INEEL/EXT-97-01383

January 1998

Site Operator Program Final Report

for Fiscal Years 1992 through 1996

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L. Stefanakos[12]
T. G. Ware[13]

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Idaho National Engineering and Environmental Laboratory
Automotive Systems and Technology Department
Lockheed Martin Idaho Technologies Company
Idaho Falls, Idaho 83415

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[1] INEEL/Lockheed Martin Idaho Technologies Co.
[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] Potomac Electric Power Company
[8] Kansas State University
[9] Arizona Public Service
[10] Texas A&M University
[11] Pacific Gas & Electric Company
[12] University of South Florida
[13] Southern California Edison Company

ABSTRACT

The Site Operator Program was an electric vehicle testing and evaluation program sponsored by U.S. Department of Energy and managed at the Idaho National Engineering and Environmental Laboratory. The Program's goals included the field evaluation of electric vehicles in real-world applications and environments; the support of electric vehicle technology advancement; the development of infrastructure elements necessary to support significant electric vehicle use; and increasing the awareness and acceptance of electric vehicles. This report covers Program activities from 1992 to 1996. The Site Operator Program ended in September 1996, when it was superseded by the Field Operations Program. Electric vehicle testing included baseline performance testing, which was performed in conjunction with EV America. The baseline performance parameters included acceleration, braking, range, energy efficiency, and charging time. The Program collected fleet operations data on electric vehicles operated by the Program's thirteen partners, comprising electric utilities, universities, and federal agencies. The Program's partners had over 250 electric vehicles, from vehicle converters and original equipment manufacturers, in their operating fleets. Test results are available via the World Wide Web site at http://ev.inel.gov/sop .

EXECUTIVE SUMMARY

The U.S. Department of Energy's (DOE's) Site Operator Program was initially established to meet the requirements of the Electric and Hybrid Vehicle Research, Development, and Demonstration Act of 1976. Over time, the Program evolved in response to legislation changes and technology advancements. The goals of the Site Operator Program included the field evaluation of electric vehicles in real-world applications and environments; the support of electric vehicle technology advancement; the development of infrastructure elements necessary to support significant electric vehicle use; and increasing the awareness and acceptance of electric vehicles. The Site Operator Program ended in September 1996, when it was superseded by the Field Operations Program.

The Site Operator Program, managed by the Idaho National Engineering and Environmental Laboratory, consisted of 11 participants under contract and two other organizations that had data-sharing agreements with the Program. The participants (electric utilities, academic institutions, and Federal agencies) were geographically dispersed within the United States and their vehicles saw a broad spectrum of service conditions.

During the 5-year period (1992–1996) that this report covers, the Site Operator Program collected data on electric vehicles that were operated by their Program partners. These 13 organizations had 250 electric vehicles in their fleets and gained significant knowledge about electric vehicle operations, vehicle components, and battery charging methods. For example, the Program partners identified

- Typical vehicle energy usage (1 to 4 miles per kWh depending on a vehicle's age and technology)
- The amount of energy that can be recaptured by regenerative braking (about 25–30% according to studies by the University of South Florida)
- The benefits of fast charging (according to Arizona Public Service, higher vehicle utilization with pack recharging that takes less than 15 minutes)
- The need for more dependable vehicles (Southern California Edison's knowledge gained while running the largest electric vehicle fleet in the United States).

Another area of Program activity was the support of the EV America baseline performance testing of electric vehicles offered for sale by vehicle converters and original equipment manufacturers. During the first year of baseline performance testing (1994), nine vehicles were tested; during 1995, three vehicles were tested; and during 1996, a prototype from Toyota was tested and the first original equipment manufacturer vehicle intended for public distribution (the EV1 from General Motors) was also tested. During the 3 years of baseline performance testing, the average annual testing results suggested significant improvements in product offerings. For instance, from 1994 to 1996:

- As measured by the SAE J1634 Driving Cycle Test, ranges increased 56%
- Driving Cycle Efficiencies in miles per kWh increased 53%

- Vehicles accelerated 0 to 50 mph, 58% faster
- Battery charging times were 22% faster.

This report, and the results of the baseline performance testing and fleet operations parameters, are available electronically at the Field Operations Program's World Wide Web site: http://ev.inel.gov/sop .

ACKNOWLEDGMENTS

I would like to thank each of the Site Operator Program participants for their input, active participation, and timely comments. This report incorporates text and data from the quarterly and final reports that each of the Site Operator participants have submitted. Because of the significant amount of text that is drawn from these reports, each Site Operator is listed as a co-author. However, any errors, omissions, or inaccuracies are my responsibility.

