooded lead acid	10.40
BAT International Metro (Geo Metro)	47.1	39.6	16.5	81	Optima	Prototype deep cycle	not available
Dodge Caravan (Dodge Caravan)	86.4	57.0	33.9	62	Picher	Nickel iron	5.07
Unique Mobility Pickup (Ford Ranger)	53.5	38.3	30.3	70	Optima	Prototype deep cycle	10.50
1994 average performance	64.8	42.8	23.3	71			8.45

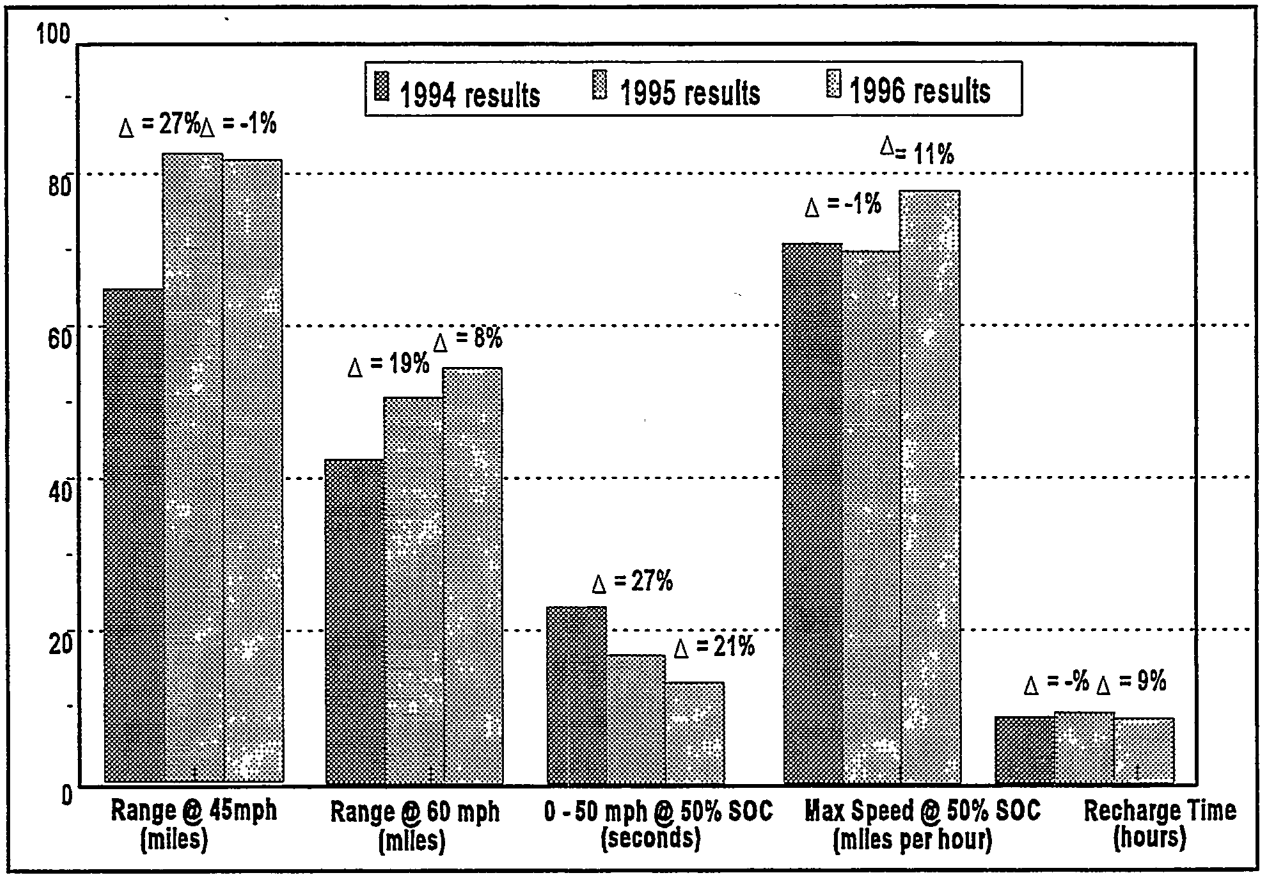

Figure 2. Site Operator Program and EV America performance trends for 1996, 1995, and 1994 tested electric vehicles. The average test results for each group of vehicles are plotted, and the listed variances are the deltas between the group averages (1994, 1995) and the Toyota (1996) test results.

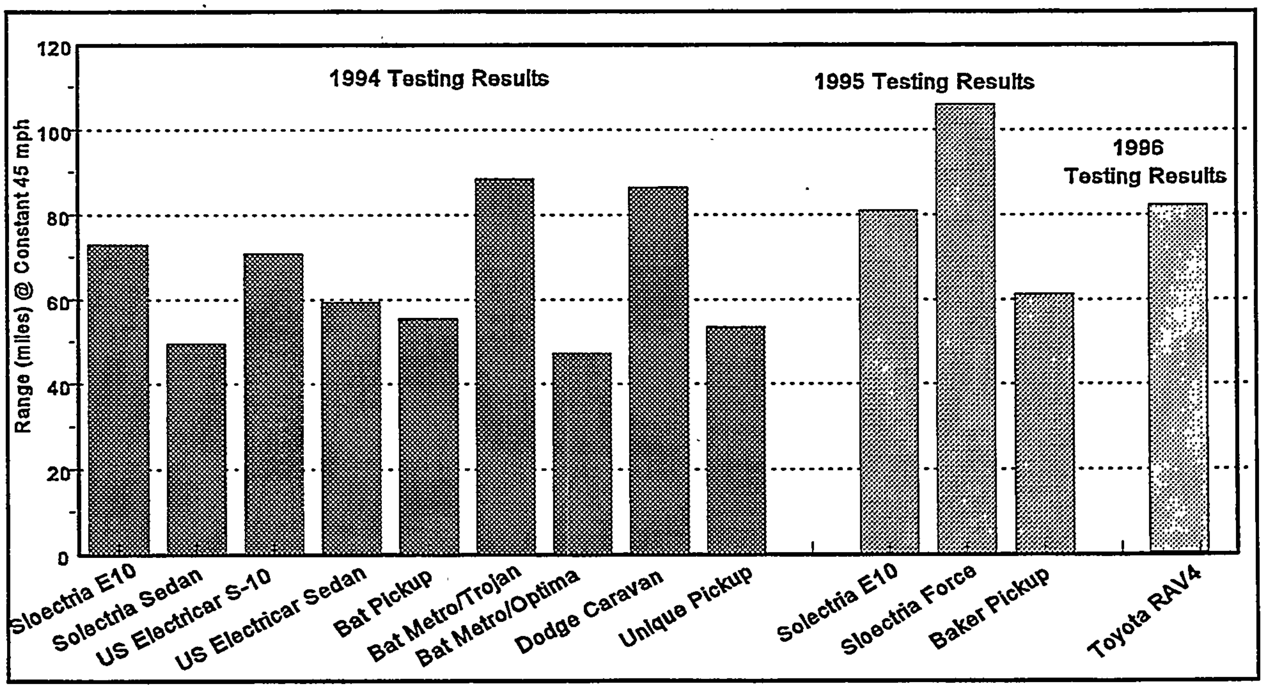

Figure 3. Range (Miles) results for constant speed test at 45 mph.

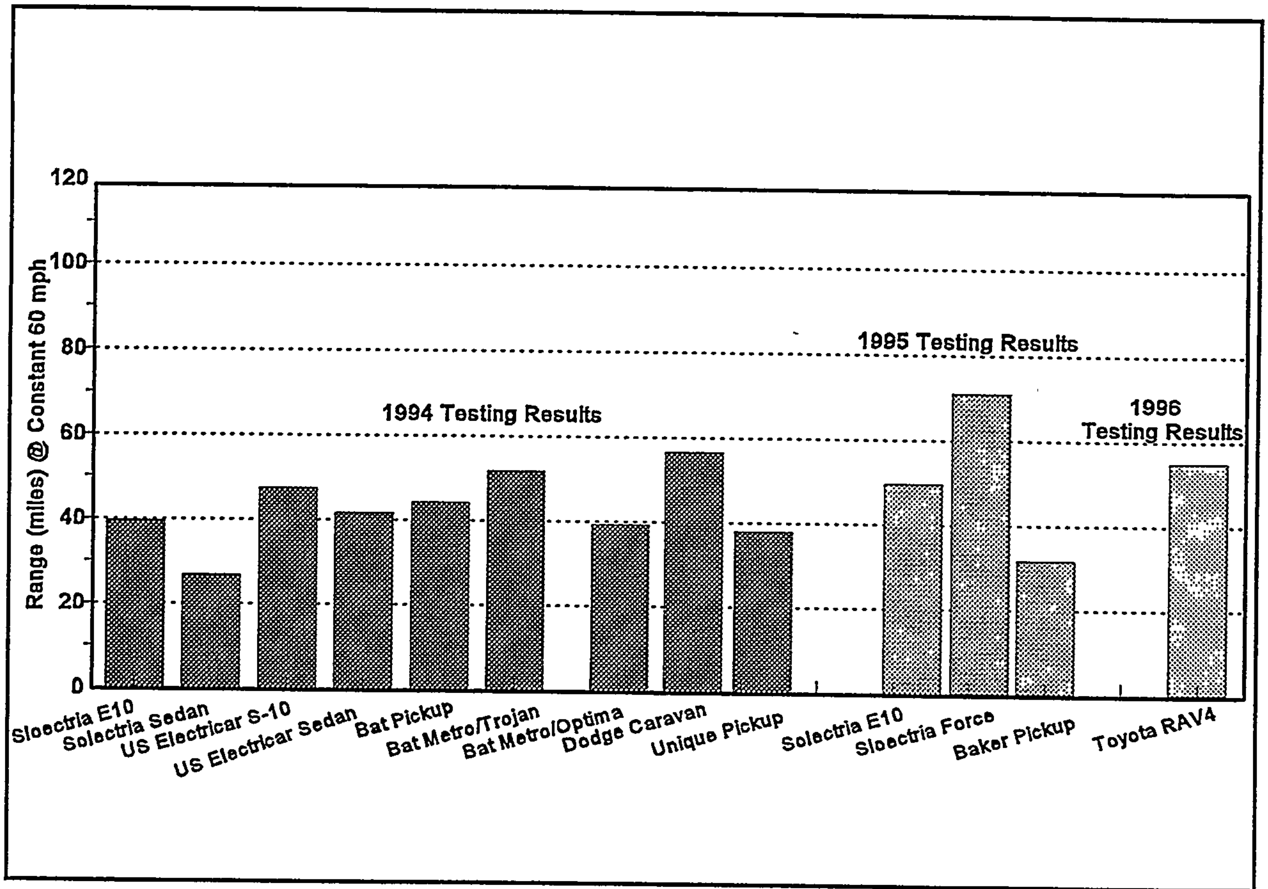

Figure 4. Range (miles) results for constant speed tests at 60 mph.

Acceleration tests from zero to 50 mph, performed at a state of charge of 50%, were performed on both the 1995 and 1994 electric vehicles. The 1995 electric vehicles, as a group, accelerated on average 28% faster (16.9 seconds) that the 1994 group (23.3 seconds). The single fastest acceleration time for the 1995 test vehicles was 14.9 seconds, while the 1994 group had a fastest acceleration time of 16.2 seconds. Two of the 1994 vehicles took over 30 seconds to accelerate to 50 mph (Figure 5).

The 1995 vehicles, as a group, displayed a 1 mph slower average maximum speed than the 1994 test group. However, this slight (1.4%) decrease in speed may be acceptable given the previously discussed significant increases in range and acceleration. Also, the 1995 test group had all of their maximum speeds within 2 mph of the average, while two of the 1994 test vehicles were more than 5 mph below the average, and three of the 1994 test group EVs failed to reach the performance goal of 70 mph for maximum speed (Figure 6).

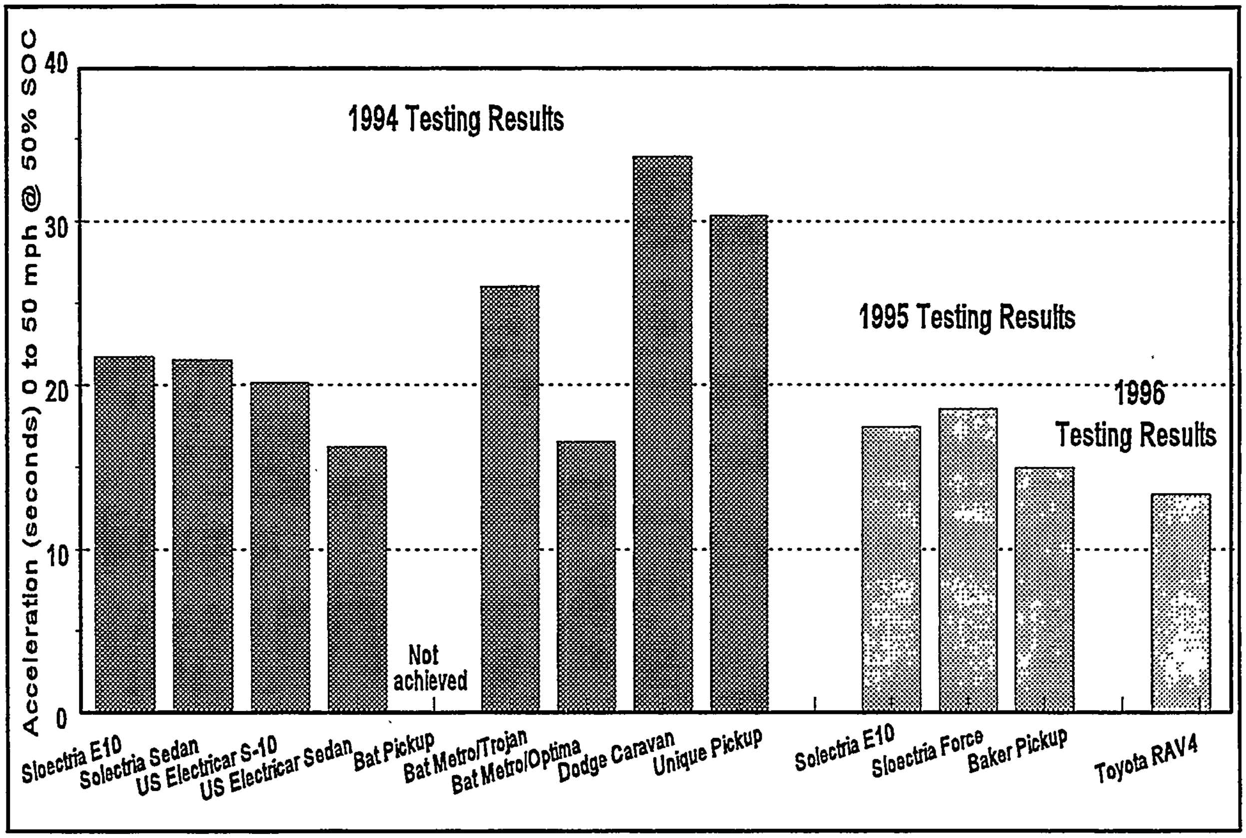

Figure 5. Acceleration (seconds) test results for 0 to 50 mph acceleration at 50% SOC.

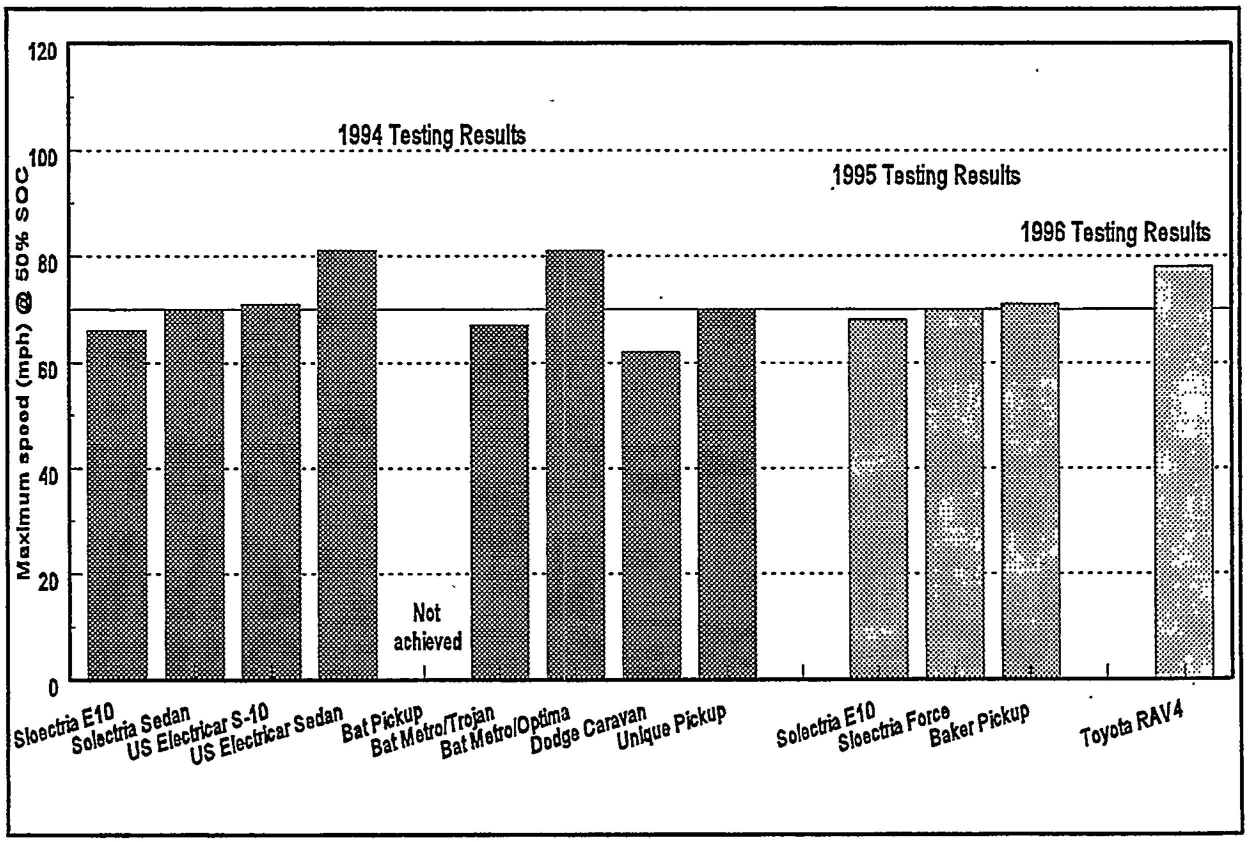

Figure 6. Maximum speed (mph) achieved by each vehicle when testing at a 50% SOC.

The charging results for the two groups indicated that 6.5% more time was required by the 1995 test vehicles to recharge their batteries than the 1994 test group. This increased recharge time, which translates to an average total time to recharge of 9 hours and 19 minutes for the 1995 group, is 34 minutes longer than the 1994 group (Figure 7). This increase in charging time should be considered in the context that the 1995 vehicle group included one vehicle equipped with Nickel Metal Hydride batteries. The Nickel Metal Hydride batteries generally have higher energy storage capabilities, providing the enhanced range results. As a generally newer and more advanced battery than the lead acid batteries mostly used by the 1994 test group, the charging methodologies used to charge the Nickel Metal Hydride batteries may not have been as advanced as those for the lead acid batteries and this may be a reason for the longer recharging times exhibited by the 1995 test group.

The Society of Automobile Engineers standard practice J1634 was used to examine the driving cycle energy efficiencies of the 13 vehicles. The energy efficiency, on a mile per kWh basis, ranged from just over 2 miles per kWh for several vehicles to almost 6 miles per kWh for two of the test vehicles (Figure 8).

