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ELECTRIC VEHICLE FLEET OPERATIONS IN THE UNITED STATES[1]

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James E. Francfort, Idaho National Engineering Laboratory[2]
and
Dana O'Hara, United States Department of Energy[3]

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Abstract

The United States Department of Energy (DOE) is actively supporting the development and commercialization of advanced electric vehicles, and advanced batteries and propulsion systems. As part of this effort, the DOE Field Operations Program is performing commercial validation of electric vehicles. These efforts have included on-board data acquisition of electric vehicle operations and baseline performance testing. The baseline performance tests focus on parameters such as range, acceleration, and battery charging. This testing, performed in conjunction with EV America, has included the baseline performance testing of 14 electric vehicles during the years 1994, 1995, and 1996. During 1997, approximately six new electric vehicles will also be baseline performance tested. The baseline performance testing has documented annual improvements in performance. This and additional information is made available to the public via the internet homepage (http://ev.inel.gov). The Field Operations Program continues to support the development of electric vehicles and infrastructure in conjunction with its new qualified vehicle test partners: Electric Transportation Applications of Phoenix, and Southern California Edison. The Field Operations Program is managed by the Lockheed Martin Idaho Technologies Company, at the Idaho National Engineering Laboratory.

Introduction

The overall goal of the Field Operations Program is the commercial validation of electric vehicles. This paper communicates recent and ongoing commercial validation efforts in support of this goal, and provides a brief history of Field Operations Program-related activities when the Program was previously known as the Site Operator Program. Currently, the Field Operations Program uses two groups of qualified vehicle testers to conduct validation efforts. Vehicle qualification is performed by capturing electric vehicle fleet operations data via on-board data loggers and through baseline performance types of tests. The paper describes data collection and data dissemination efforts. The intent is to communicate to a broad audience the electric vehicle-related efforts by the Field Operations Program in support of the commercial development and validation of electric vehicle technology.

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[2] Principle Technical Specialist, Lockheed Martin Idaho Technologies, Inc., at DOE's Idaho National Engineering and Environmental Laboratory, P.O. Box 1625, Idaho Falls, Idaho, USA, 83415-3830, (208) 526-6787, francfje@inel.gov

[3] Field Operations Program Manager, U.S. Department of Energy, 1000 Independence Ave., S.W., Washington, D.C., 20585, (202) 586-8063. DANA.O''HARA@hq.doe.gov

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Program History

The Field Operations Program has evolved substantially since its inception in response to the Electric Vehicle Research and Demonstration Act of 1976. The Program was originally intended as a commercialization effort, but this was not feasible as viable products and infrastructure were not yet available. By the early 1980s, emphasis shifted to data collection and analysis. By 1996, the program consisted of 11 geographically diverse sites and the 11 participants had over 250 electric vehicles in their fleets. Data was collected on approximately 50 vehicles. Program participants included electric utilities, universities, and another Federal agency. DOE's involvement has included cofunding of vehicle purchase costs and support of data collection efforts. The Idaho National Engineering Laboratory became the repository for the data, and an internet site is now available for the public to access raw operating data, performance testing data, and various reports. The baseline performance testing has been performed in conjunction with EV America, an organization comprising several dozen United States electric utilities interested in promoting the purchase and use of electric vehicles. EV America has promoted electric vehicle use in conjunction with vehicle manufacturers and several Federal agencies. Baseline performance testing has included acceleration, handling, braking, charging, and range testing of 14 electric vehicles during 1994, 1995, and 1996. Other important activities of the Program have included public education and infrastructure development.

During 1996, the Field Operations Program shifted emphasis, and its mission has become an effort to document the commercial viability of electric vehicles as fleet vehicles. The Program is accomplishing this by encouraging the purchase and use of electric vehicles through the evaluation and dissemination of performance and field testing results. The information is targeted towards fleet managers, policy makers, regulators, and technicians. Only the newest generation of electric vehicles will be tested, and the three types of testing are:

- Baseline performance testing, including initial performance and periodic checks
- Fleet testing, including commercial viability as a day-to-day fleet vehicle and user acceptance issues
- Reliability testing, including accelerated vehicle mileage, life-cycle performance of components and subsystems, and vehicle support requirements.