J. E. Francfort

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Site Operator Program Final Report

INTRODUCTION

This report summarizes activities of the Site Operator Program for the fiscal years 1992 through 1996. The Site Operator Program was 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 evolved in response to new legislation and interests. The goals of the Site Operator Program included the field evaluation of electric vehicles 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 electric vehicles by the public.

The Site Operator Program's focus included two major and concurrent electric vehicle testing activities. The first activity was the baseline performance testing of electric vehicles that were offered for sale by original equipment manufacturers and vehicle converters. This testing was performed in conjunction with an electric utility group known as EV America.

The second activity consisted of field operations testing of electric vehicles and the collection and dissemination of operating performance parameters. This activity also included electric vehicle public awareness activities such as ride-n-drives and electric vehicle displays, with the intent of maximizing the public's and decisionmakers' awareness of electric vehicles. This second activity was conducted in conjunction with the 11 Site Operators located in diverse areas across the United States (Figure Intro-1). Information was also shared reciprocally with two additional sites (U.S. Navy and Sandia National Laboratory) that were not under Program contract.

The Site Operator Program was managed by personnel of the Automotive Systems and Technology Department at the Idaho National Engineering and Environmental Laboratory (INEEL). The principal management functions included:

- Technical and financial monitoring of programmatic activities, including periodic progress reports to DOE.
- Data acquisition, analysis, and dissemination. The data from the Site Operator Program is made available to users through the INEEL's World Wide Web site at http://ev.inel.gov/sop .
- Coordination of Site Operator Program efforts in the areas of public awareness and infrastructure development (program-related meetings, and educational presentations).

This Final Report contains the following:

- A general discussion of electric vehicle performance testing results and an indication of performance testing trends over the years 1994, 1995, and 1996.
- A discussion about the energy economics of electric vehicles in comparison to internal combustion vehicles

Figure Intro-1. Location of the 13 Site Operator Program partners.

- Sections to provide more specific information concerning the Program participants and their overall interests, their programmatic activities, and their experiences with electric vehicles and accompanying problems. Detailed information on electric vehicle activities at each Site Operator include operations, maintenance, and electric vehicle tests of components.

The Site Operator Program has evolved substantially since its inception in 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.

In 1987, DOE transferred the contract for the Program to the INEEL, and the basic premises of the Program were refined 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.

By 1996, the Program comprised over 250 vehicles, of which about 50 were latest generation vehicles. DOE partially funded the participant's Program expenditures and the INEEL received operating and maintenance data. Program participant efforts reflected 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 Site Operator Program ended in September 1996, when it was superseded by the Field Operations Program.

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

Some tentative conclusions can be drawn about the state of electric vehicle 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.
- 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, New York, and Massachusetts) have or are considering regulatory mandates or voluntary agreements to increase the use of electric vehicles for environmental benefit. Their eventual effectiveness depends on establishing a viable electric vehicle 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 electric vehicle use, including the following:

- EV America is a utility-led program intent on accelerating the development and introduction of electric vehicles into the marketplace. A key effort is baseline performance testing and evaluation.
- DOE, the Department of Transportation, the Electric Transportation Coalition, and the Electric Vehicle Association of the Americas conducted a series of workshops in 10 Clean Cities 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 was established as a joint Federal-Industrial-Academic effort to identify and evaluate vehicular transportation alternatives, including energy storage devices and alternative fuels.

A change of Program direction in the future is expected. Probable candidates for operator testing and data acquisition are hybrids, advanced electric vehicles (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.

VEHICLE PERFORMANCE TESTS SPONSORED BY DOE AND EV AMERICA

During the early 1990s, electric vehicle performance claims were subject to significant uncertainty. In an effort to document the performance of electric vehicles using a uniform set of testing protocols, EV America and the U.S. Department of Energy's Site Operator Program sponsored independent vehicle performance tests. These tests included parameters such as acceleration, range, braking, and charging time. The performance test results are available at the end of this chapter as vehicle fact sheets. Additional information may be obtained at the Program's Internet home page; the address is:

http://ev.inel.gov/sop/

Electric Transportation Applications, in conjunction with EV America, foreign and domestic original equipment manufacturers, vehicle converters, DOE, and other electric utility groups, developed the baseline performance testing procedures. All of the vehicle testing has been performed to stringent testing procedures and minimum qualification standards that vehicles must first 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. Some of the changes in the testing procedures have been driven by the incorporation of new testing standards as developed by the Society of Automotive Engineers (SAE). Other changes include the development of the "Should" and "Shall" rules, specifying the traits that the vehicles should possess and shall (mandatory) possess. For example, the testing rules now require (Shall) that a vehicle's weight and payload capacity (400 pounds minimum for sedans) not exceed the gross vehicle weight. These rules were developed to facilitate the down-selection process to identify commercially viable products. 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. The complete testing procedures are available at the above internet address.