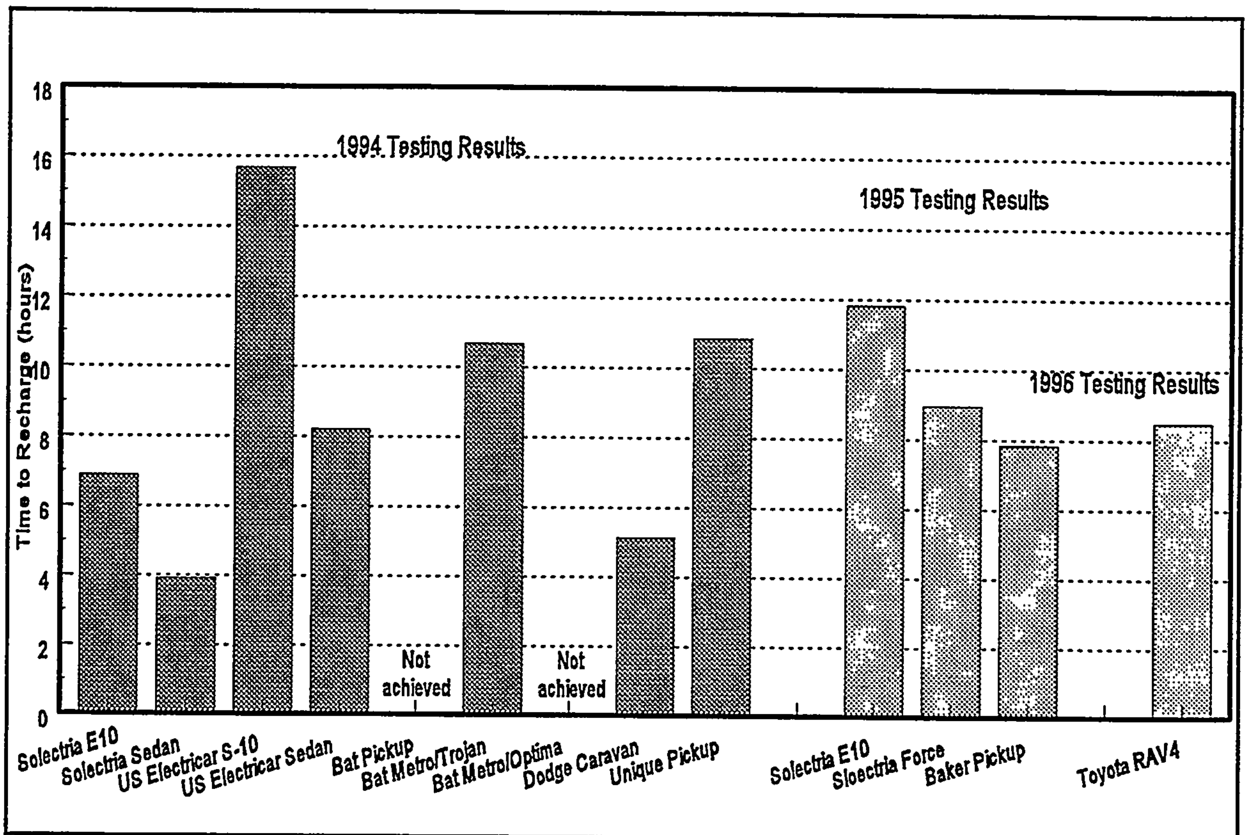

Figure 7. Time (in hours) to recharge each vehicle's battery pack.

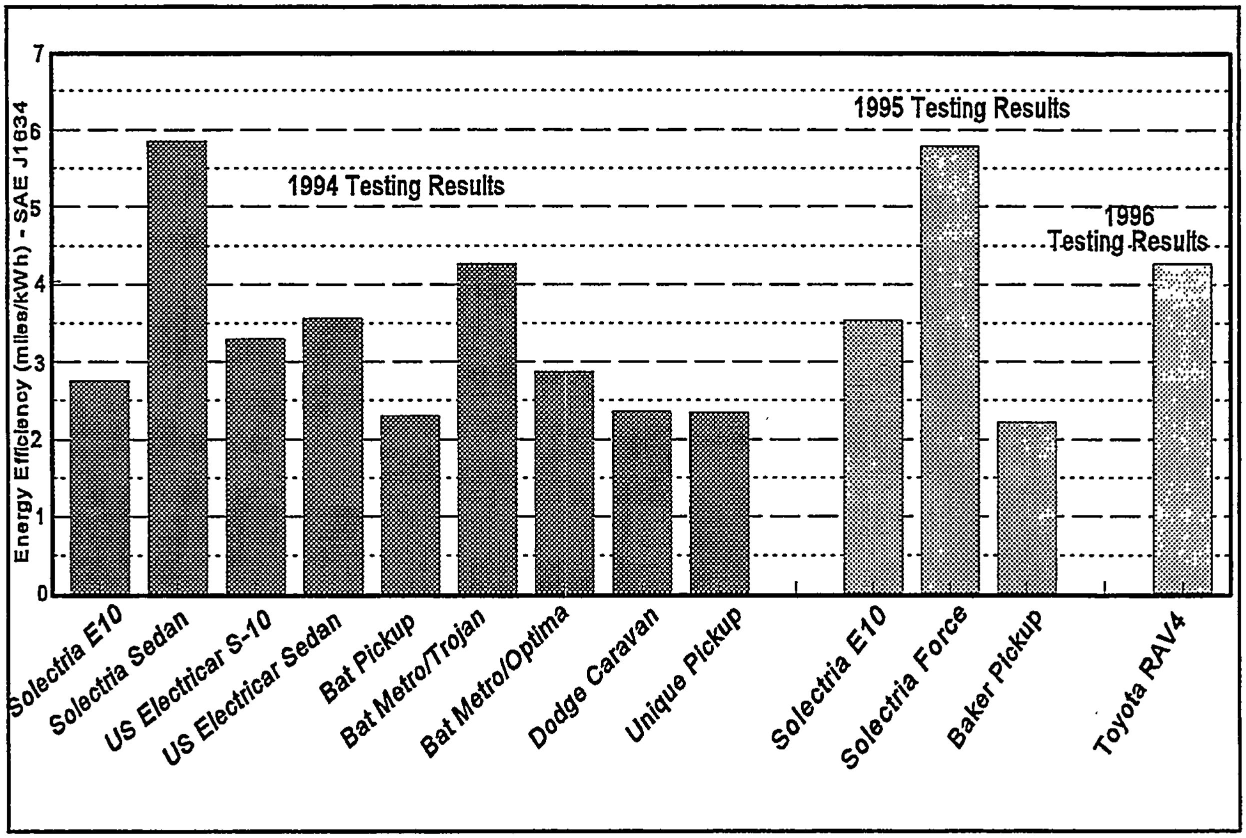

Figure 8. Driving cycle energy efficiency (miles per kWh) of each vehicle using SAE J1634 standards to define the driving cycle.

Energy Economics of Electric Vehicles

This section takes a look at the energy economics of EVs and how they compare to the energy costs of vehicles fueled by internal combustion engines (ICE). The energy costs are discussed for four types of vehicles: a gasoline-powered ICE that gets 28 miles per gallon, and three electric vehicles that respectively go four, five and six miles per kWh of electricity. The last Site Operator's Quarterly Report originally touched on this subject, but this discussion has been expounded, with dynamic comparisons of electricity efficiencies and variable fuel costs (both for electricity on a per kWh basis and for a gallon of gasoline).

While there are other variables that affect the total life-cycle costs of EVs, only the energy costs are examined here. It is acknowledged that other costs, such as the initial capital costs of the vehicle and a charger (if off-board), minus any applicable tax deductions or tax credits, can have significant impacts on total life-cycle costs. However, many of these cost comparison questions are difficult to quantify for EVs. For instance, should the cost of GM's EVI/Impact be compared to an ICE that has similar range, or similar luxury (like a Lexus?), or similar handling and acceleration (like a Porsche?). Capital and/or leasing costs will be examined in future Quarterly Reports when the capital/leasing costs to obtain an EV from original equipment manufacturers are better quantified.

Assumptions

In order to perform the energy economics comparison, several assumptions must be employed and these assumptions can generate controversy, as not all are willing to accept the same set of assumptions. To mitigate this potential controversy, the assumptions used are clearly stated and reasonable.

- An average miles per gallon (mpg) value of 28 miles per gallon is assumed for ICEs. An Energy Information Agency publication[1] lists the 1992 United States automobile miles per gallon value of 21.6 miles per gallon, with this value historically increasing at an average annual rate of 2.6% per year for the previous 19 years. This equates to a calculated 1996 rate of 23.9 miles per gallon. However, it is assumed that the newer ICE vehicles will have a combined value of 28 miles per gallon, to avoid the implication that the analysis is disfavorable to ICEs.

- An EV baseline efficiency value of 4.0 miles per kWh is assumed for the analysis. There is no strong historical basis for EV fleet efficiency, given the continuous increases in EV technology over short periods of time and the relatively short history of OEM-built EV availability. However, some miles per kilowatt-hour information is available, including the GM EVI/Impact which is expected to perform in the 4+ miles per kWh range. Southern California Edison (SCE) is reporting that their Honda and Ecostar fleet vehicles are achieving over 4 miles per kWh. The DOE/EVAmerica test results from 1996, 1995 and 1994 also support the use of 4 miles per kWh. Using the 45 mph constant speed test, the 13 tested vehicles averaged 4.52 miles per kWh (Figure 9). In fact, 8 of the 13 electric

[1] Energy Information Administration. *Alternative to Traditional Transportation Fuels*. June 1994. Table 13. U.S. Department of Energy. Washington, D.C.

vehicles exceeded the 4 miles per kWh assumed value, and 3 of the EVs exceeded the assumed 4 miles per kWh values by greater than 50% (+6 miles per kWh).

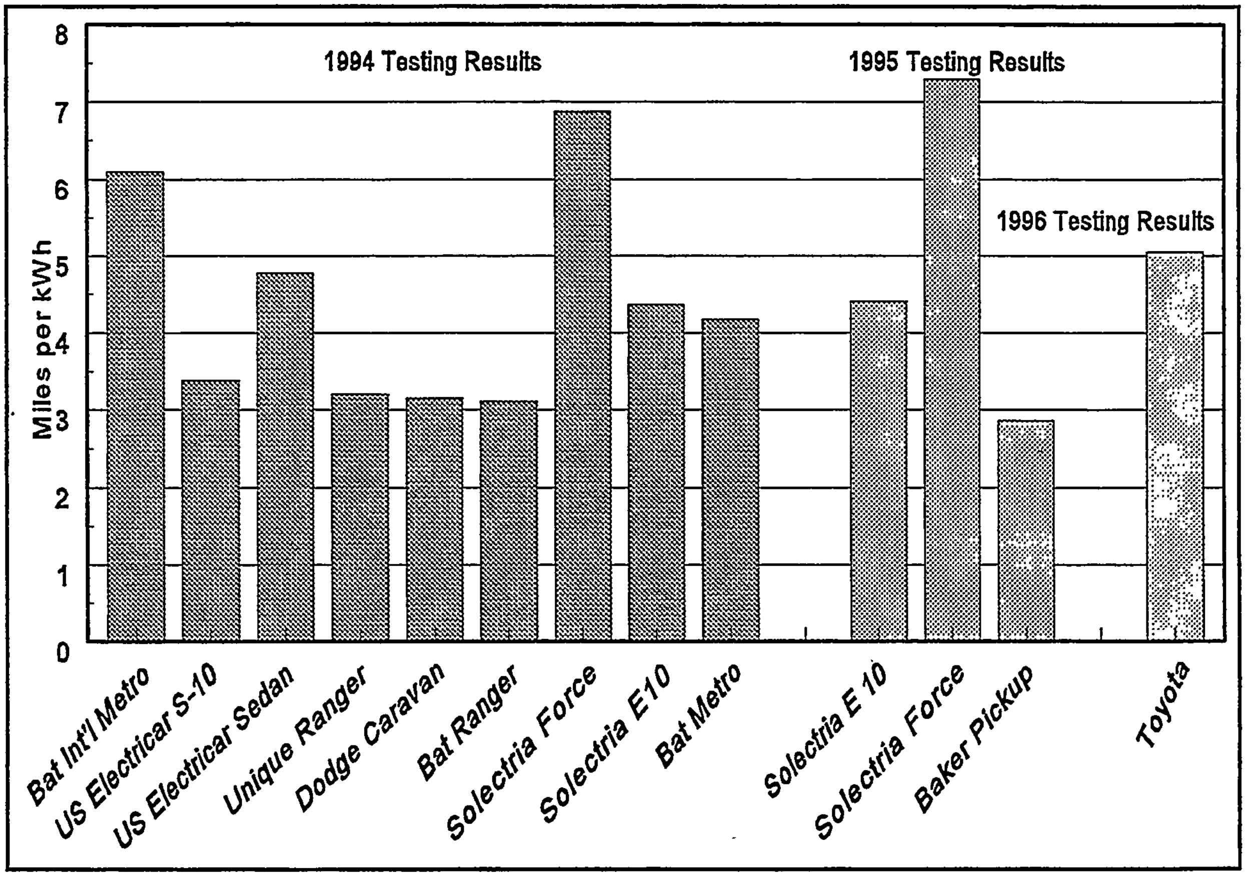

Figure 9. Energy efficiency, measured as miles per kWh. The values for all 13 vehicles are computed based on EVAmerica/DOE testing during 1996, 1995, and 1994. The miles per kWh are based on the vehicles' ranges and energy use, as demonstrated in the Constant-Speed Range Test, at 45 mph.

- The next assumption is the cost of gasoline. Based on the February twenty-third Lundberg Survey of 10,000 gas stations nationwide, the average pump price for gasoline was 119.13 cents. The prices for unleaded gas at self-serve pumps were 112.42 cents for regular, 122.64 cents for mid-grade, and 131.20 cents for premium. At full-service pumps, the nationwide average prices for regular, mid-grade, and premium unleaded gas were 149.01 cents, 157.87 cents, and 164.80 cents, respectively.[2] By June 7, the average reported price for all grades of gasoline had risen to 136.96 cents per gallon.[3] Additional media

[2] Idaho State Journal, February 26, 1996, P B4, *Biz Briefs: Gas Prices Jump Again, Up 1.5 cents*, Pocatello, Idaho.

[3] Idaho State Journal, February June 11, 1996, P B4, *Biz Briefs: Average Gas Price Up 1.62 cents*, Pocatello, Idaho.

reports sited examples of gasoline approaching $2.00 per gallon. The analysis uses a cost of gasoline for an ICE as ranging between $1.10 to $1.90 per gallon.

- The cost of electricity may be the most difficult assumption to reach agreement on, given the many different rates by region, day-of-the-week, on-peak, off-peak, off-off-peak, partial peak, and other adjustable rates per kilowatt-hour of use. However, the national average for residential customers is known, and through December of 1995, the kilowatt-hour rate for the year was averaging about 8.5 cents per kWh.[4] During the month of December 1995, the per kilowatt-hour rate in the United States ranged from about 14 cents in New Hampshire to 4.5 cents in Washington State. The California average was about 11.5 cents per kWh. All of these rates are residential, which assumes at home charging. The other types of rates include commercial (7.75 cents per kWh), industrial (4.73 cents per kWh), and others (6.70 cents per kWh). The "others" category includes street lighting, railroads, and sales to other public authorities. As previously mentioned, an additional complication is the range of variable kWh rates by time-of-day, and these rates can range from 3 cents to over 30 cents per kWh for residential EV consumption in California. Because of possible rates associated with different charging scenarios, a range of 2 cents to 40 cents per kWh is used for the analysis. Each of the three EVs, with energy efficiencies of 4, 5 and 6 miles per kWh, use the 2 to 40 cents per kWh range in the analysis.

Results

While it is possible to equate the heat (Btu) content of a kWh and a gallon of gasoline, it is less complicated to simply divide the cost per gallon ($1.10 to $1.90) of gasoline by the number of miles per gallon (28 miles) and to divide the cost per kWh by the number of miles per kWh to get fuel costs on a per mile basis. This is done in Table 2 and graphically shown in Figure 10 for comparison purposes.

To understand the relationships between the costs, the graph is read as follows.

- The solid line labeled "Internal Combustion 28 miles per gallon" represents the fuel cost per mile for a gasoline powered vehicle. The per gallon cost of gasoline uses the right scale (Gasoline cost per gallon). At $1.10 per gallon, the per mile energy cost (bottom scale) is slightly under 4 cents; at $1.40 per gallon, the per mile energy cost is about 5 cents; and at $1.70 per gallon, the per mile energy cost is about 6 cents.

- The line with the long dashes, labeled "Electric Vehicle 4 miles per kWh," represents the fuel cost per mile for an EV that has an energy efficiency of 4 miles per kWh. Using the left scale (electricity cost per kWh), one can compare the electricity cost per kWh and the cost

[4] Energy Information Administration. *Electric Power Monthly*. January 1996. Table 60. U.S. Department of Energy. Washington, D.C.

Table 2. Comparative fuel costs for gasoline and electric fuels.

Electricity (cents/kWh)	Fuel (electricity) cost per mile 4 miles/kWh	5 miles/kWh	6 miles/kWh	Gasoline (cents per gallon)	Fuel (gasoline) cost per mile
2	0.5	0.4	0.33	110.0	3.93
4	1.0	0.8	0.67	112.5	4.02
6	1.5	1.2	1.00	115.0	4.11
7	2.0	1.6	1.33	117.5	4.20
10	2.5	2.0	1.67	120.0	4.29
12	3.0	2.4	2.00	122.5	4.38
14	3.5	2.8	2.33	125.0	4.46
16	4.0	3.2	2.67	127.5	4.55
18	4.5	3.6	3.00	130.0	4.64
20	5.0	4.0	3.33	132.5	4.73
22	5.5	4.4	3.67	135.0	4.82
24	6.0	4.8	4.00	137.5	4.91
26	6.5	5.2	4.33	140.0	5.00
28	7.0	5.6	3.67	142.5	5.09
30	7.5	6.0	5.00	145.0	5.18
32	8.0	6.4	5.33	147.5	5.27
34	8.5	6.8	5.67	150.0	5.36
36	9.0	7.2	6.00	152.5	5.45
38	9.5	7.6	6.33	155.0	5.54
40	10.0	8.0	6.67	157.5	5.62
				160.0	5.71
				162.5	5.80
				165.0	5.89
				167.5	5.98
				170.0	6.07
				172.5	6.16
				175.0	6.25
				177.5	6.34
				180.0	6.43
				182.5	6.52
				185.0	6.61
				187.5	6.70
				190.0	6.79

per mile. For instance, at 5 cents per kWh (left scale), the per mile energy cost (bottom scale) is between 1 and 1.5 cents; at 20 cents per kWh, the per mile energy cost is about 5 cents; and at 30 cents per kWh, the per mile energy cost is about 7.5 cents.

- The line with the dots, labeled "Electric Vehicle 5 miles per kWh," represents the fuel cost per mile for an EV that has an energy efficiency of 5 miles per kWh. Using the left scale (electricity cost per kWh), one can compare the electricity cost per kWh and the cost per mile. For instance, at 5 cents per kWh (left scale), the per mile energy cost is about 1 cents (bottom scale); at 20 cents per kWh, the per mile energy cost is about 4 cents; and at 30 cents per kWh, the per mile energy cost is about 6 cents.

- The line with the short dashes, labeled "Electric Vehicle 6 miles per kWh," represents the fuel cost per mile for an EV that has an energy efficiency of 6 miles per kWh. Using the left scale (electricity cost per kWh), one can compare the electricity cost per kWh and the cost per mile. For instance, at 5 cents per kWh (left scale), the per mile energy cost is between 0.5 and 1 cent (bottom scale); at 20 cents per kWh, the per mile energy cost is between 3 and 3.5 cents; and at 30 cents per kWh, the per mile energy cost is about 5 cents.

To compare the per mile energy costs for EVs and ICEs, a vertical line can be draw through the graph. The vertical line allows a comparison between the cost per gallon of gasoline and the EVs at different electricity costs. To illustrate this, the graph includes the vertical line labeled "Breakeven at $1.30 per gallon". The vertical line intersects the solid line that represents the ICE fuel costs at $1.30 per gallon of gasoline (right scale). Following the vertical line to the bottom scale shows that the per mile energy cost of gasoline would be about 4.6 cents (bottom scale). To compare the per mile energy costs for the EVs, follow the vertical line to its intersections with the lines that represent the EV energy costs.

The vertical line intersects the line with long dashes (Electric Vehicle 4 miles per kWh) at about 18 cents per kWh (left scale). This means that at an electricity cost of 18 cents per kWh or lower, the EV with an energy efficiency of 4 miles per kWh has a lower per mile energy cost than the ICE that gets 28 miles per gallon and uses $1.30 per gallon gasoline.

The vertical line intersects the doted line (Electric Vehicle 5 miles per kWh) at about 23 cents per kWh (left scale). This means that at an electricity cost of 23 cents per kWh or lower, the EV with an energy efficiency of 5 miles per kWh has a lower per mile energy cost than the ICE that gets 28 miles per gallon and uses $1.30 per gallon gasoline.

The vertical line intersects the line with short dashes (Electric Vehicle 6 miles per kWh) at about 27 cents per kWh (left scale). This means that at an electricity cost of 27 cents per kWh or lower, the EV with an energy efficiency of 6 miles per kWh has a lower per mile energy cost than the ICE that gets 28 miles per gallon and uses $1.30 per gallon gasoline.