The Program today comprises two groups of Qualified Vehicle Testers:

- Southern California Edison (lead organization), California Air Resources Board, and AAA of Southern California
- Electric Transportation Applications (lead organization), Arizona Public Service, Potomac Electric Power Company, Salt River Project, and Underwriters Laboratory

Performance/EV America Testing

Electric Transportation Applications, in conjunction with EV America, vehicle manufacturers, DOE, and other electric utility groups, developed the baseline performance testing methodology, and 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 vehicle-to-vehicle and year-to-year comparisons of test results. The baseline performance testing methodology has evolved as the vehicle technology has advanced. The baseline performance testing helps the potential purchaser of electric vehicles to have greater confidence that her or his expectations of vehicle performance will be met if a vehicle passes the baseline performance tests. Table 1 provides a summary of the 14 vehicles that have completed the baseline performance testing at the end of 1996. During 1997, about six of the newest generation of electric vehicles from original equipment manufacturers will be performance tested. The 1996 models tested, and the 1997 models to be tested, represent the most sophisticated electric vehicle technology available, or soon to be available, in the United States.

Table 1. Select performance test results for 1994, 1995, and 1996 EV America/DOE performance tests. Acceleration results are in seconds, and maximum speed is in miles per hour.

	Range tests (miles)			Acceleration	Max.	Battery
Vehicle	@45 mph	@60 mph	SAE J1634	0 to 50 mph	speed	Manufacturer
1996 test vehicles						
GM EV 1	135	89	78	6.7	80	Delphi
Toyota RAV4	82	55	68	13.3	78	Matsushita
1995 test vehicles						
Solectria E-10	81	50	55	17.4	68	Hawker
Solectria Force	106	71	85	18.5	70	Ovonic
Baker p/u	61	32	57	14.9	71	Ovonic
1994 test vehicles						
Solectria S-10	73	40	58	21.7	66	Hawker
Solectria Force	50	27	45	21.5	70	Hawker
US Electricar p/u	71	47	69	20.1	71	Hawker
US Electricar Sedan	59	42	46	16.2	81	Hawker
Bat Ranger	55	44	21	failed	failed	Trojan
Bat Metro	88	52	50	26.0	67	Trojan
Bat Metro	47	40	38	16.5	81	Optima
Dodge Caravan	86	57	51	33.9	62	Picher
Unique p/u	54	38	43	30.3	70	Optima

Figure 1 shows the continued improvement in electric vehicle technology in the United States. The Figure shows, almost without exception, the year-to-year increases in performance test results. For instance, looking at the range tests conducted at a constant speed of 45 mph (Figure 1, first group of three bars on the left), shows that the range (in miles) increased 28% between the 1994 and 1995 test vehicles, and 31% between the 1995 and 1996 test vehicles. The 1996 vehicles had an average range of 108 miles when tested at a constant speed of 45 mph. The range tests conducted at a constant speed of 60 mph also saw significant increases in average distances between 1994 and 1995 (19% improvement) and 1995 and 1996 (41% improvement). The average test results for the 0 to 50 mph acceleration tests saw a 26% faster average time to reach 50 mph for the 1995 vehicles than the 1994 vehicles, and a 41% faster time for the 1996 vehicles compared to the 1995 vehicles.

Test results also show a year-to-year increase in performance when comparing the SAE J1634 results (Figure 2). This test is a Society of Automotive Engineers (SAE) range test that combines the Federal (United States) Urban and Highway range tests for electric vehicles. The vehicles on the left are 1994 test vehicles and the more recent test vehicles are on the right. There is a definite trend that reflects increasing ranges. The 1995 average SAE J1634 range was 40% greater than the 1994 average, and the average SAE J1634 range for 1996 was 12% greater than the 1995 average.