As seen in the graph (Figure 10), the per mile cost to fuel an EV can be significantly lower than the cost to fuel an ICE. The consumer has the ability to control his/her behavior as to when to fuel the EV, provided of course that the consumer does not try to exceed the vehicles's range on any given day. Attempting to exceed the vehicle's range would likely require on-peak refueling at a public recharging station. Such recharging could include the use of more expensive peak-energy costs, as well as a payment to the charging station for this convenience.

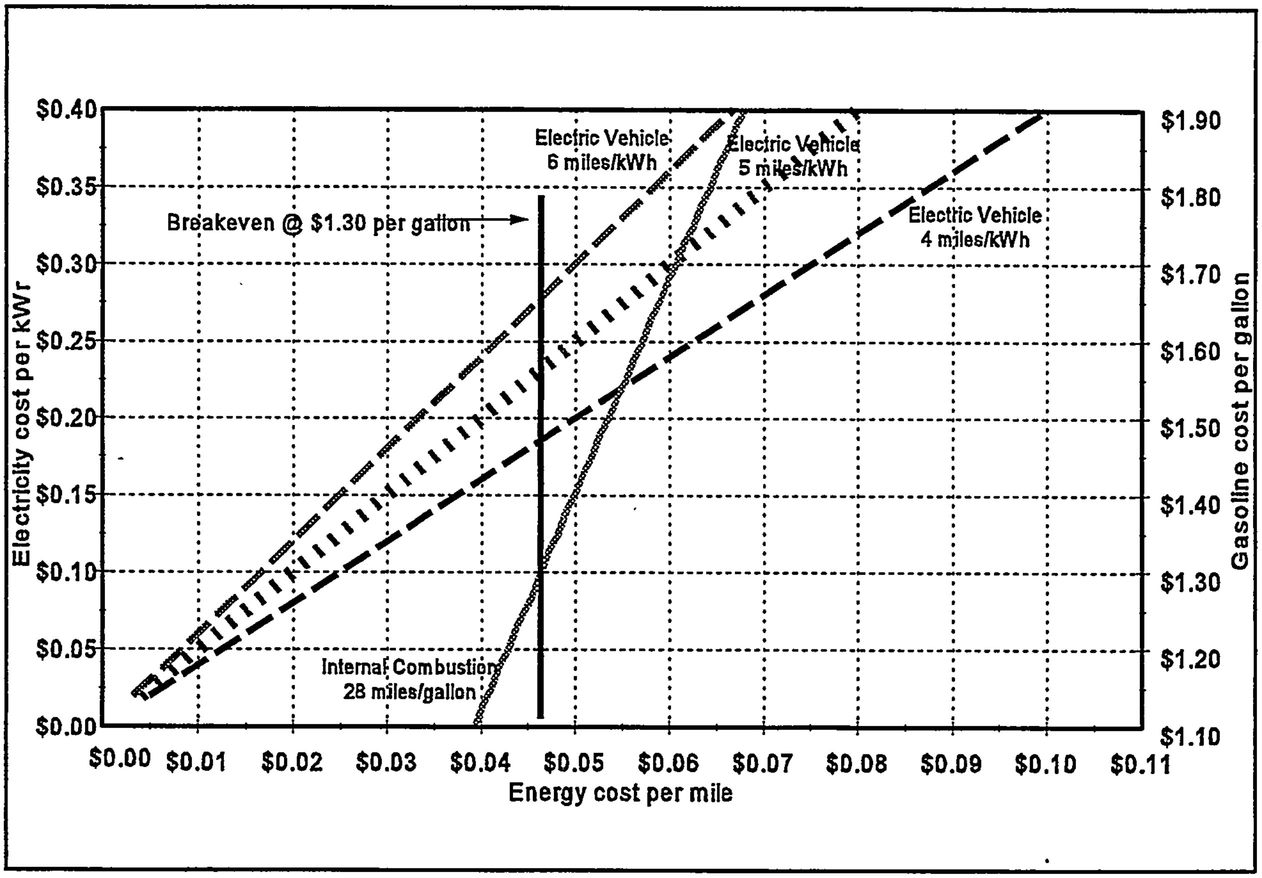

Figure 10. Comparison of the fuel cost per mile for a gasoline-fueled vehicle, and the fuel cost per mile for an EV at varying kilowatt-hour energy rates and EV efficiency rates of 4, 5, and 6 miles per kWh.

Other EV cost factors to be considered include the cost to replace the battery pack, the initial capital cost of the vehicle, tax incentives, and the avoidance of ICE costs that EVs do not incur. These avoided costs include the 3,000 mile oil changes, the replacement of the muffler system, timing belt replacements, tune ups, changing the antifreeze and fuel filter, and other miscellaneous costs. Of course EVs will have maintenance costs that are unique to EVs. Future Quarterly Reports will attempt to examine these issues and compare the cost tradeoffs. It may be difficult to quantify some EV benefits, including the noise and pollution reductions, and the shifting away from dependence on foreign fossil fuels that will someday prove to be of a finite quantity.

Site Operator Activities

This section contains an overview of the activities at each of the eleven Site Operators, the U.S. Navy, and Sandia National Laboratory. The Site Operator Participants, the U.S. Navy, and the Sandia National Laboratory currently employ a total of 258 vehicles (Figure 11) that constitute a variety of models, manufacturers, and converters (Figure 12). The number of vehicles is constantly changing, as new vehicles are acquired, catastrophic breakdowns occur, and vehicles are totaled due to accidents resulting from real-world use. Table 3 contains a listing of the types of vehicles at each of the Site Operators. The EV operations, maintenance, and performance data presented for the site operator vehicles is for the October, November, and December period, unless otherwise noted.

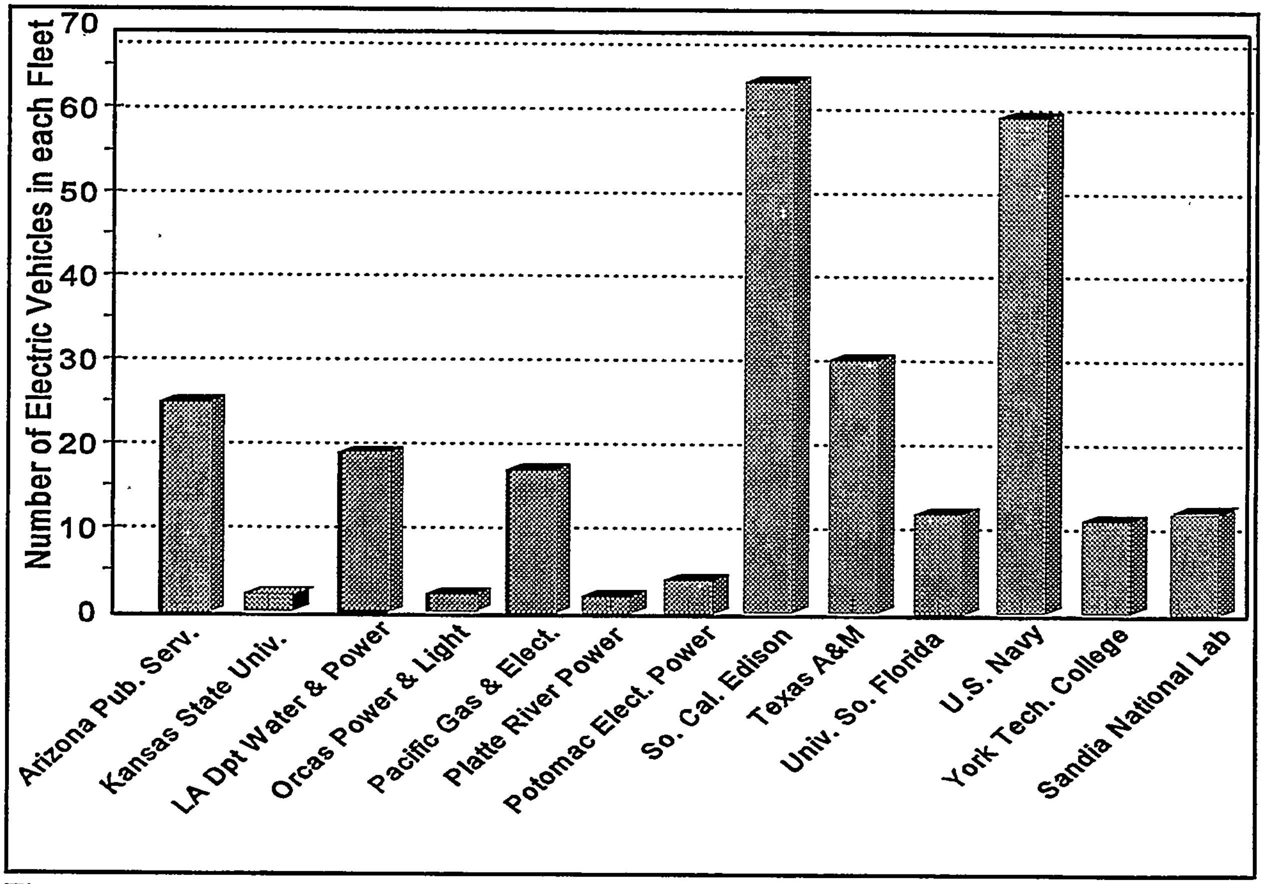

Figure 11. Number of vehicles in the Site Operator Program.

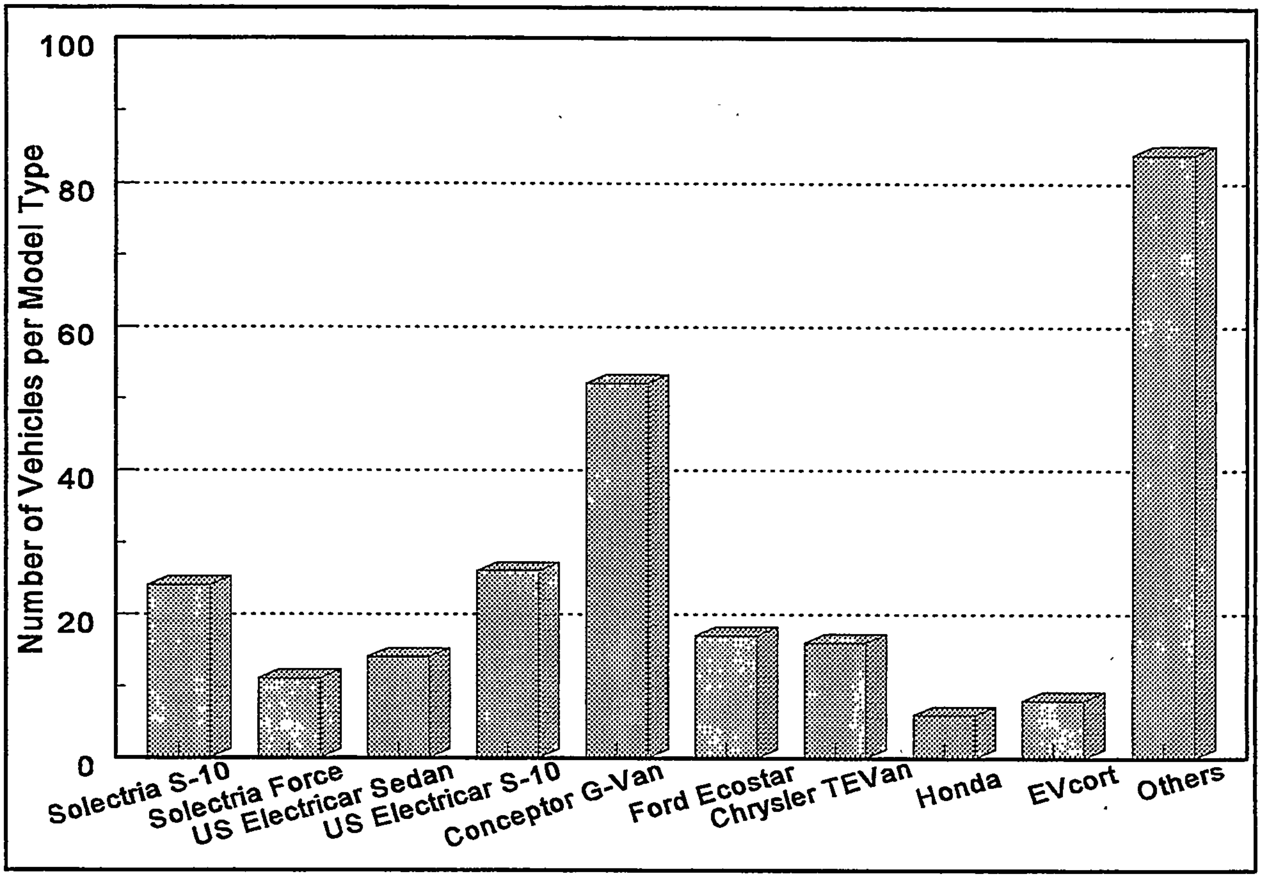

Figure 12. Number of vehicles by model/manufacturer/converter. The "others" category includes various vehicle models, manufacturers, and converters, including: BAT Metro and Ranger; Specialty; Demi TVan; Ford Ranger; Venus Ranger; Griffin; Solar Car' Spartan; Unique; Soleq; Bear Skin; Jet; Volkswagen; Mitsubishi; utility company conversions, and others. It is assumed that these "other" vehicles, while perhaps providing satisfactory day-to-day operating capabilities to their owners, generally have been and will be of limited production, and they do not represent the future EV market in the United States.

Table 3. Site Operator Program vehicle fleet.

Arizona Public Service Company

Unique sedan	2 ea.
Conceptor G-Van	4 ea.
Spartan/GE S-10	1 ea.
Soleq EVcort sedan	3 ea.
Solar Car Electric Colt	1 ea.
Chrysler TEVan	1 ea.
Solectria Force	2 ea.
Solectria S-10	6 ea.
DTS S-10	1 ea.
Brawner Motorsport S-10	1 ea.
US Electricar S-10	3 ea.
TOTAL	25

Kansas State University

EVcort sedan	2 ea.

Los Angeles Department of Water and Power

Conceptor G-Van	6 ea.
Unique Mobility van	1 ea.
Chrysler TEVan	4 ea.
US Electricar S-10	4 ea.
US Electricar sedan	4 ea.
TOTAL	19

Orcas Power and Light Company

Jet Ford Escort	1 ea.
Solectria Force	1 ea.
TOTAL	2

Pacific Gas and Electric Company

Conceptor G-Van	3 ea.
Honda	3 ea.
Ford Ecostars	5 ea.
Kewet El Jet	1 ea.
US Electric S-10	5 ea.
TOTAL	17

Platte River Power Authority

Soleq EVCORT sedan	2 ea.
TOTAL	2

Potomac Electric Power Company

Solectria S-10	3 ea.
Solectria Force	1 ea
TOTAL	4

Sandia National Laboratory

Jet Electricas	12 ea.

Table 3. (continued)

Southern California Edison Company

Conceptor G-Van	14 ea.
Solectria Force	5 ea.
Ford Ecostar	12 ea.
Solectria S-10	2 ea.
US Electricar S-10	10 ea.
BAT Metro sedan	1 ea.
BAT Ranger pickup	1 ea.
US Electricar sedan	10 ea.
Chrysler TEVan	2 ea.
Honda CUV-4 sedan	3 ea.
TDM Ranger	1 ea.
TSD Ranger	1 ea.
Venus Ranger	1 ea.
TOTAL	63

Texas A&M University

Conceptor G-Van	15 ea.
Jet Ford Lynx	1 ea.
Chrysler TEVan	9 ea.
Solectria Force	1 ea.
GM Opal	1 ea.
US Electricar S-10	3 ea.
TOTAL	30

U.S. Navy

Jet	16 ea.
Griffin	15 ea.
Solectria S-10	13 ea.
Conceptor G-Vans	7 ea.
Taylor Dunn	1 ea.
Manufacturer not known	5 ea.
Shuttle Bus	2 ea.
TOTAL	59

University of South Florida

Conceptor G-Van	2 ea.
Solar Car Corp. S-10	7 ea.
Florida Power S-10	2 ea.
Mitsubishi Mirage	1 ea.
TOTAL	12

York Technical College

Conceptor G-Van	1 ea.
Jet Escort Sedan	3 ea.
Unique Sedan	1 ea.
US Electricar S-10	1 ea.
Bear Skin Escort	1 ea.
Volkswagen Pickup	3 ea.
Solectria Force	1 ea.
TOTAL	11

(York maintains for others - 6 EVs)

Total All Sites 258

Arizona Public Service Company

Arizona Public Service (APS) maintains and operates 25 electric vehicles of various types (Figure 13) in its EV Program. During this reporting period, APS added a total of four new vehicles, one Solectria Sedan and three Solectria pickups. One of APS's G-Vans is operated by the City of Phoenix and another is operated by the City of Scottsdale. The remaining 23 APS EVs are operated by APS in the Phoenix area. Both passenger and cargo vehicles are represented. While some of the vehicle usage is demonstration, often under loan or lease arrangements, the main objective is to test and evaluate the viability of electric vehicles, and to collect operation, maintenance, and battery data in everyday utility use. Technical information is also coordinated with Southern California Edison, and the Electric Power Research Institute (EPRI).

Technical

Since 1979, APS has logged over 644,000 miles on their EVs as part of the Site Operator Program. During the October, November and December quarter, the APS fleet was driven 22,880 miles, for a total of 74,955 miles for the year. Because the below eleven vehicles (Table 4) represent some of the most current commercially available EV technology, the maintenance requirements are described. Only some of the cost information is provided for these maintenance activities, as some of the work is under warranty. However, the "old" fleet vehicles maintenance costs to APS are noted in the second table below (Table 5). Some of the maintenance costs may not necessarily be related to the electric propulsion system; the maintenance costs may include whole-vehicle costs such as mirror replacement.

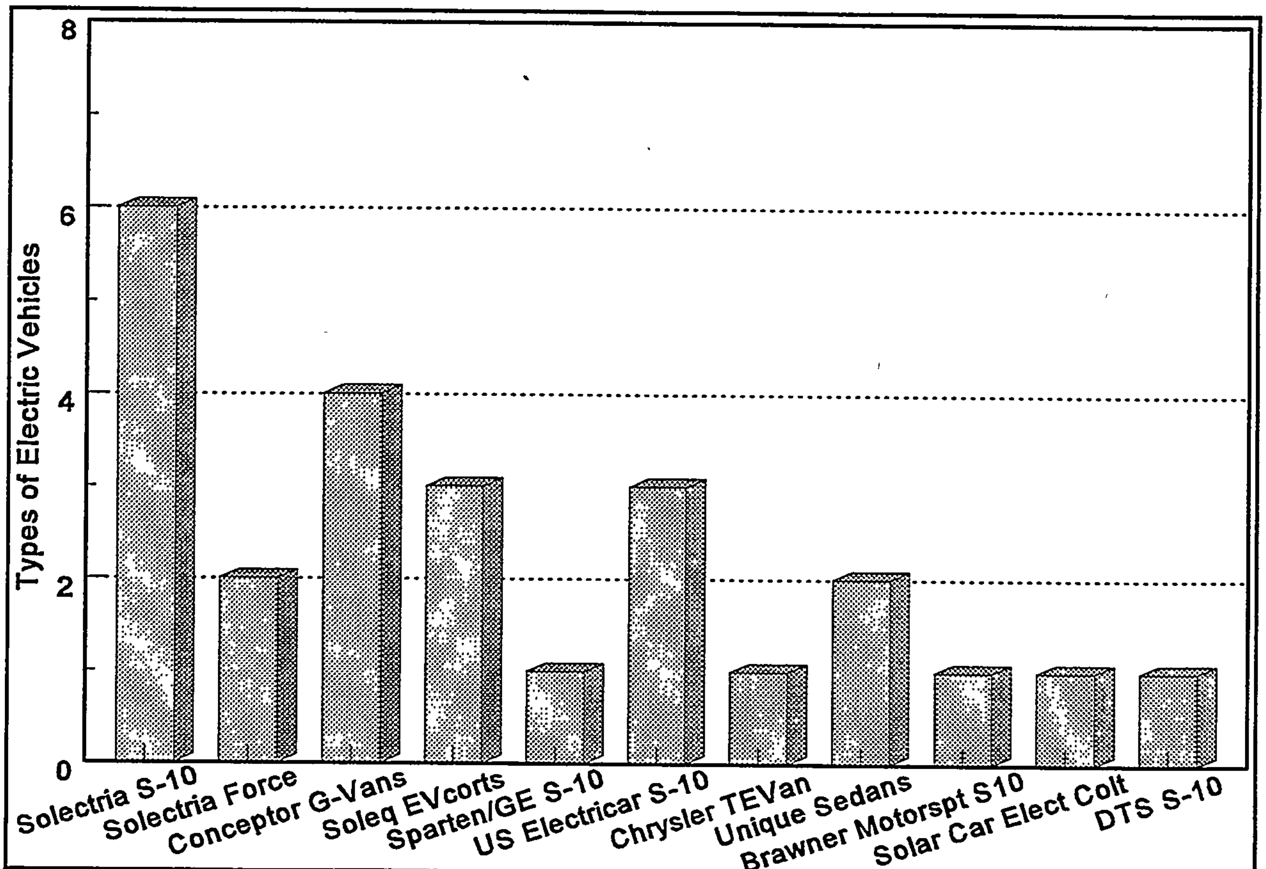

Figure 13. Number and types of vehicles in the Arizona Public Service EV fleet.

Table 4. Availability and miles driven for the months of October, November, and December. The eleven vehicles, which are Arizona Public Service's newest EVs, are all 1995 models. (n.a. indicates the information was not available.)

			Availability			Miles driven		
	Battery	Pack miles	Oct. (%)	Nov. (%)	Dec. (%)	Oct. (miles)	Nov. (miles)	Dec. (miles)
Solectria Force APS #124	Ovonic NiMH	3,993	100	100	100	1830	953	1210
Solectria S-10 APS #130	Hawker	2,941	100	100	100	1232	513	1196
Solectria S-10 APS #131	Hawker	1,088	100	100	100	929	44	115
Solectria S-10 APS #132	Hawker	619	45	100	100	573	1	45
Solectria E-10 APS #133	Hawker	8,819	100	80	100	569	328	430
Solectria E-10 APS #134	Hawker	4,025	71	57	87	170	139	139
Solectria E-10 APS #135	Hawker	0	100	43	0	323	202	0
Spartan S-10 APS #136	GNB	734	48	77	94	152	276	306
US Electricar APS #137	Hawker	14,661	94	100	97	2098	3060	1000
US Electricar APS #138	Hawker	3,718	100	33	87	103	186	293
US Electricar APS #139	Hawker	3,525	100	97	100	354	108	283

The time required, and the types of fleet maintenance and upgrade requirements performed on these "new" vehicles during the reporting period are listed below by their APS vehicle numbers:

APS #132 Out of service for 17 days for a vehicle upgrade.

APS #133 Out of service for six days during November for the replacement of 5 failed battery modules. The materials cost $550, and the labor requirements were 8 hours.

APS #134 Vehicle upgrade for 9 days during October and 13 days during November. The vehicle required 4 days for the removal and replacement of the motor during December.

APS #135 The vehicle was out of service of 17 days during November and the entire month of December for the replacement of the battery pack.

APS #136 Vehicle upgrades during the reporting quarter. Note: the battery pack was replaced during the month of September.

APS #137 The 12 volt auxiliary battery was replaced during October at a material cost of $80 and a labor requirement of 1 hour. One traction battery was replaced during October at a material cost of $110 and a labor requirement of 2 hours. During December, 3 traction battery modules were replaced at a material cost of $330 and a labor requirement of 4 hours. Note: 6 battery modules were replaced during January 1995.

APS #138 The vehicle's heater and hose required replacement during November and December. The total material cost was $1,324, the labor requirement was 21 hours, and nine days were required that included waiting for parts. Sixteen days for vehicle upgrades during November.

APS #139 One day was required for a vehicle upgrade during November.

Table 5. Maintenance costs and miles driven for the months of October, November, and December. The 14 vehicles are considered as members of Arizona Public Service's "old" EV fleet.

	Battery manufacturer	Labor man hrs	Labor cost	Part(s) cost	Total cost	Miles driven	Odometer reading
Unique sedan APS #100	GNB	0	0	0	0	0	16,895
Conceptor G-van APS #102	Trojan	4	$92	$7	$99	355	15,145
Conceptor G-van APS #103	Sonnenschein	0	0	0	0	320	19,887
Solectria Force APS #104	Hawker	183	$4209	$1146	$5355	229	14,580
Solar Car Sedan APS #105	GNB	0	0	0	0	10	6,551
DTS S-10 APS #114	Trojan	0	0	0	0	157	8,853
BMS S-10 APS #115	Hawker	Vehicle incomplete			-	-	n/a
Chrysler TEVan APS #116	SAFT	0	0	0	0	631	8,270
Unique sedan APS #298	GNB	0	0	0	0	0	37,471
Soleq EVcort APS #300	Sonnenschein	2	$48	$25	$73	0	23,385
Soleq EVcort APS #301	Sonnenschein	0	0	0	0	622	30,538
Soleq EVcort APS #302	Sonnenschein	0	0	0	0	0	16,130
Conceptor G-Van APS #3045	Trojan	0	0	0	0	0	9,917
Conceptor G-Van APS #3051	Trojan	0	0	0	0	164	9,481

Kansas State University

The Kansas State University (KSU) Site Operator Program is conducted at Manhattan, Kansas, in conjunction with the Kansas Electric Utilities Research Program (KEURP). The KEURP effort is a contractual joint venture of the seven major electric utilities that serve the residents of the State of Kansas; its mission is to undertake applied research and development to enhance reliability and minimize the cost of electric service in Kansas. Several industrial organizations within the state provide technical and financial support to the KSU Electric and Hybrid Vehicle demonstration program.

The KSU Site Operator Program is currently based on two Soleq EVcort electric vehicles, maintained at the KSU campus and available for demonstration purposes on short-term loan to interested utilities and other companies. Further use is routine transportation by the Program and the Engineering Technology Department, under differing weather and driving conditions. Four Ford Ranger EV pickups have been ordered from The Troy Design and Manufacturing (TDM) Company. The first vehicle was delivered during December, and vehicle use will commence as soon as the vehicle is properly insured and licensed. This EV is owned by Western Resources and operated by KSU.

The TDM, with assistance from KSU, has started construction of a plant to convert Ford Ranger (pickups) gliders into EVs and other alternate fuel vehicles in Manhattan, Kansas. Kansas State University has entered into an agreement to assist the TDM in supporting the infrastructure and technical development for these vehicles.

Technical

The EVcort, DOE number 151, was driven 1,387 miles during the October, November and December quarter (Table 6). Assuming a price of $0.056 per kWh for electricity, and an equivalent 25 miles per gallon for an internal combustion engine 1993 Ford Escort, the cost of operating the EVcort on electricity equates to $0.96 per gallon of gasoline. This is an increase of about $0.10 per gallon of gasoline over the last reporting quarter. This increased operating cost can be attributed to increased use of the heater and lower battery efficiency during the colder October, November and December quarter. This vehicle was operated without incident during this quarter.

The second EVcort, DOE number 152, was driven 449 miles during the October, November and December quarter (Table 6). Assuming a price of $0.056 per kWh for electricity, and an equivalent 25 miles per gallon for an internal combustion engine 1993 Ford Escort, the cost of operating the EVcort on electricity equates to $1.33 per gallon of gasoline. Its efficiency is lower than vehicle 151 because the 152 vehicle is kept in a garage and its preheat feature is used more often.

EVcort 152 experienced a total loss of power when one of the lead battery cable terminals in the rear battery tray overheated and melted open. The failure was caused by a buildup of corrosion between the heavy wire cable and the molded lead terminal. Inspection of the remaining cables revealed that other cable failures were imminent during high current levels which cause heating of the terminals. Soleq (vehicle manufacturer) provided a replacement cable and they have begun production of a new type of cable to be retrofitted on the two Soleq vehicles. The two front tires showed excessive wear due to the increased weight of the vehicle propulsion system conversion, and these tires were replaced.

Table 6. Operations summary for Kansas State University's two Soleq EVcorts.

	Miles	Daily Miles	Number of charges	Miles per charge	kWh used	mi/kWh
EVcort # 151						
This quarter	1387	16.1	86	16.1	951	1.46
Vehicle total	8,662	17.1	507	17.1	5380	1.61
EVcort # 152						
This quarter	449	7.1	63	7.1	428	1.05
Vehicle total	4,601	13.3	345	13.3	3,163	1.45

Public Awareness

A presentation was given to the Shawnee, Kansas High School advanced physics class during their visit to KSU. The students were taken on a short ride after the presentation.

One of the EVcorts was transported to the Fort Worth, Texas area and it was demonstrated to area utility companies and state officials. The interest shown in EVs by the Texas utility companies is significant, given their well documented history of supporting petrochemical sources for vehicle propulsion.

The program manager was interviewed by a local radio station to discuss EVs and hybrid vehicles, as well as the TDM's construction of a automotive conversion plant in the KSU area. The interview tape was provided to other Kansas radio stations.

An EV presentation was made to the local Optimists Club.

Other Electric Vehicle Activities

A program member visited the TDM's Detroit plant were the EV rangers are being built. He was shown how to install the data acquisition equipment on the Rangers for performance evaluation.

Los Angeles Department of Water and Power

The Los Angeles Department of Water and Power (LADWP) is a municipal utility serving the citizens of Los Angeles. LADWP marked its eighth year of involvement in aggressively promoting the electric transportation agenda of Los Angeles' overall air quality improvement program and as a means of improving the region's economic competitiveness through the creation of new industries. LADWP currently operates twenty electric vehicles (Figure 14). LADWP's electric transportation program extends beyond vehicle deployment to include infrastructure, public transit development, public education and awareness, and regulatory activities.

Technical

US Electricar S-10 Pickups

Tests performed on the five pickups continued to show a range of 55 to 60 miles under normal operating conditions. Some battery degradation has occurred, resulting in reduced range. A complete charge takes approximately 21 kWh of energy and about seven hours. The pickups logged over 1,600 miles during the reporting quarter. The maintenance requirements for the pickups included:

- Original MDAS voltage sensors were replaced with new isolated voltage sensors

- One of the MDAS units was upgraded to include an AC power sensor and an inclinometer/accelerometer to provide improved evaluation of the pickup's operating efficiency

- Loose wiring connections which caused vehicles to fault were repaired.

Chrysler TEVans

LADWP reports that the reliability of the four TEVans has improved slightly with the installation of upgraded motor controllers and the vehicles logged over 1,100 miles during the reporting quarter. Several problems were encountered and fixed, including:

- Failure to shift properly, requiring transmission cable adjustment

- Leaking battery watering systems required repairs

- Inaccurate state of charge gauge which results in low battery indication

US Electricar Sedans

These five vehicles continued to maintain a 50 to 55 mile range under a variety of driving conditions. A full charge continues to take 6 to 8 hours and require 17 kWh of energy. The sedans logged over 2,700 miles during the reporting quarter. One of the sedans is used as an employee car pool and the other four vehicles are used for fleet applications. The sedans had the following maintenance activities:

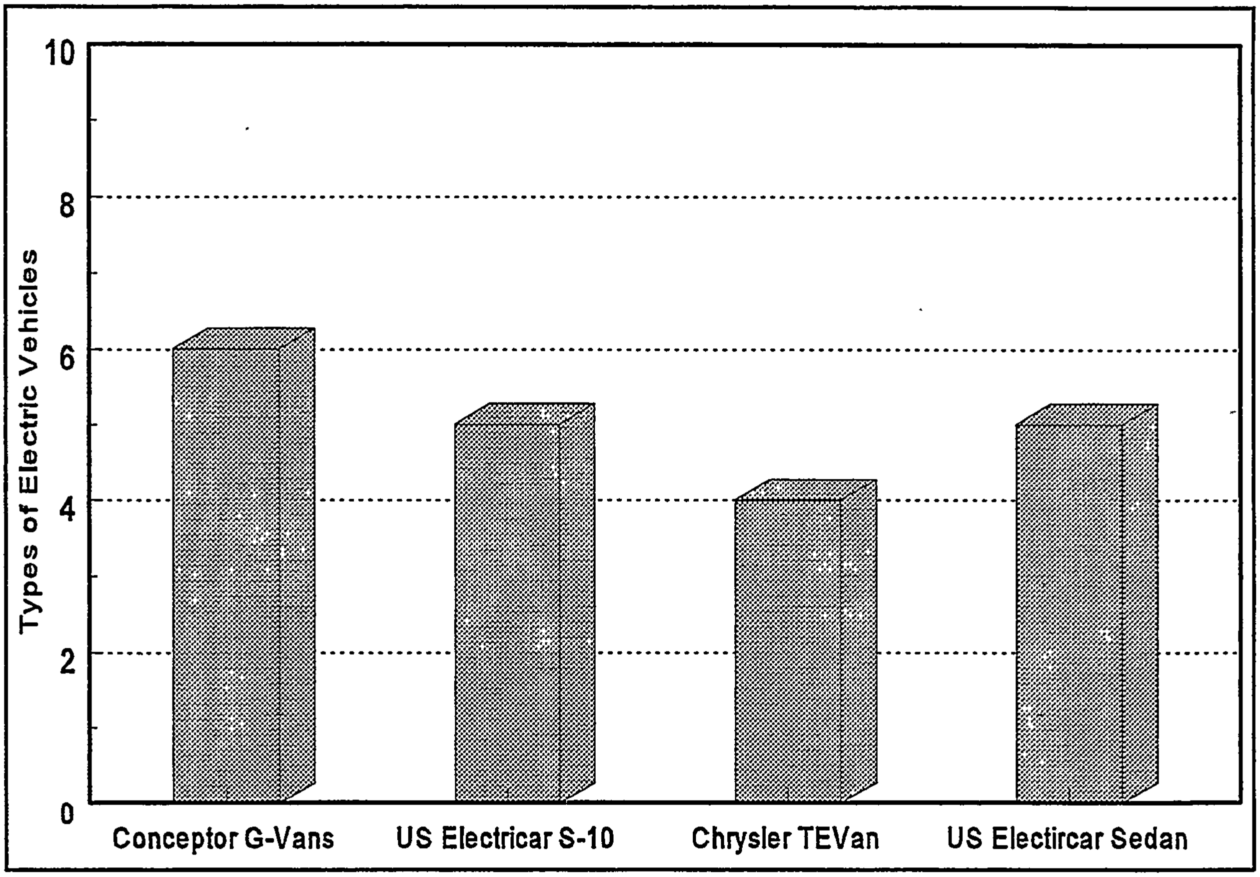

Figure 14. Number and types of vehicles in the Los Angeles Department of Water and Power EV fleet.

- MDAS data acquisition systems were installed on two of the sedans
- US Electricar provided power steering noise reduction kits were installed
- Unexpected fault conditions caused vehicles to suddenly lose power while in operation, requiring adjustment of controls
- Battery degradation caused the range on some of the sedans to be less than 40 miles until defective batteries were replaced.

Other Electric Vehicles

LADWP continued to support the maintenance and operation of the six G-Vans. Two of the G-Vans are being operated at Los Angeles International Airport (LAX), and four are operated in LADWP's fleet. The Unique Mobility minivan is still not operational.

LADWP continued to support the operation of three 22-foot electric shuttle buses in the San Pedro Harbor area and one 31-foot electric bus at LAX. During the October, November and December reporting quarter, the three 22-foot shuttle buses consumed a total of 12,400 kWh of energy, logged 9,892 miles, and carried 11,268 passengers.

Public Awareness

Public awareness and education focused on several areas, including:

- Providing displays at several California Air Resource Board hearings
- Posted various articles in industry journals and community papers
- Provided community outreach using electric transportation displays at different events throughout the city.

Orcas Power and Light Company

The Orcas Power and Light Company (Orcas) of Eastsound, Washington, operates a Ford Escort that was converted to an EV by Jet Industries, and one Solectria Force EV as part of its participation in the Site Operator Program. This electric utility serves customers in the islands of San Juan County, Washington. Orcas is actively encouraging EV ownership/operation by both public demonstrations and enlarging the necessary infrastructure with additional EV charging stations. San Juan County now has five public EV charge stations. There are a total of 13 electric vehicles (11 private + 2 Orcas EVs) operating in the county.

Technical

Orcas reports driving their two EVs a total of 290 miles for the period. The mileage efficiency for Orcas' Escort was 0.63 miles per kWh and for Orcas's Solectria Force the efficiency was 2.9 miles per kWh (Table 7).

Table 7. Orcas Power and Light Company's vehicle performance profile.

Vehicle	Total Miles Driven	Miles per day driven	Miles per month	Average kWh/mile	Average Miles/kWh
Ford Escort	42	0.7	14	1.6	0.63
Solectria Force	247.5	4.1	82.5	.35	2.9

Public Awareness

A research project, titled *Estimating the Potential for Electric Vehicles in Rural Cooperatives*, is being conducted by Q4 Associated for the National Rural Electric Cooperative Association. During October, survey materials and software were received at Orcas; the survey has been sent to 500 of Orcas' randomly selected accounts. It is expected that this survey will be well received and the response rate will be high, given the high visibility of EVs in San Juan County.

Orcas has ordered a booklet titled *Electric Vehicles: A Moving Story*, for dissemination to it customers. The booklets address various EV-related issues, including: how they work, performance, economics, reduced emissions and pollution, energy efficiency, batteries, reduced dependance on foreign oil, and battery and charging operations. The booklets direct the reader to obtain additional information about EVs from various national organizations such as the Edison Electric Institute.

Pacific Gas and Electric Company

Pacific Gas and Electric Company (PG&E), a public utility based in California's Bay Area, currently has 17 vehicles in its fleet of EVs (Figure 15). The overall program effort relates to many broad areas of interest in addition to vehicle testing and performance evaluation, including:

- Infrastructure R&D is concerned with charging systems, and their load and distribution impacts.

- Joint efforts with the Bay Area Rapid Transit (BART) District reflect the benefits of increased usage of public transportation in the Bay Area.

- Collaboration with EPRI and the Electric Vehicle Association of the Americas is directed toward increased public awareness of EV technologies and benefits.

- Cooperative efforts with California universities and other utilities are studying demand-side load management.

- PG&E is actively involved in the California Electric Vehicle Task Force, concerned with issues affecting EV commercialization. Other Task Force members represent utilities, private industry, and state regulatory agencies.

- PG&E is also participating in the efforts of the Infrastructure Working Council, a subgroup of EPRI. The membership of this organization represents automakers, utilities, code specialists, and other EV stakeholders; with the goal of a standard, safe, and reliable EV charging infrastructure.

- PG&E is a member of CALSTART, a consortium of more than 40 public and private entities mobilized to create an electric transportation industry in California, and to address related issues.

Technical

PG&E's five Ecostars, which use sodium-sulfur batteries, report a consistent range of 90 to 100 miles and top speeds of 70 to 72 mph. The Ecostars are used by meter readers, customer service representatives, electrical inspectors, parts delivery personnel, and commuting employees. During the reporting period, the Ecostars had three battery failures, connector failures and lower PEC failures.

While the three Hondas have been only getting 35 to 40 miles per charge, they have demonstrated an excellent reliability record. The vehicles operated with no failures during the reporting period. The Hondas have been used for marketing calls and short trips in the San Rafael, Concord, San Francisco, and San Luis Obispo areas.

The five US Electricar S-10s had been used for meter reading, parts pickup, and other missions, but fell into disfavor with PG&E drivers, who consider them unsafe to drive as the S-10s can not achieve speeds above 35 mph. Charging times have proved too long to be practical and the current positioning of the ground fault circuit interrupter on the vehicles potentially leaves the driver at risk to electrical shock. The vehicles are inoperable until modifications can be made.