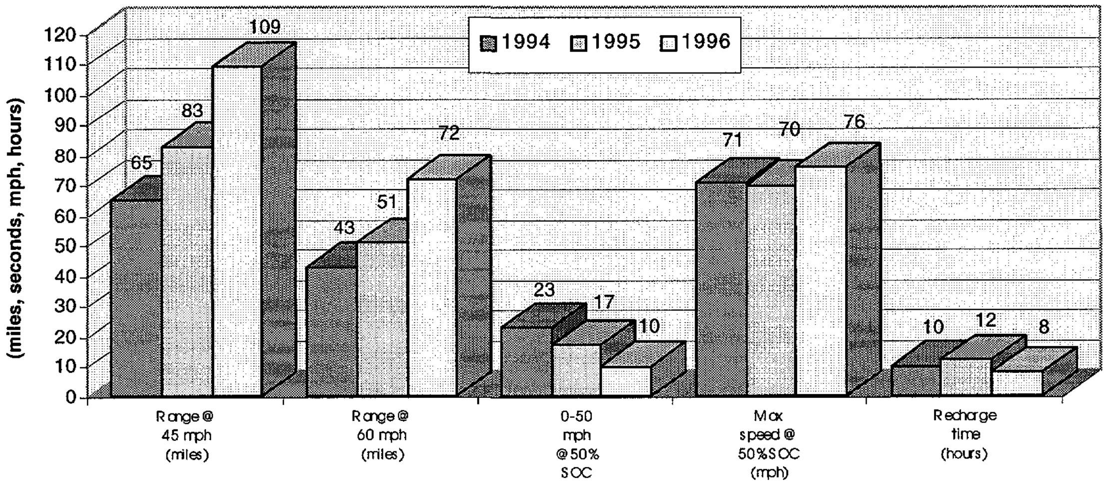

Figure 1. Test trends for electric vehicles performance tested during the years 1994 (9 vehicles), 1995 (3 vehicles), and 1996 (2 vehicles). The annual average results are graphed.

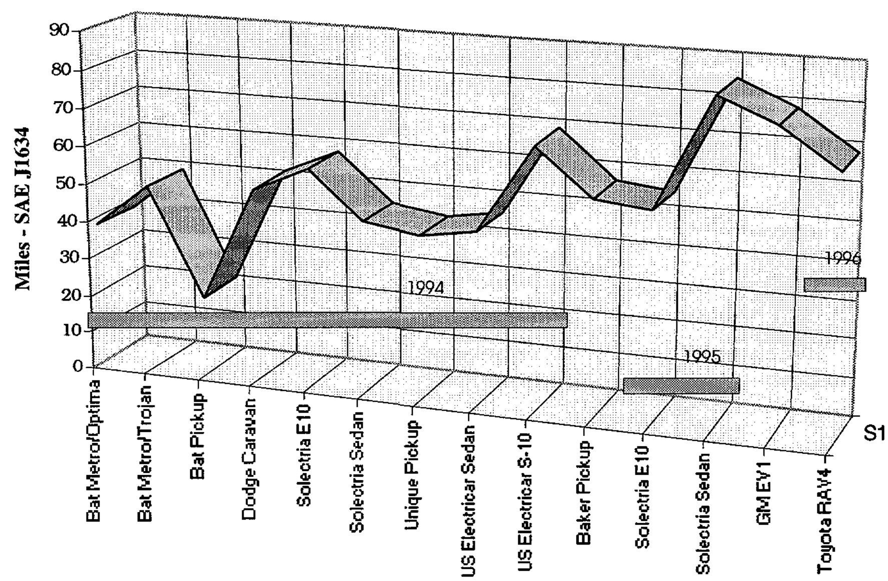

Figure 2. Range test results (miles) using SAE J1634. The first nine vehicles were tested during 1994, the next three during 1995, and the GM EV1 and Toyota RAV4 during 1996. The vehicles are plotted alphabetically by year.

Fleet Operations

The 11 Program participants operated over 250 electric vehicles, representing more than 15 different manufacturers during 1996. (Figure 3). The vehicles in the Program during 1996 represented the mix of models that were previously available in the United States. Early 1997 will see the probable deployment of the Chevrolet S-10, and late 1997 should see the deployment of the Toyota RAV4, the Chrysler EPIC minivan and the Ford Ranger as electric fleet vehicles. In the meantime, data collection continues on the older generation vehicles. Recent data is available to the public in several different forms. Table 2 shows a summary as it is displayed on the Program's internet home page. The summary data includes total energy and miles, energy use per mile, and average battery and ambient temperatures for twelve electric vehicles. The three vehicles in the example (Table 2) have energy use rates of between 2.5 and 3.2 miles per kWh. This is representative of 10 of the 12 vehicles in the operations database. Two of the vehicles, both operated by the Potomac Electric Power Company, have energy use rates slightly over 4 miles per kWh.