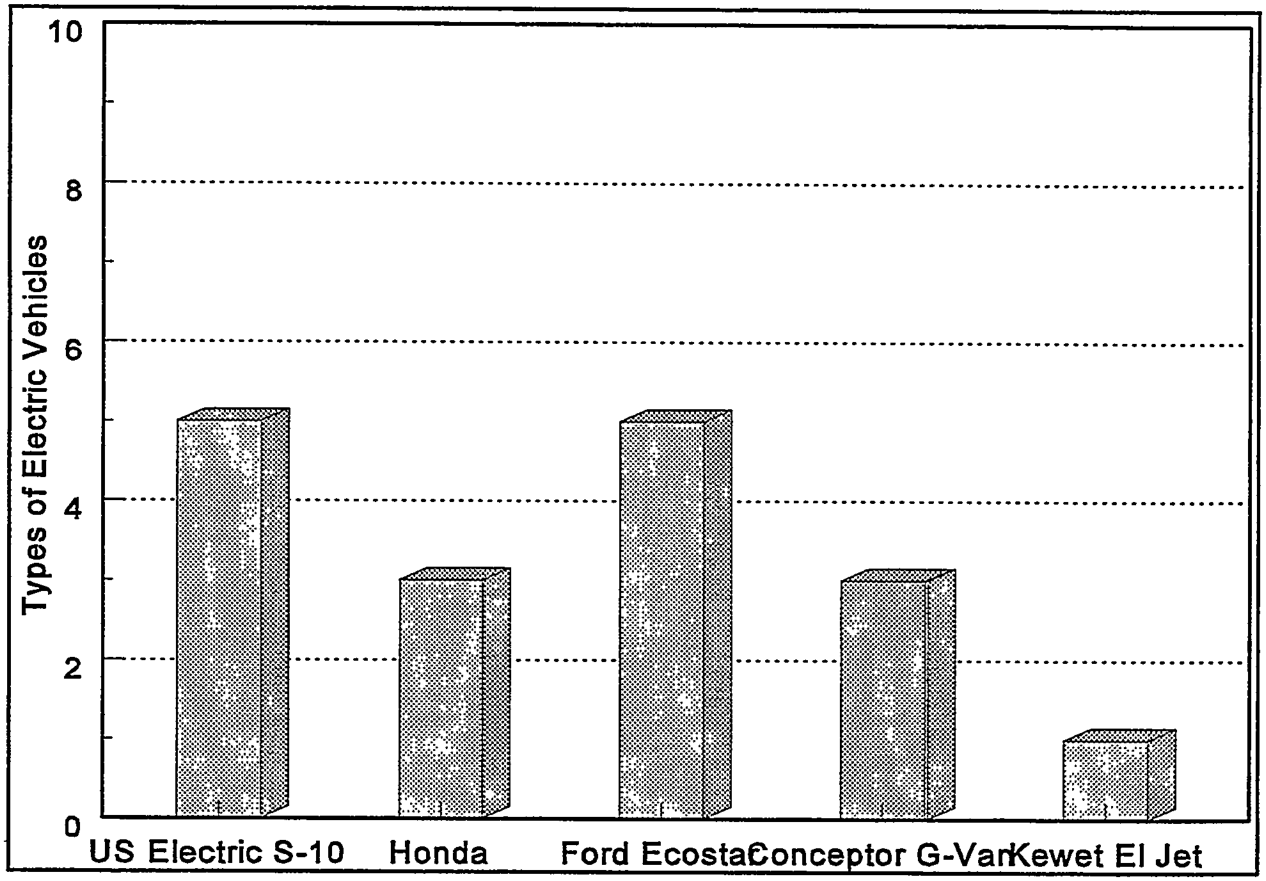

Figure 15. Number and types of vehicles in Pacific Gas and Electric's EV fleet. fleet.

PG&E possesses three electric G-Vans. Two are in San Luis Obispo, where they are used for Phase 3 of the rapid battery interchange project with Cal Poly State University. The third G-Van remains at PG&E's San Ramon R&D Facility; the motor is out of the vehicle and there are no current plans to return the vehicle to operating condition.

The Kewet El Jet remains at the San Ramon R&D facility, inoperable due to dead batteries. PG&E is currently negotiating an arrangement with Green Motor Works to provide vehicle maintenance service in exchange for new batteries for the Kewet.

PG&E also has four electric buses. A 22-foot Specialty Vehicle Manufacturing passenger bus is currently on loan to the City of San Luis Obispo. This bus is used as a lunchtime shuttle and a group transport by arrangement. A 22-foot U.S. Electric bus is located in Fresno and used for similar purposes. Two other buses, a 31-foot Specialty Vehicle bus and a 35-foot APS Systems bus are in Yosemite National Park as part of the shuttle bus demonstration project.

Public Awareness

PG&E's outreach efforts include loaning electric cars and buses to various communities; providing literature and vehicles at regional Ride & Drives; and making presentations at schools, Earth Day events, and other events as invited.

PG&E is a co-sponsor of the Rapid Battery Interchange Program at California Polytechnic, which is a demonstration of the rapid automated exchange of battery packs. The fully automated sites are intended to function much like conventional service stations. "Refueling" occurs in a matter of minutes through exchange of the vehicles's used battery packs for new, fully-charged battery packs. Phase 3 of the Program, a full-scale multi-vehicle road test, began during the reporting quarter.

Other Electric Vehicle Activities

PG&E is working with the Bay Area Air Quality Management District and other groups to demonstrate "station cars." These cars are leased to local business employees to be driven between their residences and Bay Area Rapid Transit (BART) stations, between BART and work, and for running daytime errands. Leasing costs are estimated at $100 to $150 per month plus insurance; maintenance and emergency road service are included in the fee. The project employs a Norwegian car, the Citi by Personal Independent Vehicle Co. (PIVCO). Nine vehicles are currently in operation; most are leased by employees of SyBase, an Emeryville software firm participating in the demonstration. The demonstration will include a total of forty vehicles by June 1996.

PG&E has installed charging stations at the Ashby BART station in Berkeley to provide 120 volts or 208 volts charging for up to 19 vehicles. Battery charging can also occur at home. Additional demonstrations will take place at two other BART stations. Work to accommodate the PIVCO vehicles at the Walnut Creek BART station should be completed in the spring of 1996, and PG&E is seeking customers to participate in the demonstration from the newly-opened Colma BART station.

Platte River Power Authority

The Platte River Power Authority (PRPA) operates two Soleq EVcorts EVs (Table 8) as part of its participation in the Site Operator Program. The Soleq EVcorts are Ford Escort station wagon conversions. PRPA, a political subdivision of the State of Colorado, maintains and operates facilities for generation and wholesale distribution of electrical energy to four Colorado municipalities: Estes Park, Fort Collins, Longmont, and Loveland. The thrust of PRPA activities under this program is threefold:

- Evaluate the year-round performance, operational costs, reliability, and life cycle costs of EVs in the front range region of Northern Colorado.
- Evaluate an EV's usability and acceptability as a pool vehicle.
- Develop, test and evaluate, and demonstrate components to be used in charging EVs.

The vehicles are operated in a real-world environment, for personnel transportation and public demonstrations.

Table 8. Platte River Power Authority vehicle fleet description.

Vehicle	DOE No.	Battery Type	No. of Battery Modules	System Voltage	Charger Type	Charger Voltage
Soleq EVcort	355	Sonnenschein Lead Acid Gelled-electrolyte	18 (6 volt)	108	Soleq (onboard)	110
Soleq EVcort	356	Sonnenschein Lead Acid Gelled-electrolyte	18 (6 volt)	108	Soleq (onboard)	110

Technical

Both EVcorts are equipped with an onboard load profile meter that continually integrates the AC energy used for charging over every 15-minute time period; the data is stored with its corresponding time interval. All vehicle charge data is automatically captured by the meter without any action by the vehicle user. The meter data is downloaded once a month by the City of Fort Collins when the other Platte River Facility meters are read. The meter data, along with monthly vehicle odometer data, is compiled and used to produce a Quarterly Operational Summary report (Table 9), a EV Performance and Operations & Maintenance Summary report (Table 10), and a Fuel Cost Comparison Summary report (Table 11).

During the reporting quarter, vehicle No. 355 was used primarily as a pool vehicle while vehicle No. 356 was out of service for the majority of the quarter. Vehicle use decreases during the winter months. The cold winter weather in the Fort Collins area deceases the range of the vehicles, and driver comfort becomes an increasing issue since the performance of the electric heating systems in the Soleqs are marginal during the winter months.

The fuel cost for operating the EVcort is $0.014 per mile, as compared to the $0.041 per mile fuel cost for operating a 1991 Ford Escort wagon. The $0.014 value uses the City of Fort Collins small commercial electric energy rate of $0.027 per kWh (Table 10).

Table 9. Monthly summary of the onboard meter and the odometer data for the Platte River EVs. (Note: the EVcort 356 was out of service for the majority of the quarter due to controller problems. N/A signifies Data Not Available due to AC charge meter problems.

	Total Energy Usage (kWh)		Miles Driven		Miles/kWh	
	EVcort 355	EVcort 356	EVcort 355	EVcort 356	EVcort 355	EVcort 356
Oct.	256.6	n/a	450.6	7.0	1.76	n/a
Nov.	92.2	n/a	112.5	0.0	1.22	n/a
Dec.	73.6	n/a	70.9	0.0	0.96	n/a
Total	422.4	n/a	634	7	1.50	n/a

Table 10. Platte River's EVcorts variable operation and maintenance costs. The data presented is for a full one-year period, from January through December of 1995.

(12 month reporting period)					Maintenance			
	Miles	AC Charge Energy (kWh)	Energy Efficiency (miles/kWh)	Total Energy Cost at $0.0269/kWh	Labor (hours)	Labor (@$28/hr)	Parts & Service	Variable Cost ($/mile)
EVcort #355	3,609	1,841	1.96	$49.53	4	$112	$0	$0.045
EVcort #356	2,991	n/a	n/a	$n/a	10	$280	$1,208	n/a
Average	3,300	n/a	n/a	$n/a	7	$196	$604	n/a

Table 11. Platte River electric vehicle versus gasoline fueled vehicle fuel cost comparison. (Notes: a. The numbers are 12 month rolling averages; b. Fuel cost for energy only assumes vehicle charging during off-peak period; c. Fuel cost with demand charge assumes vehicle charging over peak demand period).

	Gasoline ($ per gallon)	AC demand cost ($/kW)	AC energy cost ($/kWh)	Vehicle efficiency (miles per gallon)	Veh. max demand (kW)	Vehicle efficiency (miles/kWh)	Fuel cost w/ demand charge ($/mile)	Fuel Cost energy only ($/mile)
Ford Escort	$1.14	–	–	28	–	–	$0.041	$0.041
Soleq EVcort	–	$8.01	$0.027	–	3.079	1.96	$0.221	$0.014

Soleq EVcort, DOE# 355

During the October, November and December reporting quarter, this vehicle was driven a total of 422 miles with an average total energy efficiency of 1.50 miles per kWh. The total cost of electricity for the quarter was $11.36.

Controller regeneration gain was lowered to increase stability of braking when traction batteries are nearly at full charge and controller current limit gain was lowered to increase stability at high acceleration. Modifications were performed by the manufactures on-site.

The original 13 inch tires were replaced due to excessive wear and to increase the rated load carrying capability of the vehicle. The wheels were also replaced to allow for the use of 15 inch tires. The new Michelin Energy MXV4 195/60R15 tires have a load rating of 1,235 lbs per tire at 44 psi. This increased the total rated payload capability of the tires from a approximately 400 pounds to approximately 900 pounds.

Soleq EVcort, DOE# 356

During the quarter, this vehicle was out of service for a majority of the quarter. The motor controller and the capacitor/contactor module was sent to Soleq for inspection/testing and repair. The base drive rectifier was bad and was replaced. During the period the vehicle was driven a total 7 miles. The AC charge meter would not down-load its data so the energy efficiency for the quarter is not available. The meter was sent to the manufacturer for repair.

Public Awareness

Platte River is participating as a member of the steering committee for developing the Weld/Larimer/Rocky Mountain National Park Clean Cities Program

An EVcort was loaned to the City of Longmont for events associated with Public Power Week. The EVcort was on display in a mall during the week.

Potomac Electric Power Company

The Potomac Electric Power Company (PEPCO), serving over 1.6 million people in the Washington, D.C. area, operates four EVs in the Site Operator Program. The principal vehicle use is fleet service. With the exception of one county, the entire 640 square-mile service region is classified as a serious, ozone non-attainment area, and PEPCO is considering whether to utilize EVs to meet the requirements for fleet conversion to alternative fuels.

The objectives of the PEPCO EV program include:

- Generate local interest in EVs in the Washington, D.C. metropolitan area
- Demonstrate the capability of existing and emerging EV technology to the Washington, D.C. community
- Evaluate the current ability as well as support the future development of EV components and systems to meet the challenges of fleet driving requirements
- Demonstrate PEPCO's commitment to supporting EV development and the Clean Air Act objectives
- Assist in the education of the utility industry as to the current and projected future status of EV development so that informed EV purchase decisions can be made
- Work to establish a self-sustaining market for EVs which would in turn result in higher EV reliability and lower per unit costs.

Three EVs were delivered to PEPCO during the previous quarter for integration into PEPCO's corporate fleet as part of the EVAmerica field test evaluation. Two of the vehicles are 1995 Solectria E-10's which were ordered last January under a cost share agreement with DOE. The third EV is a 1994 Solectria E-10 that was converted under the ARPA Program and assigned to PEPCO to manage. All three of these vehicles are equipped with MDAS units for data acquisition.

As a result of dated technology it was determined that PEPCO's fourth EV, a Solectria Force, would be removed from fleet service. This vehicle will either be sold or donated to a local high school.

Technical

In order to benchmark the performance of the Solectria pickups, a 10-mile course was established on the George Washington Parkway that provided a means of operating the EVs at a constant speed of 45 mpg. Each of the vehicles were run on the route several times during the quarter (Table 12). For the purpose of the evaluations, the test was considered completed when the vehicles were no longer able to maintain 45 mph on a level surface. One result of the 45 mph test was the identification of a problem with the range of the S06 vehicle. After performing a load test, it was determined by Solectria that the vehicle had six defective battery modules. Six 12 V 38 Ah Hawker replacements were provided by Solectria under the vehicle warranty.

In addition to the 45 mph range test, each vehicle is equipped with an MDAS unit for onboard data capture. The MDAS units collected performance and use data such as the per vehicle net DC energy efficiency (from 3.9 to 4.7 miles per kWh for the quarter) for the three Solectria pickups (Table 13). Charge data, such as the gross DC energy efficiency (from 2.2 to 3.4 miles per kWh for the quarter) was also collected for the three pickups (Table 14). Per vehicle mileage for each month ranged from 9.7 to 461.7 miles for the quarter (Figure 16). Measured on a monthly basis, the total miles per kWh charged for each vehicle ranged from 3.4 to 4.1 miles (Figure 17).

Solectria S-10, #S06 Maintenance Activities

- 10/27/95 Due to low range, a load test was performed on the battery pack by a Solectria representative
- 10/31/95 Auxiliary battery chargers failed and were replaced by a Solectria representative.
- 12/14/95 Consistently low range values prompt another load test of the battery pack by PEPCO personnel; six modules were detected as being out of tolerance.
- 12/19/95 PEPCO personnel replace six battery modules

Solectria S-10, #S07 Maintenance Activities

- 11/03/95 On-board 3.3 kW charger failed
- 11/07/95 Replaced charger with one shipped from Solectria
- 12/12/95 On-board charger tripping off intermittently
- 12/18/95 Replaced charger with one provided by Solectria

Solectria S-10, #S08 Maintenance Activities

- 08/15/95 Vehicle received with damaged batteries. Battery damage was discovered during installation of MDAS and appeared to be damaged from over-charging. Solectria provided a complete replacement.

Table 12. Constant speed range test results at 45 mph, for PEPCO's three Solectria S-10 pickups. Test run on a 10-mile course on the George Washington Parkway in the Washington, D.C. area.

Vehicle	Date	Range (miles)
Solectria S-10 #S06	10/17	34.5
	10/18	29.5
	10/27	66.2
	10/30	59.7
	11/10	40.3
Solectria S-10 #S07	10/15	57.8
	10/17	71.2
Solectria S-10 #S08	12/1	70.6

Table 13. Vehicle performance summaries for PEPCO's three Solectria S-10 pickups during the October, November, and December Quarter. Some data was not available (n/a) because of faulty sensors. The pickups are numbered S06, S07, and S08.

Parameters	Units	S06	S07	S08
# of days in use	days	22	21	15
Total # of trip cycles		45	54	18
Total Trip time	hours	18.4	16.1	6.0
Total time at rest	hours	2.0	2.6	0.4
Total distance driven	miles	571.8	412.8	145.0
Max. speed	mph	74.1	67.6	70.8
Average speed	mph	31.2	23.2	24.9
Max battery temp.	°C	50.3	30.2	18.7
Avg. battery temp.	°C	30.3	23.3	6.9
Total regen braking energy	Wh	20,604	18,592	n/a
Total air cond energy	kWh	5.0	3.5	2.0
Total discharge energy	kWh	122.9	106.1	34.5
Net DC energy efficiency	mi/kWh	4.7	3.9	4.2

Table 14. Vehicle charger summaries for PEPCO's three Solectria S-10 pickups during the October, November, and December Quarter. Some data was not available (n/a) because of faulty sensors. The pickups are numbered S06, S07, and S08.

Parameters	Units	S06	S07	S08
Total # of charger cycles		20	24	18
Total charge time	hours	293.8	155.8	102
Max. charge current	A	36.3	38.2	n/a
Avg. charge current	A	7.3	4.6	n/a
Max. battery temp.	°C	42.9	36.4	33.2
Avg. battery temp.	°C	27.9	25.4	20.2
Total charge energy	kWh	264.6	121.5	49
Gross DC energy eff.	mi/kWh	2.2	3.4	3
Battery pack eff.	%	46.4	87.3	70.4

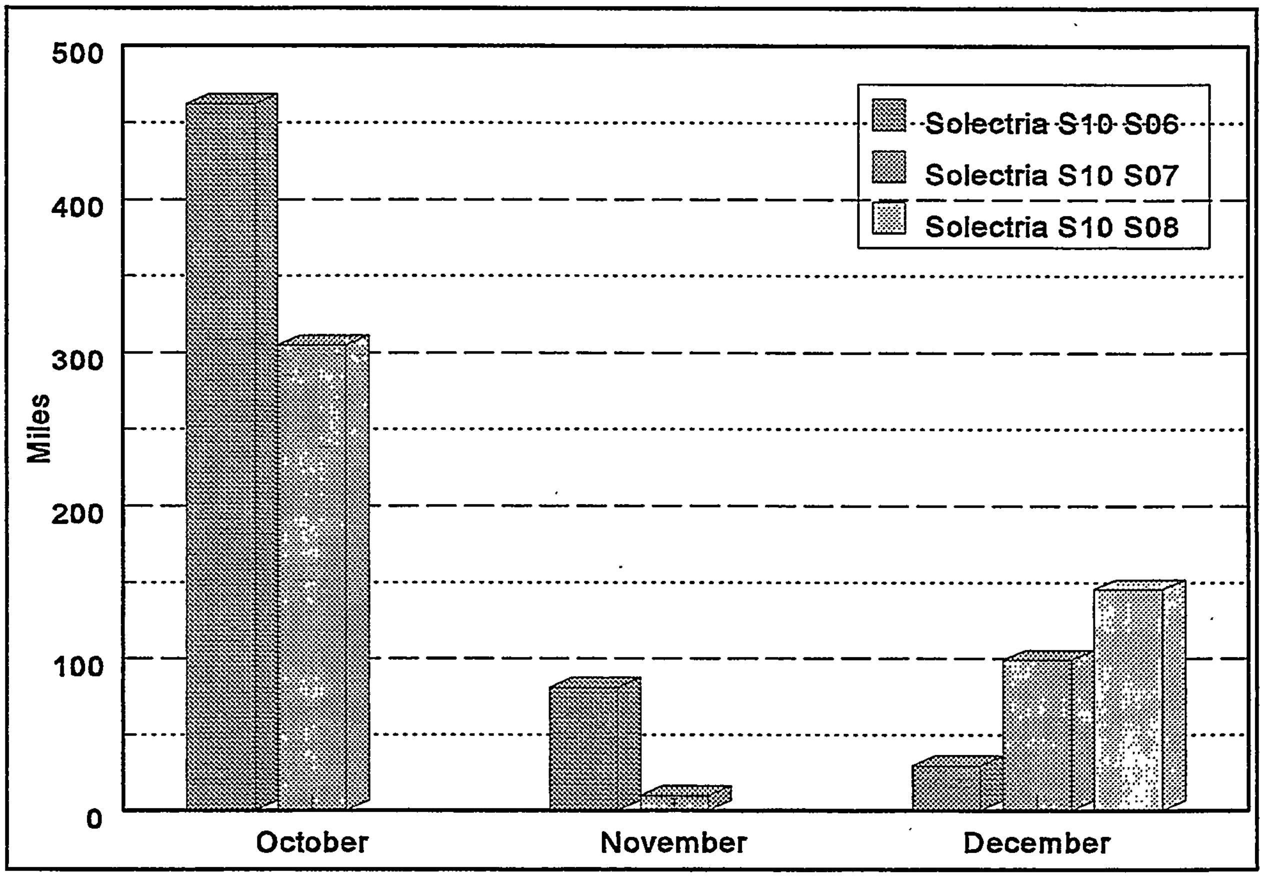

Figure 16. Total monthly vehicle miles for each of PEPCO's three Solectria S-10 pickups for the reporting quarter.