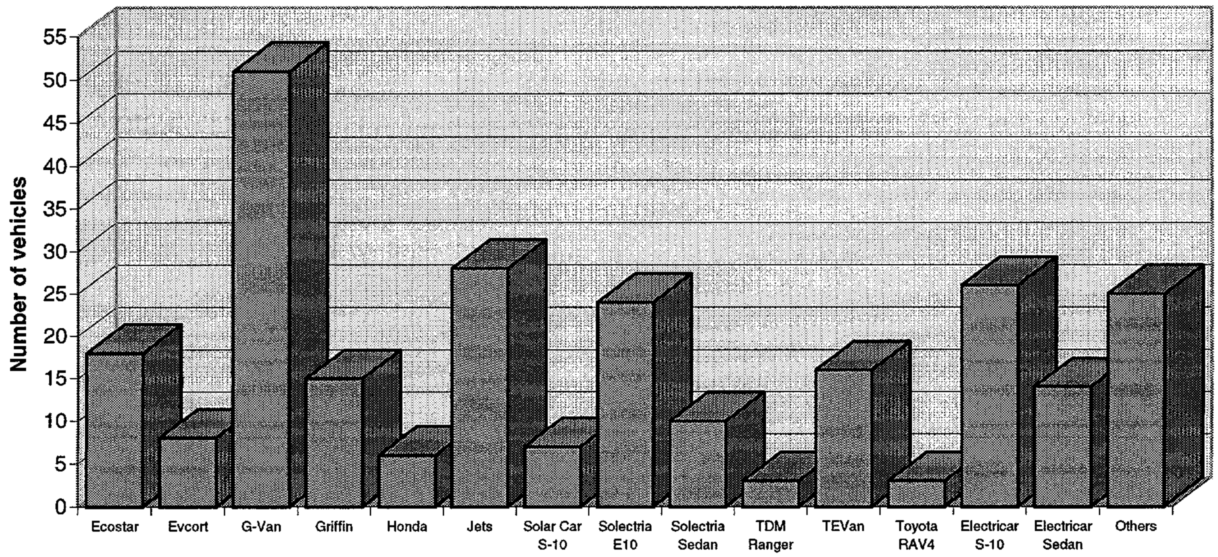

Figure 3. Number of electric vehicles, by vehicle model and manufacturer, operated by the 11 Field Operations Program participants during 1996. Data is not collected on all vehicles.

Table 2. Example of the *Summary of Operations by Vehicle* Table on the Field Operations Program home page (http://ev.inel.gov). This is an example of actual data.

Vehicle Operations Data	Total Miles Traveled	Total kWh Used	Miles per kWh	Total kWh Charged	Total Num Trips	Total Num Charges	Avg Ambient Temp deg C	Avg Battery Pack Temp deg C	Battery Type	Regen Brakes
1994 US Electricar S10 at LAWP P17	160	62.5	2.55	-230.7	121	14	25.8	26.5	Lead-Acid Sealed	Y
1994 US Electricar S10 at VA PWR E19	370	120.4	3.07	-207.6	50	17	32.1	32.6	Lead-Acid Sealed	U
1994 US Electricar Prizm at LAWP P17	300	95.1	3.16	-81.1	68	24	26.2	26.6	Lead-Acid Sealed	Y

The fleet operations data is also displayed as summaries on a by-trip basis. An example is not included but is similar to Table 2. The only difference is that each row of data is for individual trips, of which several may occur per day, while in Table 2, each row is for all trips by a single vehicle. The internet user can access per-trip data to view second by second operations parameters. Figure 4 shows the detail that is available on a per-trip basis if the database user desires. The data can also be downloaded to a PC in a spreadsheet format, as well as plotted via the internet. The example (Figure 4) shows the second-by-second data for a trip taken in a Geo Prizm converted by U.S. Electricar and operated by the Los Angeles Department of Water and Power. The trip lasted 30 minutes, used 8.46 kWh of energy, the Prizm went 25.8 miles, the average air temperature was 28.5°C, and the energy efficiency was 3.16 miles per kWh. This information is all available from the per-trip summary (Table 2). The plot (Figure 4) shows the battery temperature, voltage and current use, as well as the vehicle speed on a per second basis. The plot (Figure 4) shows the correlations between speed changes, and volt and current changes. The internet plotting also allows zoom viewing of any of the graphed area. This allows closer viewing of volt, current, and speed changes during periods of acceleration, coasting, or deceleration.