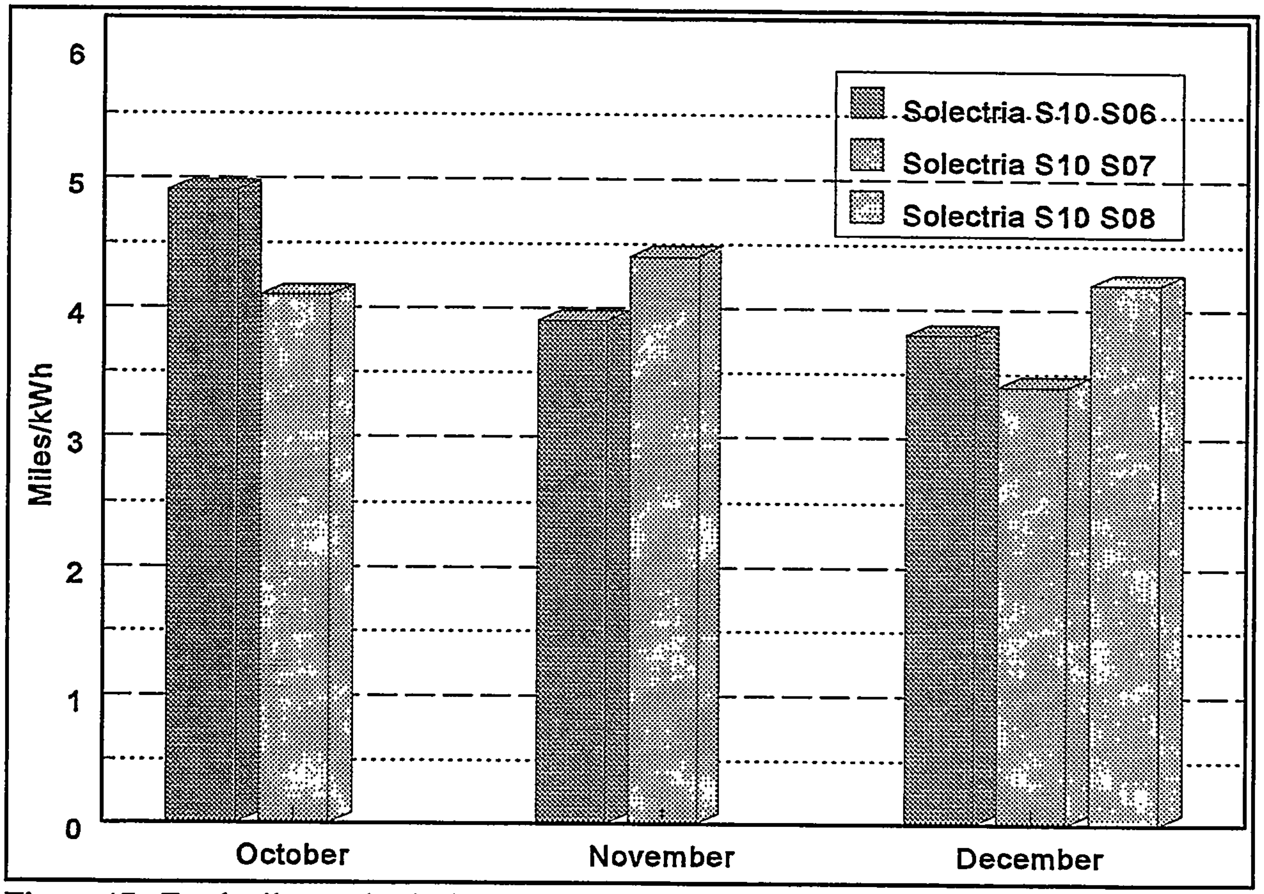

Figure 17. Total miles per kWh charged for the three PEPCO Solectria S-10 pickups, by vehicle and month.

Public Awareness

PEPCO personnel completed the following EV-related demonstrations and public awareness activities during the reporting quarter.

- Discussed the upcoming GM PreView Program at PEPCO on radio station WWRC's "Car Show" program
- Demonstrated a Solectria S-10 for the President of Costa Rica and the Assistant Secretary of Transportation
- Demonstrated the Solectria S-10 for the Washington D.C. EV Association
- Demonstrated the Solectria S-10 to SAE members at their Washington D.C. meeting
- Demonstrated the Solectria S-10 at a Fleet Manager's Conference
- Demonstrated the Solectria S-10 and made a presentation on EVs for the annual PEPCO Commercial Energy Service Conference
- Demonstrated the S-10 to Edison Electric Institute personnel
- Demonstrated the S-10 to a local explorer scout meeting
- Demonstrated the S-10 to representatives of the U.S. Generating Company.

Sandia National Laboratory

The Sandia National Laboratory provides an annual report of the operations of its 12 EVs to the DOE Site Operator's program once a year. (This summary covers Sandia's operating experience for the 1995 fiscal year – October 1, 1994 to September 30, 1995). The 12 Electricas EVs were manufactured by Jet Industries during the early 1980s. Information about the Sandia program can be find in the December 1995 and March 1996 versions of the Site Operator Program Quarterly Progress Reports on the WWW.

Southern California Edison Company

Southern California Edison Company (SCE), an electric utility, currently operates and maintains 63 EVs as part of its participation in the Site Operator Program (Figure 18). Out of the 63 EVs, ten are considered inactive for reasons such as the installation of a new battery pack; the pending donation or sale to other organizations; receiving pack conditioning, warranty work, or upgrades; or they may be awaiting reassignment to another SCE organization. During this reporting period the 53 "active" EVs were driven a total of 31,792 miles, they averaged 600 miles per EV for the reporting period, and they averaged 46 miles per EV per week. SCE is also awaiting the delivery of a second TDM Ranger, two Solectria Forces, and an AC Propulsion Honda CX sedan. The SCE urban, semi-urban, and rural fleet applications for their EVs include:

- Meter Readers
- Field Service Representatives
- Service Planners
- Managers/Supervisors
- Mail Routes
- Pool Cars

The SCE EV effort involves major roles in electric vehicle and component testing/evaluation, battery technology development, recharge infrastructure development, demand-side management, and overall technological leadership in meeting the air quality and transportation requirements of the area.

In filling the final role, SCE shares its technical expertise and test results with two California regulatory agencies: The South Coast Air Quality Management District and the California Air Resources Board. The results of this continuing cooperation can be seen in the electric shuttle operated by several Southern California cities and technical assistance in feasibility studies of truck and bus conversions.

SCE also provides support at many levels to the CALSTART program, which is intended to position California "high tech" industries in a leadership role as developers and suppliers of EV-related products. In the Site Operator Program, CALSTART's participation ranges from battery recycling processes and vehicle/infrastructure testing, to promoting public interest in zero-emission vehicles.

The Research, Development, and Demonstration Department of SCE has the primary responsibility for carrying out the tasks covered by the Site Operator Program. In turn, it has access to the necessary corporate resources and facilities/manpower.

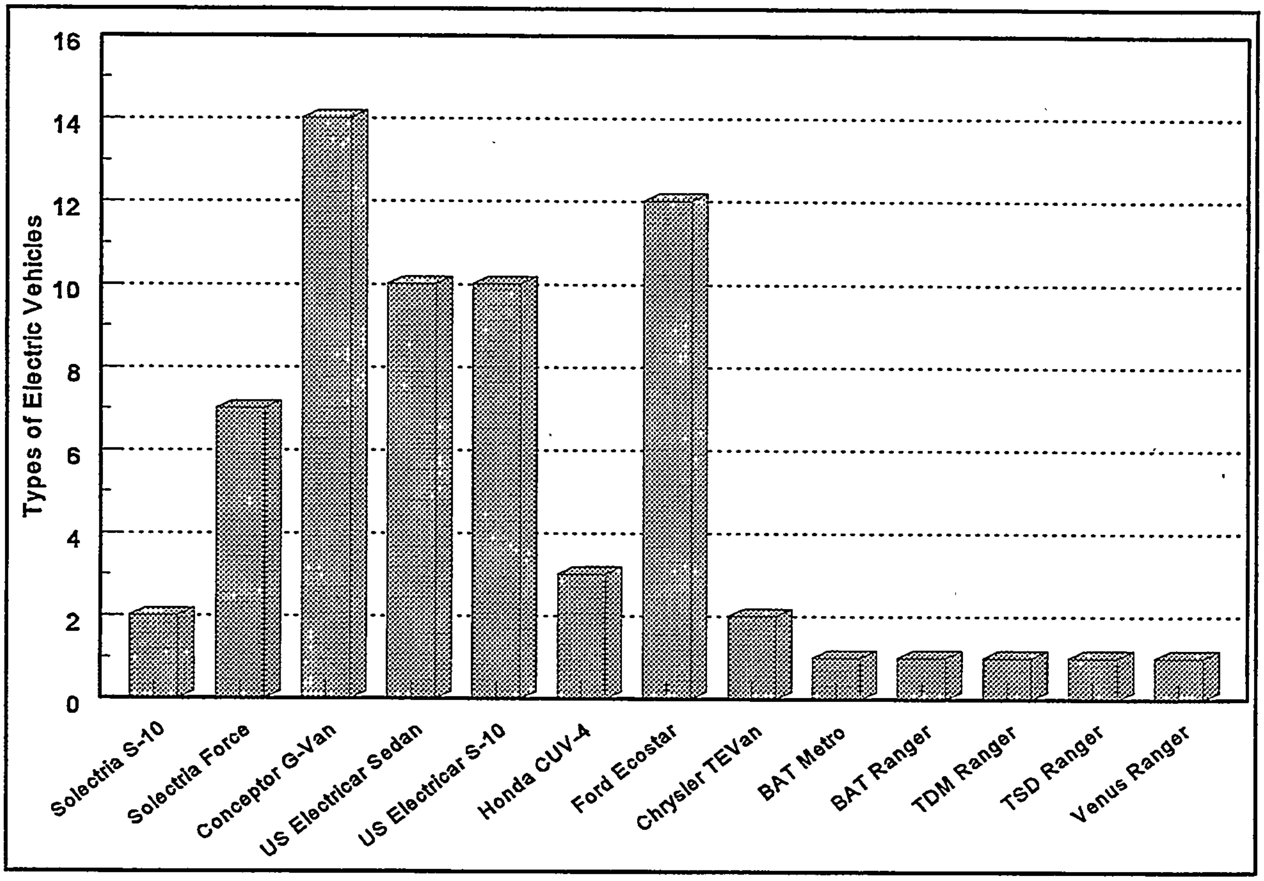

Figure 18. Number and types of vehicles in the Southern California Edison Company EV fleet.

Technical

SCE has implemented their own data acquisition system (DAS) in several SCE vehicles. The DAS consists of an "Alpha" kilowatt-hour meter and a "Silent Witness" trip logger. The SCE DAS measures fleet operations performance metrics such as miles per vehicle, miles per AC kWh, miles per trip, and recharge time and time of use. To date, 28 SCE vehicles have been equipped with this DAS system and most of SCE's remaining vehicles will be so equipped. The SCE instrumented fleet includes three Conceptor G-Vans, five Solectria Force sedans, one Solectria S-10 pickup, nine US Electricar sedans, six US Electricar S-10 pickups, three Honda CUV4 sedans, and a Chrysler TEVan. SCE also continues to use the factory supplied data system for the Ford Ecostars. Most of the SCE EVs are equipped with lead acid batteries, except for a G-Van which uses a Nickel Cadmium battery pack, a US Electricar S-10 which uses nickel metal hydride batteries, and the Ford Ecostars which use sodium sulfur batteries.

The SCE EV fleet has a combined total mileage of almost 400,000, with two vehicles having over 20,000 miles of use. Several other EVs have also accumulated over 15,000 miles each (Figure 19). The variation in monthly usage is high, with ten vehicles reporting over 1,000 miles of use during the latest three month reporting period (Figure 20).

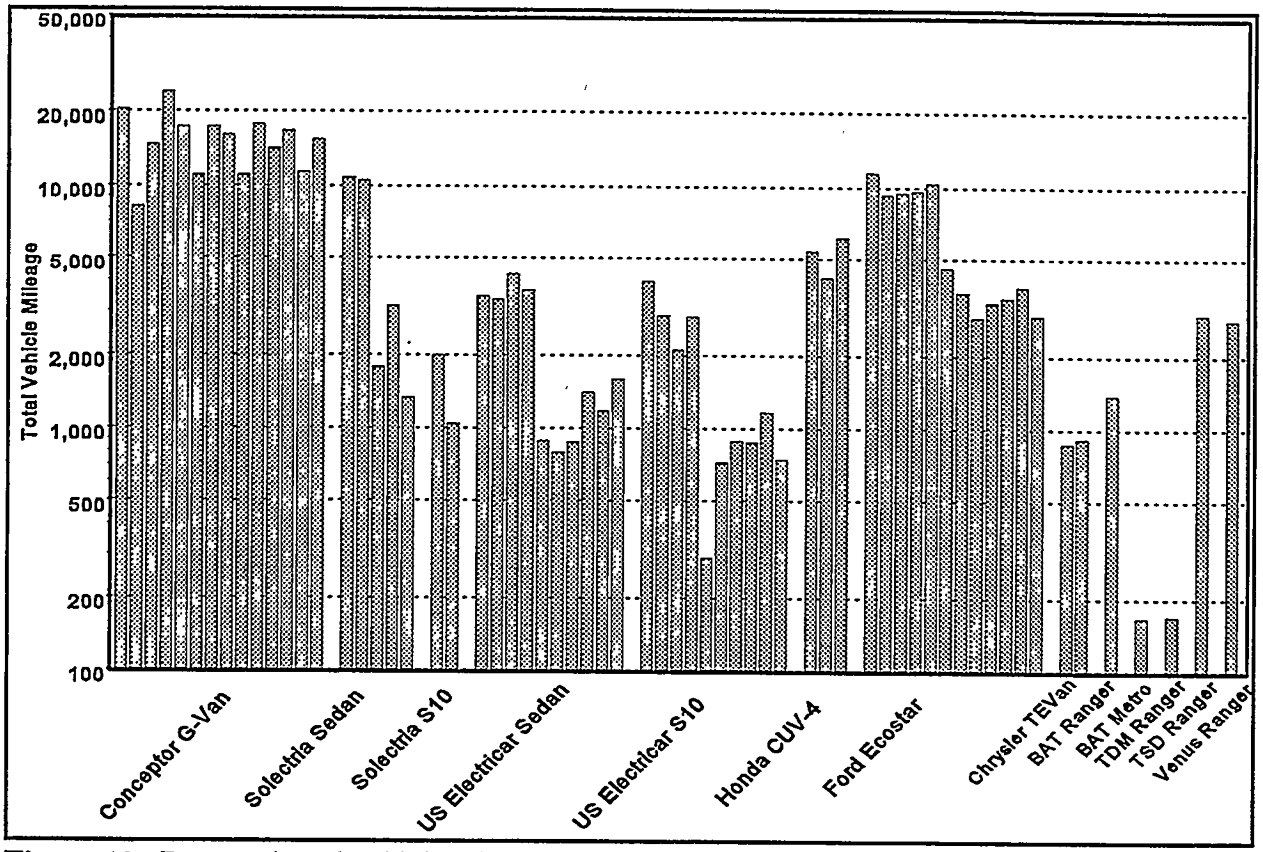

Figure 19. Reported total vehicle miles for each of Southern California Edison EVs as of December 30, 1995. The Evs are grouped by vehicle model, for instance, there are three (3) Honda CUV-4s, with about 5,000 total miles on each vehicle.

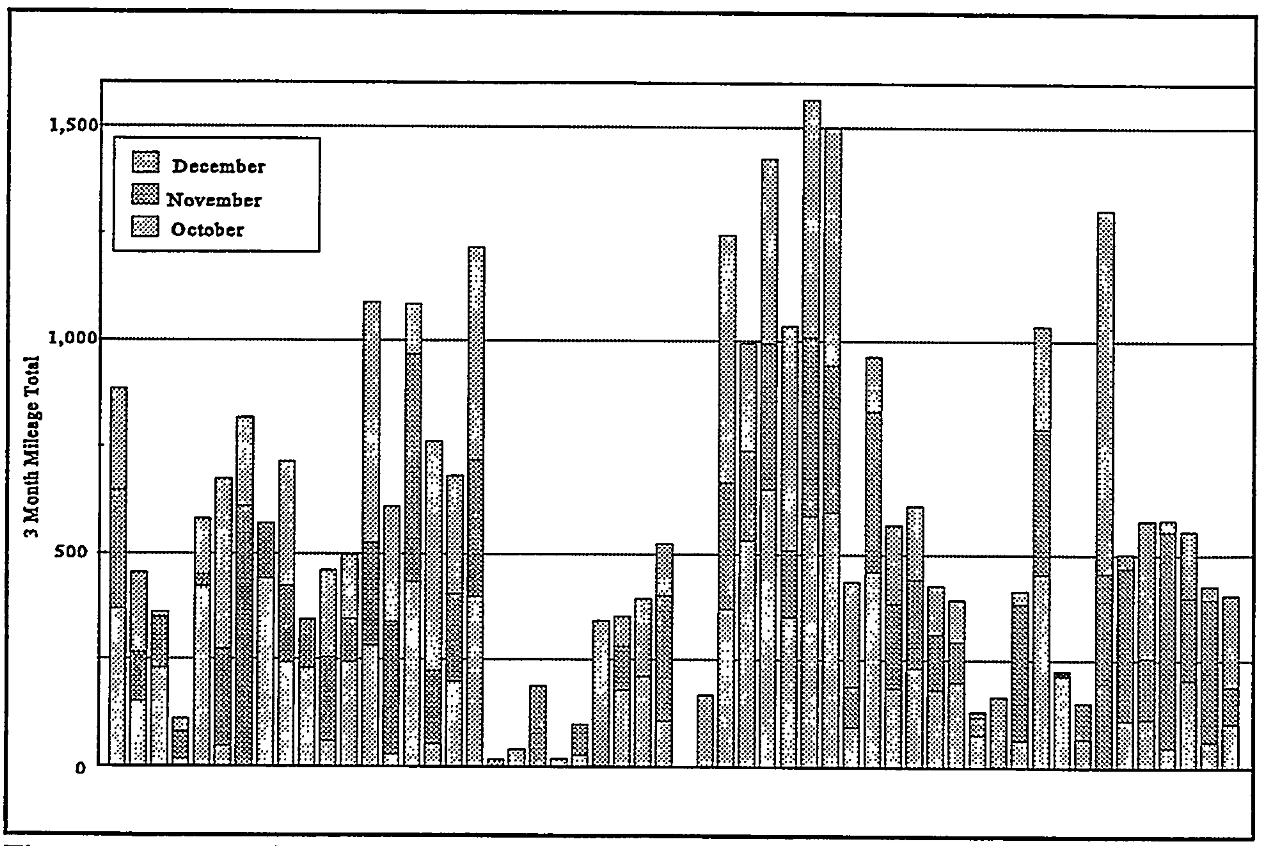

Figure 20. Reported mileage for SCE EVs during the 1995 months of October, November, and December.

Texas A&M University

Texas A&M University (TAMU) has been actively involved in the research, development and demonstration of EVs and hydrogen fuel cells. The Center for Electrochemical Systems and Hydrogen Research, with the help of the South Central Electric Vehicle Consortium (SCEVC) and DOE, has demonstrated and field tested 30 EVs (Figure 21) which have jointly accumulated over 140,000 miles and made over 150 presentations and demonstrations.

Technical

During the reporting quarter, TAMU reports that their three US Electricar trucks did not experience any significant problems beyond their usual charger and battery failures. The vehicles experience lower ranges due to the heaters being in use due to the winter temperatures. One of the US Electricar (DOE #628) had 3 monoblocks fails. These were replaced and a new charging algorithm recommended by Hawker was also installed on the inductive charger. This will provide a four-hour equalizing charge to the batteries.

Another US Electricar pickup (DOE #627) experienced charging (inductive charger) and air-conditioning problems which were fixed by the local Hughes distributor. In the process it was discovered that the conductive charger only provided a 20-mile range, and that the auxiliary battery was discharged during the main battery pack charging.

An incident of significance occurred to a US Electricar S-10 pickup truck owned by the City of Farmers Branch, Texas. This vehicle, which is also fitted with an inductive charging system, was experiencing a range problem. The batteries were removed, tested, and replaced. In doing this, the technician failed to notice a critical minuscule difference in the length of the bolts used to tie down the solid battery jumpers. Consequently, some bolts bottomed out without tightening the jumper to the posts. The vehicle was cycled a couple of times, and one Saturday morning, after a full charge, it was driven 0.2 miles from the garage. A loud explosion took place in the battery box when the operator used the brakes. No one was hurt, but the battery box lid tore off from the retaining bolts and warped the truck bed. Upon investigation, it was discovered that a loose jumper in the lower battery row and had burned holes in three other batteries sitting on top of it. This jumper was tightened with a bolt of the wrong length which had bottomed out before the jumper and the battery post made a good contact. It is obvious that after a complete charge there was hydrogen present in the battery container, but it is not clear what the source of ignition was. However, there are two most likely scenarios: either the loose jumper got hot enough first on discharge and then on the recharge (regen current) and ignited the hydrogen or, when the brakes were applied to the vehicle the movement of the batteries caused a spark at the loose jumper which ignited the hydrogen. This incident has shaken the confidence of the operators. The vehicle has been shipped to US Electricar for further analysis and repairs.