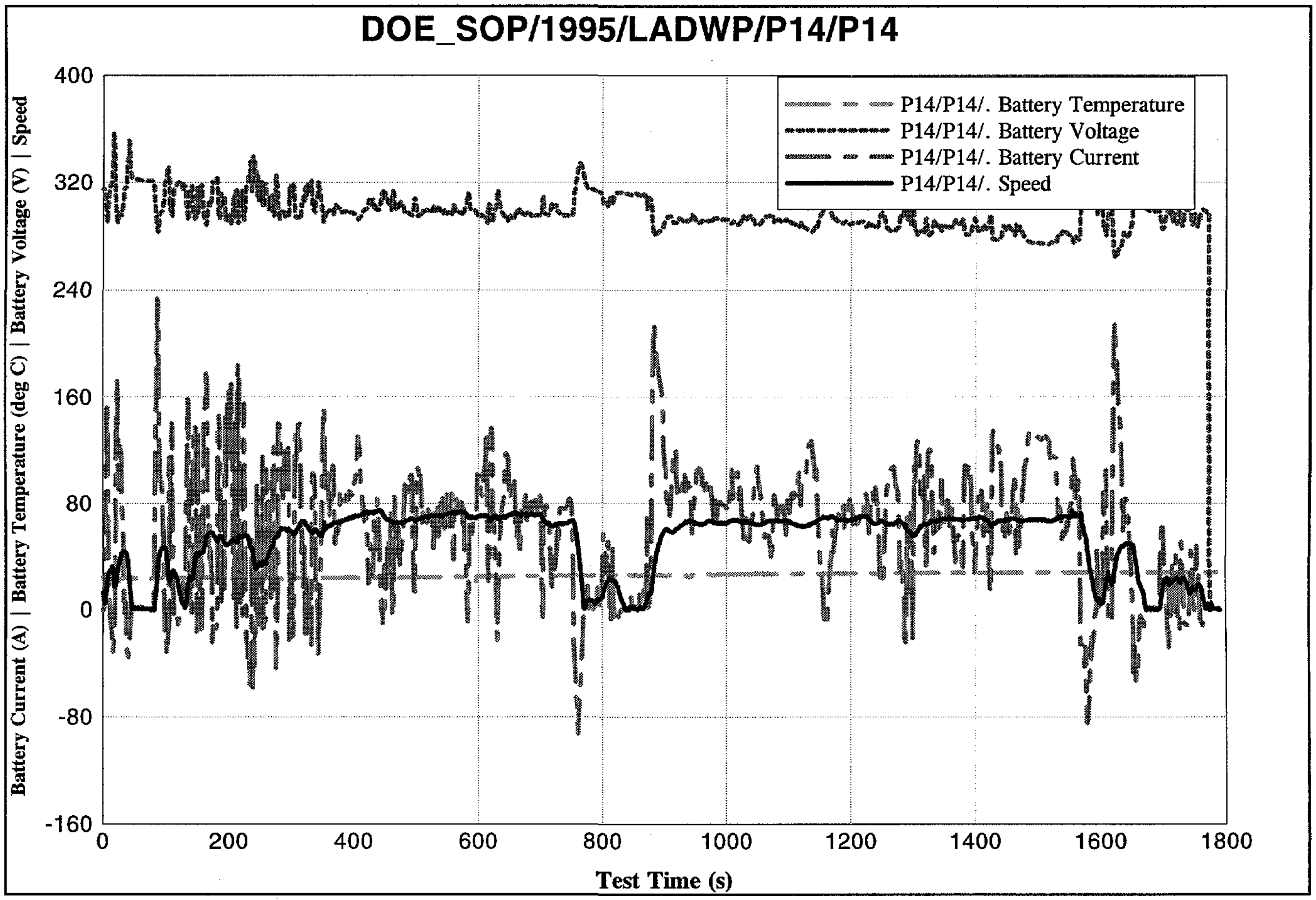

Figure 4. Operations data for a 1994 US Electricar Geo Prizm electric vehicle conversion, captured by an onboard data acquisition system. Battery temperature, volts, and current, as well as the vehicle speed, is captured and displayed on a per-second basis, and available to the public on the internet.

Infrastructure Development

The United States Departments of Transportation and Energy, through the Field Operations Program, are supporting the efforts of the Electric Transportation Coalition and the Electric Vehicle Association of the Americas to inform and educate key industry leaders, government officials, and public and private organizations about electric vehicles through a series of ten workshops. The workshops were held in the United States cities of Atlanta, Boston, Detroit, Fort Lauderdale, Los Angeles, New York, Phoenix, Richmond, Sacramento, and Washington, D.C. The workshops included information about electric vehicle infrastructure requirements such as vehicle safety and emergency response requirements, chargers, and electric vehicle-related building codes and highway signs. The workshops also included discussions of electric vehicle product offerings in the United States by domestic and foreign vehicle manufacturers, as well as opportunities to highlight local EV infrastructure development such as public charging stations. Ride-n-drives featuring the newest electric vehicles were also available to workshop attendees.

Energy Economics

An area of intense interest is determining the life-cycle cost of operating an electric vehicle and how this compares to the life-cycle cost of operating a gasoline-powered vehicle. Defining and documenting the costs of operating electric vehicles in fleet use is an additional objective of the Program. Unfortunately, there is not a well-documented history of electric vehicle operations to use to determine operating costs, nor is the cost of purchasing an electric vehicle as well defined as the cost of purchasing a gasoline vehicle. However, sufficient information does currently exist to compare the energy costs of electric vehicles and the energy costs of gasoline vehicles. Figure 5 shows the energy costs per mile for four vehicles along the bottom axis (X). The left axis (Y) contains a scale for the cost of electricity per kWh from 1 cent to 40 cents, and the right axis (Y) is a scale of the cost of gasoline with a range of $1.20 to $2.00 per gallon.