TAMU has inspected its DOE vehicles for similar problems and some loose jumpers were discovered. The reason for the loose jumpers appears to be excessive vibration and the movement of batteries due to acceleration and braking. TAMU suggests that owners and users of this type of vehicle should consider the following precautionary measures:

- Battery boxes should be fitted with fan-forced air circulation to function at the time of charges and discharges

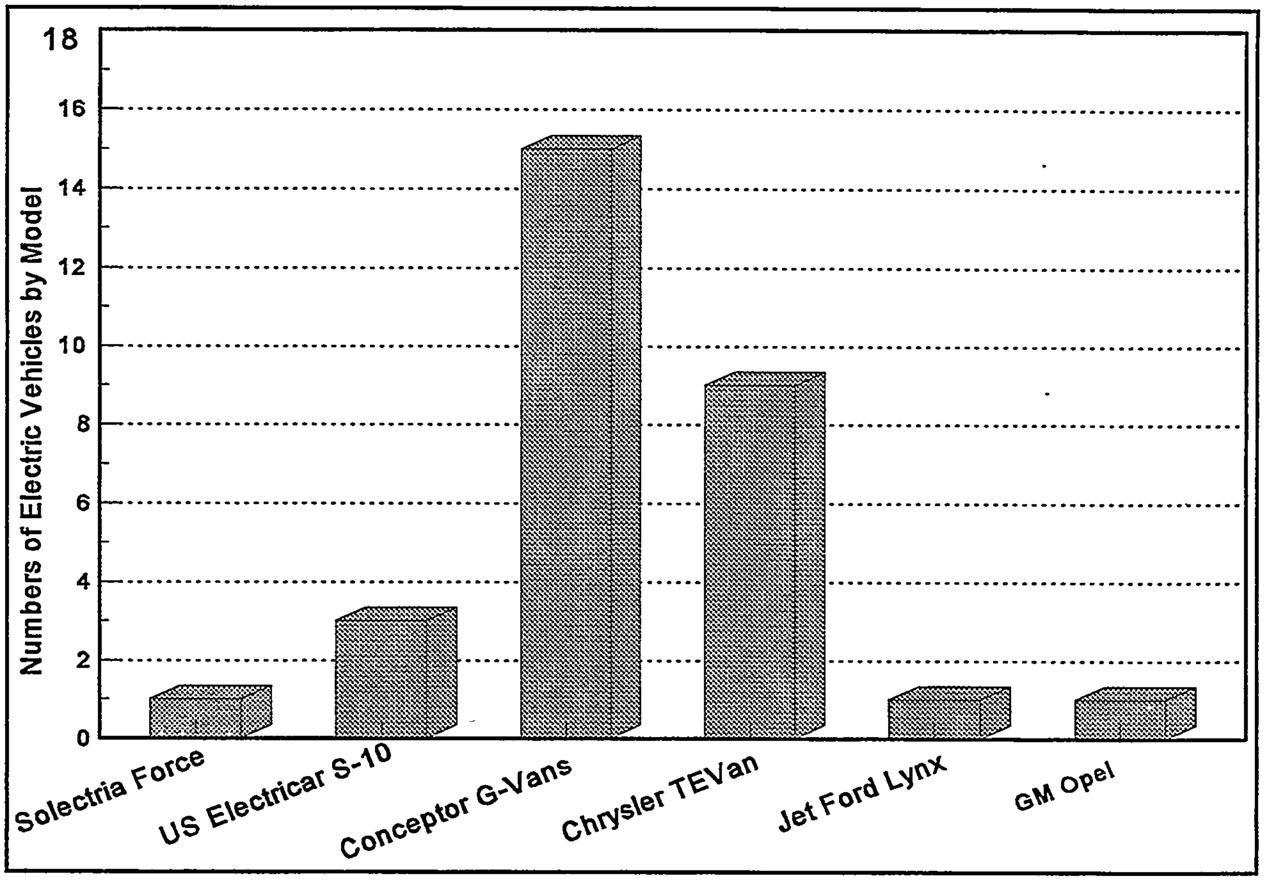

Figure 21. Number and types of vehicles in the Texas A&M EV fleet. fleet.

- The use of spring-type Bellville washers to tie down the battery jumpers.

Other issues that should be considered include:

- Different lengths of bolts on battery terminals should be marked or color coated, and warnings should be printed in the shop manual
- Battery jumpers should be flexible, not solid
- Reduce or control brake regenerative current when the battery pack is fully charged
- Hydrogen sensors should also be considered to warn the operators of potential dangers.

Another important lesson was learned this winter about the 1 kW electric heater in the pickups. These heaters use fresh air, which at sub-zero temperatures cannot warm the passenger compartment. The recirculated air setting on the dash works only with the air-conditioner on. Hence, with reconfiguration of the vacuum hoses, TAMU was able to shut the trap door and recirculate the heated air which heated the passenger compartment in 5 to 7 minutes. A temperature control is also being considered for the optimal comfort level.

The drive line modification supplied by US Electricar has substantially reduced the harmonic vibration at 35-60 mph on the US Electricar vehicle DOE #628.

TAMU reports that they have learned different lessons from each of the three types of vehicles (G-Vans, TEVans, US Electricar pickups) that they have mainly used. The early vehicles had flexible jumper cables which required welding on the terminals. These would sometimes result in battery explosions in the process of welding. Hence, changing to solid metal jumpers seemed like a good idea until learning about the unique problems which can lead to hydrogen explosions.

TAMU reports that two of their TEVans averaged about 1.2 miles per kWh (Table 15) during the reporting period.

Table 15. Summary of TEVan performance at Texas A&M University.

	Miles Driven		kWh Used		Miles/kWh	
	TEVan 623	TEVan 624	TEVan 623	TEVan 624	TEVan 623	TEVan 624
Oct.	275	511	249	337	1.10	1.52
Nov.	224	315	178	250	1.26	1.26
Dec.	258	251	231	238	1.12	1.05
Total	757	1077	658	825	1.15	1.31

U.S. Navy

As seen in the below Figure (Figure 22), the U.S. Navy has 59 EVs. The Navy's EVs represent several manufacturers and body styles, and a broad span of vehicle ages. The 59 EVs are located at eight different Navy facilities (Figure 23). The principal thrust of this Navy operation is fleet evaluation. The current age span of their EV inventory contributes substantially to a vehicle experience (rather than test) data summary. The Navy, as part of a larger Department of Defense procurement effort, will be ordering more than 30 newest generation EVs during the 1996 fiscal year.

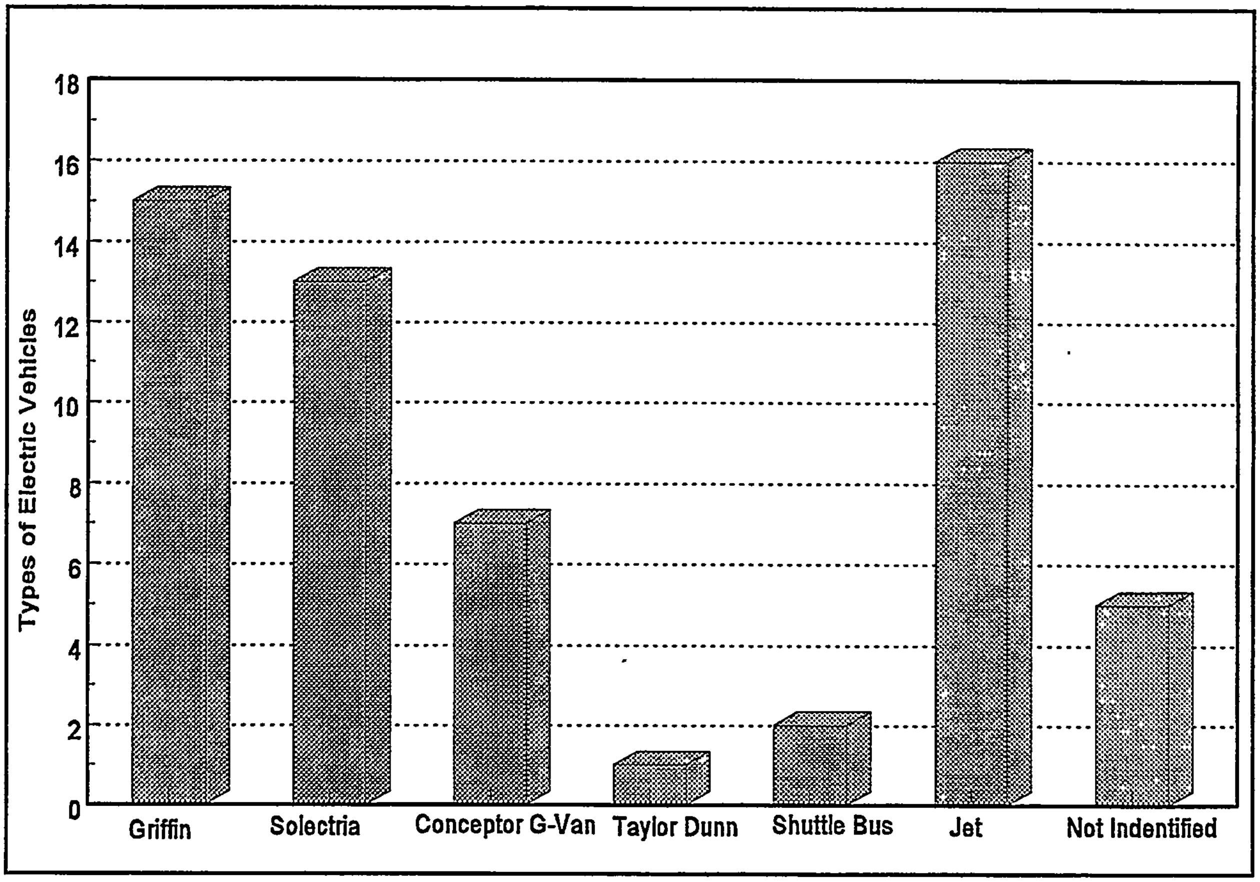

Figure 22. Number and types of vehicles in the U.S. Navy's EV fleet.

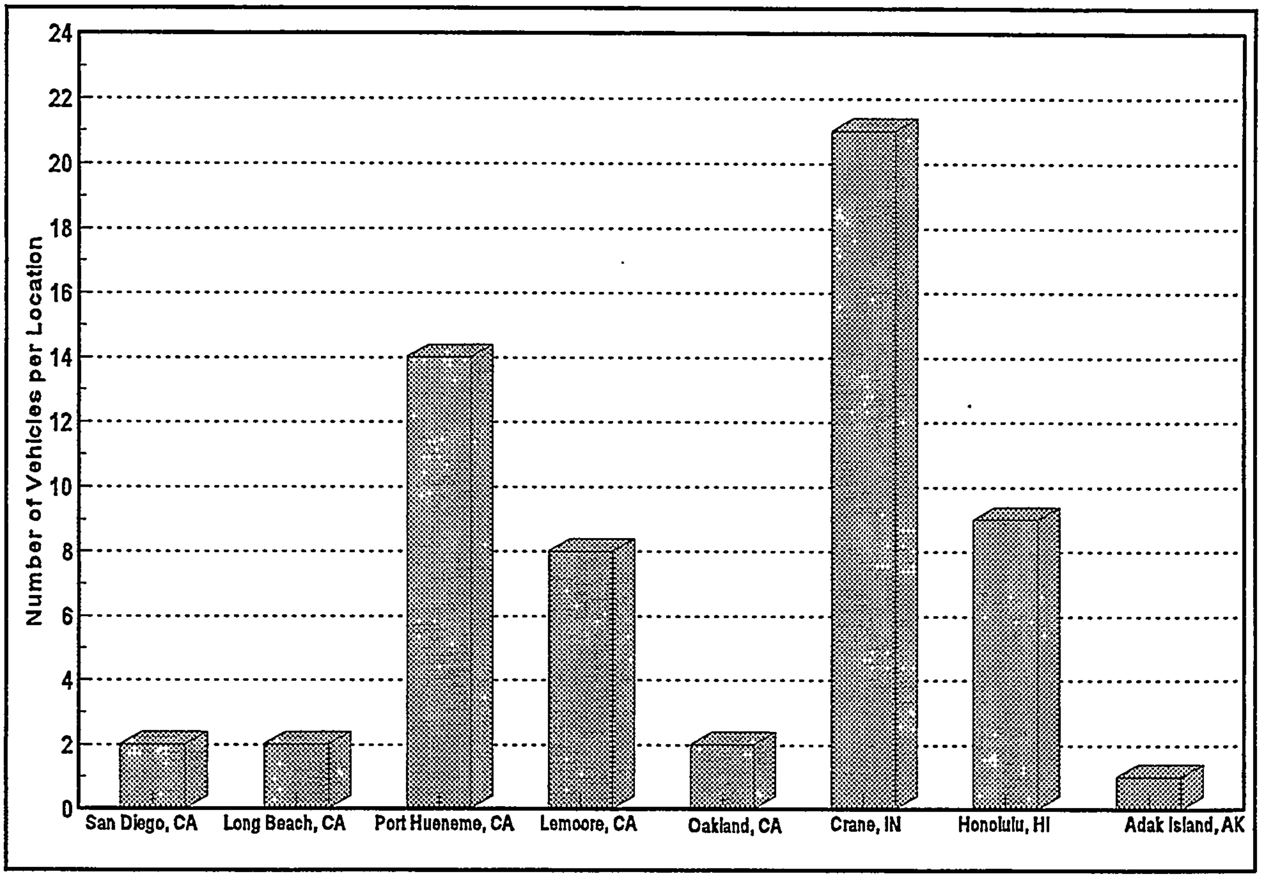

Figure 23. Locations of U.S. Navy's EV fleet.

University of South Florida

The University of South Florida (USF) at Tampa, monitors and tests 12 electric vehicles as a participant in the Site Operator Program (Figure 24). USF's principal collaborating organizations are Florida Power Corp. (FPC), Tampa Electric Co., Hillsborough County, and the City of Tampa. The purpose of the USF effort is to determine EV efficiency under commuter and fleet conditions in Florida. A part of this effort is the testing of a utility-interconnected photovoltaic 12 bay EV parking/charging system. Additional associations include Florida Power and Light Co., Florida Energy Office, Naval Weapons Center, GTE Mobilnet, and the National Renewable Energy Laboratory. The specific USF program objectives are:

- Gather data relating to the performance of EVs under actual commuter and fleet conditions
- Determine public acceptance of EVs through questionnaires and personal interviews with drivers
- Determine the specific regional vehicle maintenance requirements through the use of daily operation and maintenance logs
- Evaluate battery performance as a function of vehicle range and driving conditions
- Determine typical vehicle ranges for commercially available EVs during commuter and fleet operations
- Evaluate the effect of an air conditioner on EV range and performance
- Determine the best role for photovoltaic systems in charging EVs
- Determine the technical feasibility and economic advantages of returning the extra power generated by the photovoltaic system to the power grid.

Technical

Vehicle Performance

Table 16 provides a summary of the performance characteristics for two of USF's EVs during the reported quarter. The performance results were obtained from data collected by Mobile Data Acquisition system (MDAS) units developed by the USF. The charging summaries are derived from driver logs. As can be seen in this Table, the G-Van battery pack efficiency was 34.4%. Unfortunately, the range of this vehicle continues to decrease. However, the fact that the battery pack has accumulated over 11,000 miles may explain this downward efficiency trend.

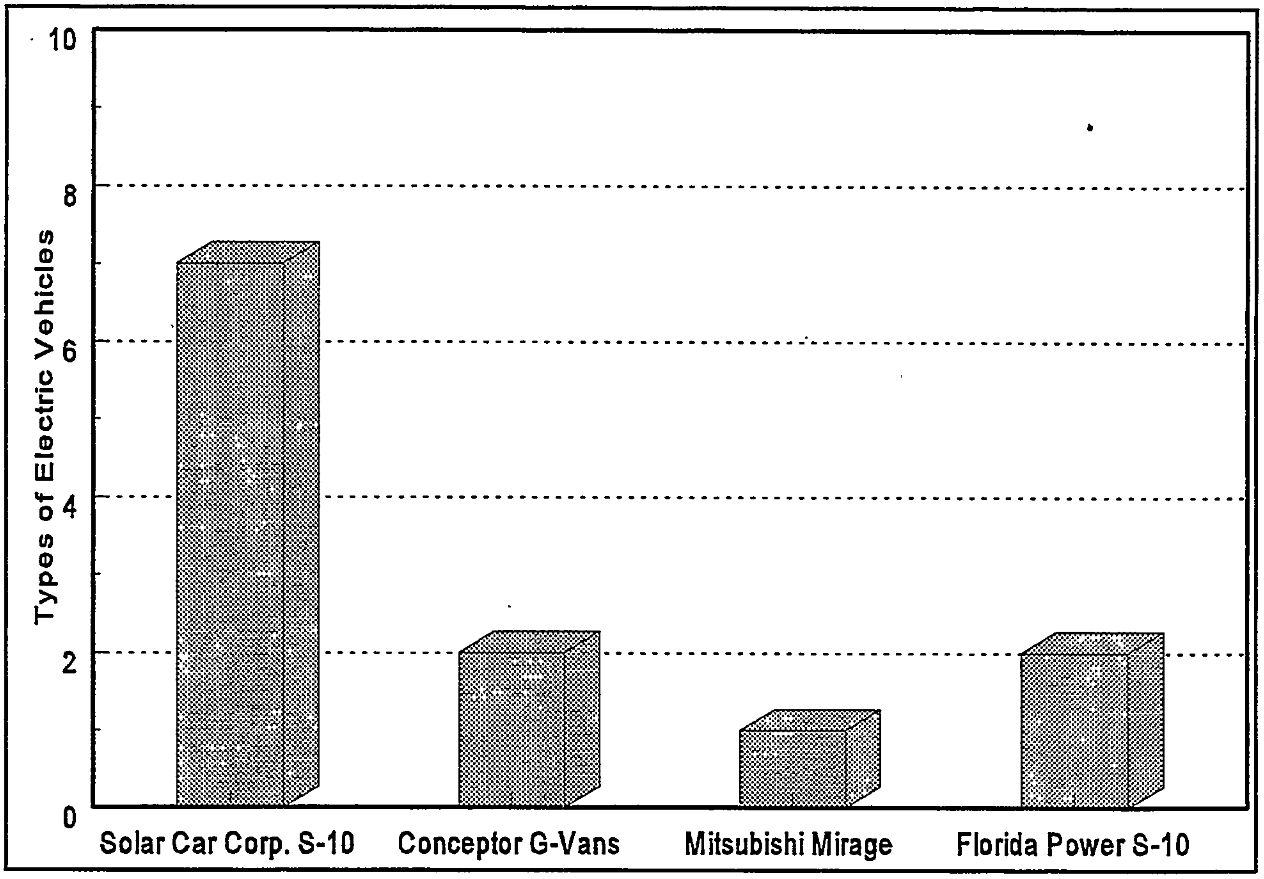

Figure 24. Number and types of vehicles in the USF EV fleet.

During the reporting quarter, the G-Van was driven almost 800 miles and it had a mile to kWh (AC) efficiency rate of 0.63 (Figure 25). One of the S-10's (S01) was driven 137 miles and it had a mile to kWh (AC) efficiency rate of 1.05 (Figure 26). Vehicle S01's low efficiency in November is a result of 1) a charge in early November to replenish energy used during October (making the October efficiency higher), 2) an overcharge during November due to a sticking relay in the off-board charger and, 3) little use of the vehicle during November provided little chance for leveling the effects of the carryover charge. A second S-10 (S02) was driven 215 miles and it had a mile to kWh (AC) efficiency rate of 1.17 (see Figure 27).

Table 16. Vehicle performance results for two of the University of South Florida's EVs. The G01 vehicle is a G-Van and the S06 vehicle is a Chevrolet S-10 pickup Solar Car conversion.