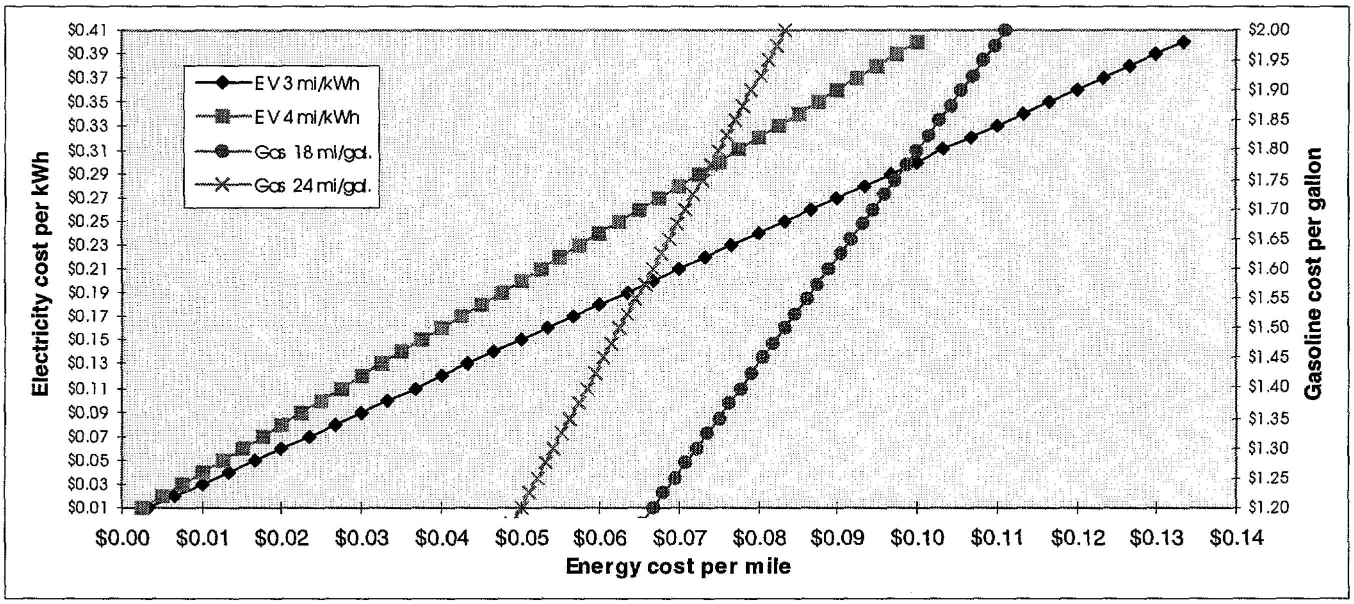

Figure 5. Costs per mile to operate two electric vehicles and two gasoline vehicles. The two electric vehicles are assumed to have energy efficiencies of 3 miles per kWh and 4 miles per kWh. The electricity costs range from one cent to 40 cents per kWh. The gasoline powered vehicles have energy efficiencies of 18 and 24 miles per gallon. The per gallon cost of gasoline ranges from $1.20 to $2.00 per gallon.

To determine the energy cost per mile, go to the left Y axis (Electricity cost per kWh) and find the 9 cents value. Find where 9 cents horizontally bisects either the 3 mi/kWh or 4 mi/kWh lines, and draw a vertical line down to the X axis (Energy cost per mile) which is bisected at about 2.5 cents per mile. The gasoline-powered vehicle energy costs at $1.35 per gallon of gasoline, are between 5.5 cents per mile for the 24 mile per gallon gasoline vehicle, and 7.5 cents per mile for the 18 mile per gallon vehicle. Using these average costs for electricity and gasoline, the typical electric vehicle fleet-type of vehicle has energy costs per mile of only one-half to one-third of a comparative gasoline fleet vehicle.

The light duty pickup trucks in the Field Operations Program database are fairly typical of the type of electric vehicles used in fleet applications in the United States, and these older technology vehicles are currently getting between almost 3 miles per kWh to over 4 miles per kWh. The average cost of electricity in the United States is about 6.9 cents per kWh, with an average residential rate of 8.4 cents per kWh.[i] California has off-peak and on-peak electric vehicle charging rates of 3 cents to 40 cents per kWh,[ii] and some of the Public Utility Districts in the Pacific Northwest region of the United States have electricity costs to the public of only slightly over 1 cent per kWh.[iii] The cost of gasoline has ranged from about $1.20 to occasionally $2.00 per gallon in the United States. The average price seems to be in the $1.35 per gallon range.[iv] It should be noted that the cost of gasoline in the United States includes various Federal, state, and sometimes local taxes that represent up to half the gasoline purchase cost for activities such as highway repairs. The electricity prices do not (as yet) include highway use-taxes and this may change as electric vehicles come into wider use.

Summary

The performance characteristics of electric vehicles are continually improving, infrastructure is being developed, and the energy economics for electric vehicles are very favorable. There is a national effort by the car manufacturers, electric utilities, and various local, state, and Federal agencies to support the wide-spread use of electric vehicles as a clean transportation alternative.

The Field Operations Program is supporting electric vehicle deployment in the United States, both by purchasing electric vehicles, and by collecting relevant and accurate data. The Program will continue to dissemination electric vehicle performance and operations information to help the fleet manager make intelligent procurement decisions. Successful fleet deployment will only occur when electric vehicles are matched to duty cycles, and the fleet managers and operators have confidence that the electric vehicles they purchase are fully capable of meeting their performance expectations.

The commercial validation of electric vehicles by the Field Operations Program will help minimize any uncertainties as to whether or not electric vehicles are the right choice for the fleet manager.

References

[i] *Electric Power Monthly, December 1996.* Energy Information Administration. Office of Coal, Nuclear, Electric Alternate Fuels U.S. Department of Energy. Washington, DC 20585. Table 55.

[ii] Personal communication with several California public utilities, including Southern California Edison, Los Angeles Department of Water and Power, and Pacific Gas and Electric.

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[iv] Idaho State Journal. February 26, P B4, *Biz Briefs: Gas Prices Jump Again,* Up 1.5 cents., and June 11, 1996. P. B4, *Biz Briefs: Average Gas Price Up 1.62 Cents.* Pocatello, Idaho.