Quarterly Trip Summary		
	G-Van DOE# 650, USF# G01	SCC S-10 DOE# 658, USF# S06
# of days in use (days)	53	26
Total # of trips	195	73
Total trip time (hours)	35.2	6.3
Total time at rest (hours)	12.6	2.0
Total distance (miles)	589	106
Average speed (mph)	20.9	19.0
Max. battery temp. (°C)	45.1	37.4
Avg. battery temp. (°C)	31.8	28.9
Total A/C energy (kWh)	12.4	5.0
Total discharge energy (kWh)	343.6	43.2
Net DC energy eff. (mi/kWh)	1.9	2.5
Quarterly Charger Summary		
	G-Van DOE# 650, USF# G01	SCC S-10 DOE# 658, USF# S06
Total # of charges	27	14
Total charge time (hours)	245.6	297.6
Max charge current (A)	39.0	23.9
Ave. charge current (A)	20.5	3.6
Max. battery temp. (°C)	43.4	35.3
Avg. battery temp. (°C)	23.6	21.8
Total charge energy (kWh)	1000	104.6
Gross DC energy eff. (mile/kWh)	0.6	1.0
Battery pack eff. (%)	34.4	41.3

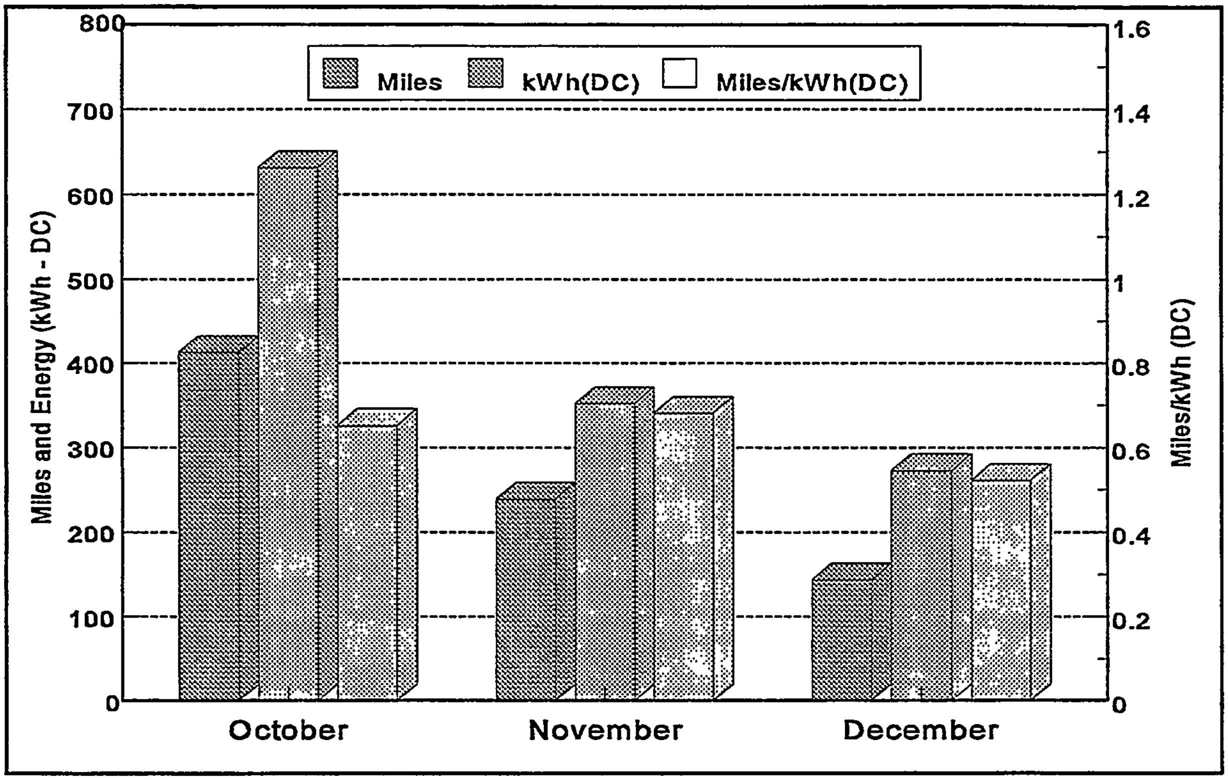

Figure 25. Total miles driven, kWh (AC), and miles per kWh (AC) for a G-Van (DOE #650, USF # G01) at USF. Miles and kilowatt-hour values use the left scale, and the miles per kilowatt-hour value uses the right scale.

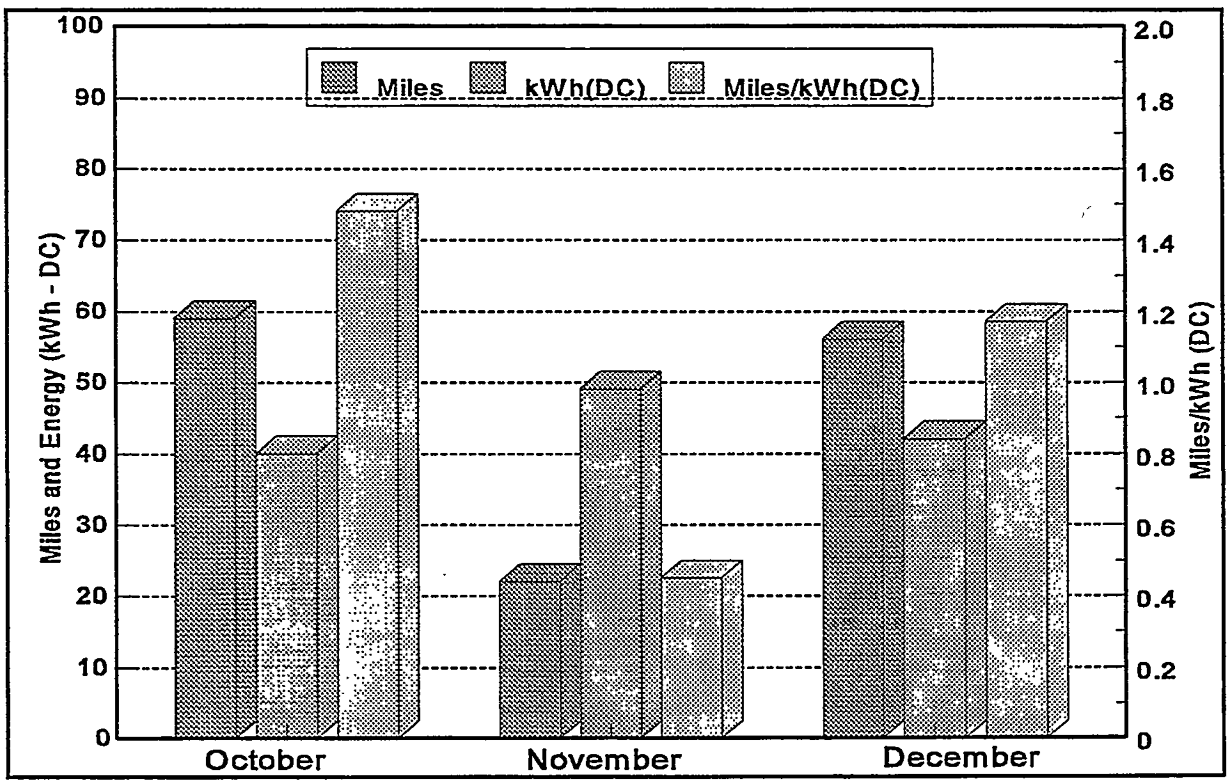

Figure 26. Total miles driven, kWh (AC), and miles per kWh (AC) for a converted Chevrolet S-10 pickup (DOE #652, USF #S 01) at USF. Miles and kilowatt-hour values use the left scale, and the miles per kilowatt-hour value uses the right scale.

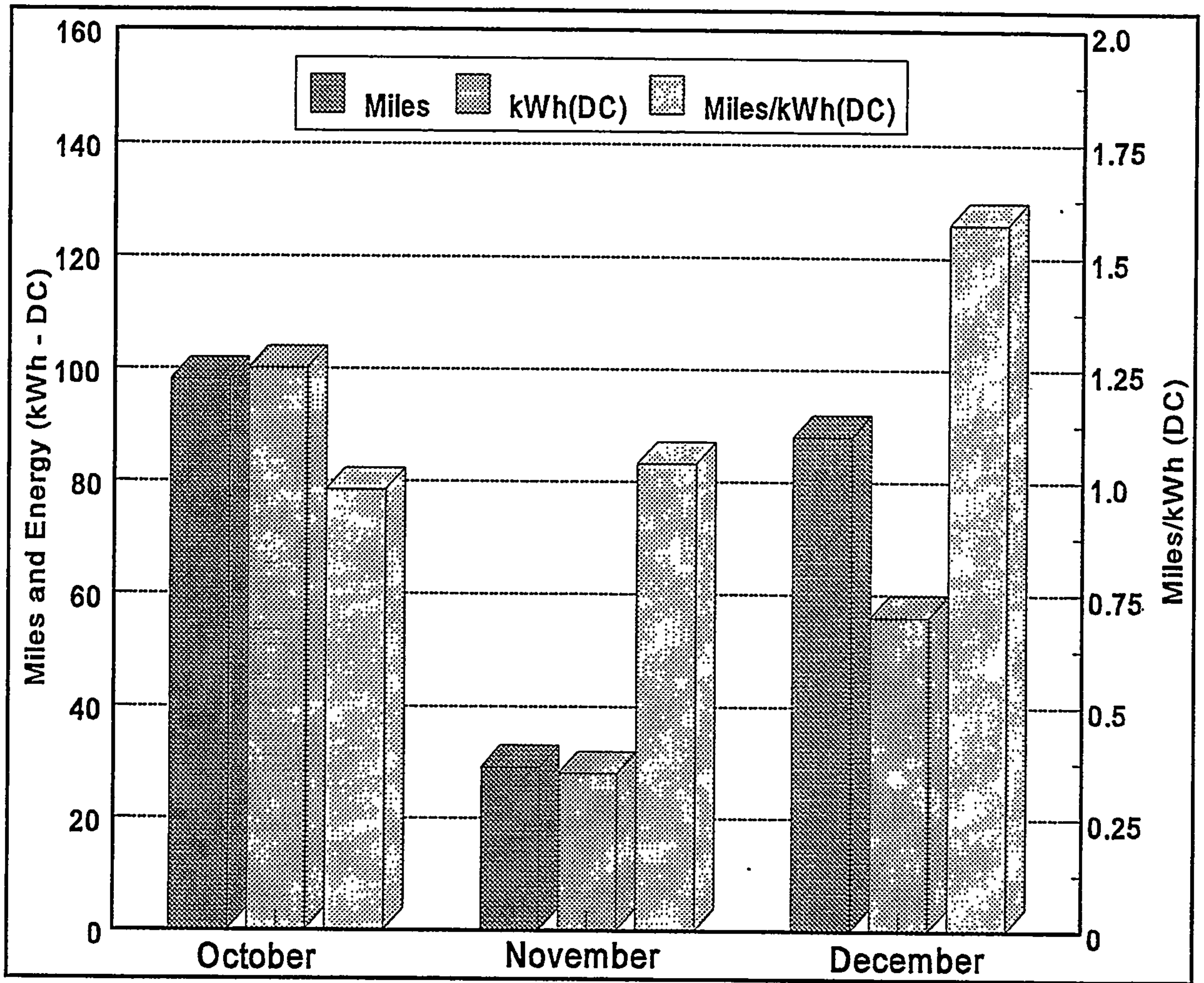

Figure 27. Total miles driven, kWh (AC), and miles per kWh (AC) for a converted Chevrolet S-10 pickup (DOE #653, USF #S 02) at USF. Miles and kilowatt-hour values use the left scale, and the miles per kilowatt-hour value uses the right scale.

Battery Watering

Two EVs, a G-Van and S-10 pickup, both with lead acid batteries, required a total of 5.5 man-hours (Table 17) for battery watering during the reporting period.

Table 17. Battery watering requirements for a G-Van (DOE #650, USF #G01), and a Solar Car Corporation converted S-10 Chevrolet pickup (DOE #652, USF #S01).

Vehicle	Dates	Liters of water added	Miles between watering	Miles per liter of water	Man hours to water vehicle
G01	9/29 to 12/31	49	800	16.33	3
S01	9/16 to 12/31	5.75	130	22.61	2.5

Regenerative Braking Test

A test was conducted to investigate whether driving style has any impact on the efficiency of the regenerative braking system for USF's G-Van G01. The test was carried out as follows:

- Bring the EV to a speed of 50 mpg
- Brake hard to 0 mph on the first run
- Brake easy to 0 mph on the second run.

The calculations were made using the following equation:

Amp*hour (Ahr)=Σ\{motor current*sample interval(hours)\}

The results suggest a 68% increase in Amp hours generated by the slow braking test compared to the hard braking test (Table 18). The regeneration voltage was not measured.

Table 18. Comparison of Amp hours captured during fast and slow regenerative braking.

Run	Begin Speed (mph approx.)	End speed (mph)	Braking period (seconds)	Total Amp*hours generated
Hard braking	50	0	12.75	0.41
Slow braking	50	0	38.75	0.69

Other Maintenance/Repair Activities

The battery pack on one of the S-10's (S02) had a terminal melt down due to high current draw. This rendered the vehicle inoperative. After a external study of the battery pack, it was discovered that a loose cable permitted a tiny space to exist between the terminal post and the battery cable. Sparking across this gap may have caused the terminal to heat and melt. To prevent nay further damage, washers were installed on each side of the terminal bolts to eliminate this space.

The cooling fan of the motor of the Mitsubishi Mirage (M01) was replaced as the original cooling fan did not appear to be large enough for the motors capacity. A more reliable vacuum pump for the M01 brake system was installed.

Air Conditioning Energy Use

The cumulative results from air conditioning (A/C) energy consumption data collected on the USF G-Van number G01, by the MDAS for the fourth quarter of 1995 is listed in Table 19. Row one is the total amount of energy discharger by the vehicle. Row two is the total energy consumed by the A/C. Row three is the percentage of the total discharge energy that the A/C consumed (row two divided by row one).

Table 19. Air conditioning energy consumption data for a USF G-Van.

	October	November	December	Total
Vehicle discharge energy	108.3	151.8	82.9	343.6
Total energy consumed by A/C (kWh)	9.47	2.87	0.055	12.4
Percentage of vehicle discharge energy consumed by A/C	8.7%	1.9%	0.1%	3.6%
Average ambient temperature (°F)	85.3	65.2	61.0	

Photovoltaic Solar Power Charging Station

During the reporting quarter, the twelve-vehicle photovoltaic (PV) solar power charging station generated 4,463 AC kWh of energy, and 9.8 DC kWh of energy. All of the DC was used to charge EVs, and 1,318 AC kWh of the 4,463 AC kWh generated by PV station, was used to charge the EVs. Of the excess PV energy, 2,911 AC kWh was supplied to the grid.

Public Awareness

USF personnel were involved in several public awareness efforts this quarter, including:

- Participation in American Education week by displaying an EV at Progress Village School. The role of engineers in society was explained and the importance of getting an education was stressed.

- USF's Clean Energy and Vehicle Research Center hosted a special Battery /Charger and Monitoring Workshop.

- Attended a SCAT meeting that included plant visits to Trojan's battery manufacturing facility where electric transportation batteries are designed and manufactured, and to Hugh's space and Communications design and construction complex.

- The Clean Energy and Research Center hosted a national data collection and analysis software workshop, covering MDAS hardware and software analysis programs.

York Technical College

Located at Rock Hill, South Carolina, York Technical College operates 11 EVs (Figure 28). Interest in EV technology at York Tech goes beyond the nominal Program scope and is well demonstrated by the school's growing Electric Vehicle Program and emphasis on public awareness. Programmatic associations and interchanges continue with local electric utilities, other Program participants, municipalities, South Carolina State Energy Office, regional secondary schools and colleges, and the Clean Air Transport Association.

Technical

- Repairs were made to the Duke Power Company US Electricar Prizm, including capacity testing of the battery pack and the replacement of six modules.
- Complete the conversion of a 1981 Volkswagen pickup truck, utilizing an advanced DC motor, Curtis controller, Trojan flooded cell batteries, and other new components. This vehicle is now in service at the Palmetto Electric Co-op.
- Completed preparations to a Ford Escort Sedan including replacement of the motor controller and DC/DC converter. The brakes and the heater in this car were also repaired. The car is now being used by the Coastal Center in Summerville, South Carolina.
- Repairs were made to the battery charger and MDAS system on a Solectria Force belonging to Duke Power Company.
- The PCU from a US Electricar Prizm belonging to the City of Charlotte was removed and shipped to Hughes Power Control Systems for repairs.
- Kits to change the pinion and transmission angle on the US Electricar S-10 pickups were installed on two of the vehicles in an effort to eliminate a drive line vibration. The power steering hoses on the two vehicles were also replaced with hoses compatible with power steering fluid.

Public Awareness

York Tech's public awareness activities included the below events.

- Three EVs were placed on display at the Baxter Hood Continuing Education Center during a seminar held for technical college instructors from across the state. These instructors also toured the EV lab.
- A Solectria Force was placed on display at the People Feast Celebration in Wadesboro, North Carolina. This was a manned exhibit and drew much interest from the people attending the celebration.

- Representatives from the Santee Cooper Power Authority visited the York Tech campus and the EV lab.

- Presentations were given to three classes of students at the Fort Mill, South Carolina High School, where EV technology was discussed and demonstrations of various types of EV components were given.

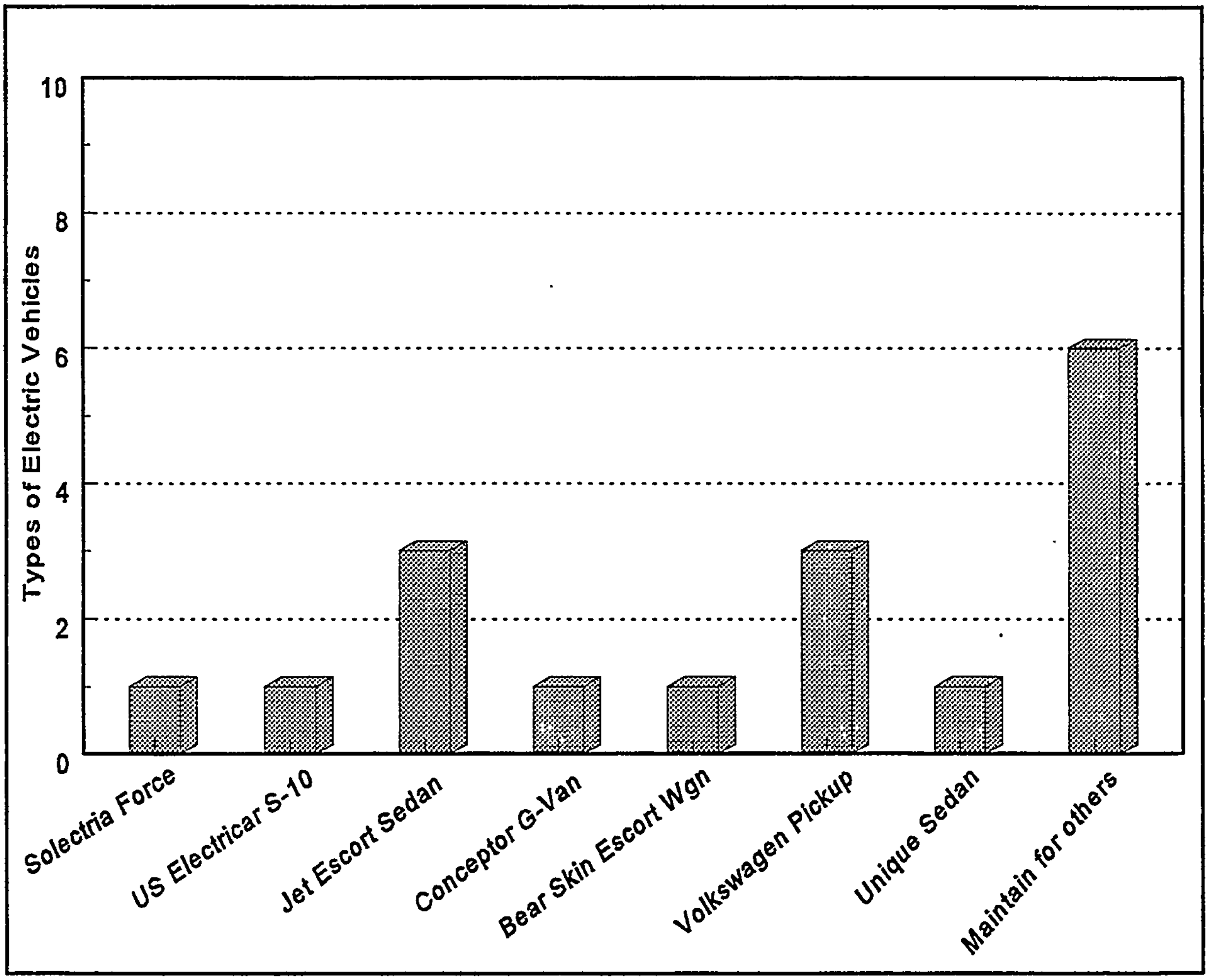

Figure 28. Number and types of vehicles in the York Tech EV fleet.