The average annual test results show an increase in vehicle performance from year to year. For instance, the average vehicle ranges for 1995 have increased over 60% compared to the 1994 test results. All three types of range tests (Figure EVA-1) show overall increases in range for each year. The 1996 increase in range is accomplished by increasing the average energy efficiency, measured in miles traveled per kWh of energy used. The results of both the charging efficiency tests and the driving cycle range test (SAE J1634) (Figure EVA-2) show increases in energy efficiencies. Figure EVA-3 also shows the performance increases achieved between the 1994 and 1996 test groups; the average time required to recharge the battery packs decreased, the average maximum speed increased, and the average time required to accelerate from 0 to 50 mph decreased.

The performance testing of electric vehicles did not cease with the termination of the Site Operator Program. Additional testing continues under the Field Operations Program. Table EVA-1 lists the general characteristics of the vehicles that have completed the DOE/EV America testing as part of the Site Operator Program.

Table EVA-1.

Manufacturer	Model	Type	Battery	Battery type
Tested 1996				
General Motors	1997 EV1	Sport coupe	Delphi	Lead-acid
Toyota	1996 RAV4	Sport utility vehicle	Matsushita	Lead-acid
Tested 1995				
Solectria	1995 Force	Sedan	GM Ovonic	Nickel-metal hydride
Solectria	1994 E10	Pickup	Hawker	Lead-acid
Baker	1994 EV100	Pickup	GM Ovonic	Nickel-metal hydride
Tested 1994				
BAT International	1994 Metro	Sedan	Optima	Lead-acid
BAT International	1994 Metro	Sedan	Trojan	Lead-acid
BAT International	1994 Pickup	Pickup	Trojan	Lead-acid
Dodge	1994 Caravan	Van	Eagle-Picher	Nickel Iron
Solectria	1994 Force	Sedan	Hawker Energy	Lead-acid
Solectria	1994 E10	Pickup	Hawker Energy	Lead-acid
Unique Mobility	1994 Pickup	Pickup	Optima	Lead-acid
U.S. Electricar	1994 Sedan	Sedan	Hawker Energy	Lead-acid
U.S. Electricar	1994	Pickup	Hawker Energy	Lead-acid

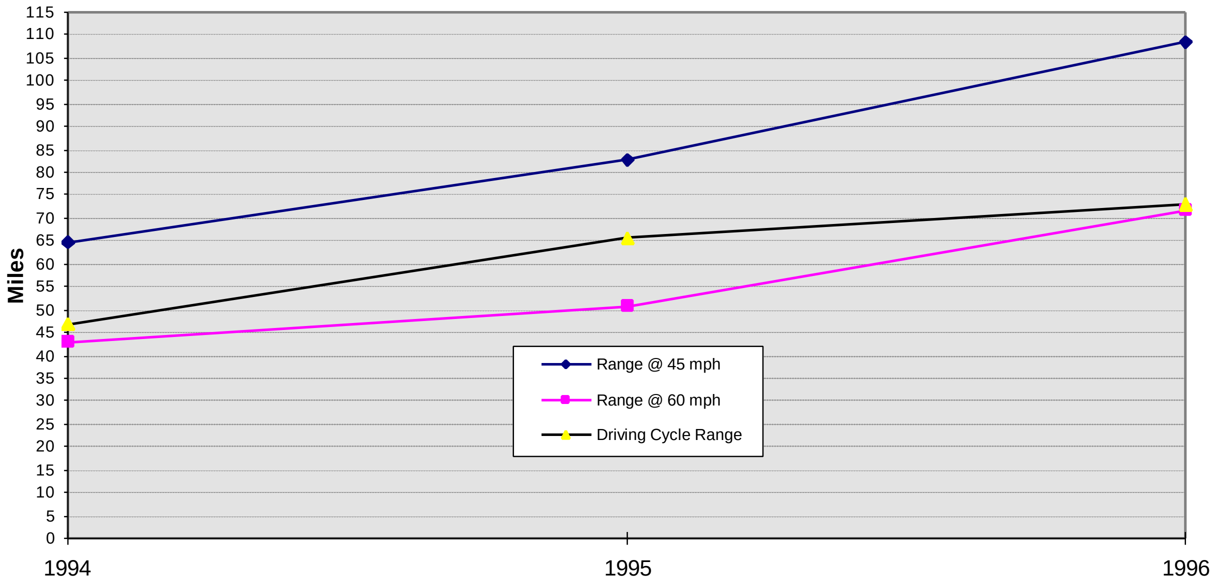


Figure EVA-1. EV America range test results (in miles) for constant-speed tests at 45 and 60 mph and range test results for the SAE J1634 driving cycle test. The plotted results are the average test results for all vehicles tested during each respective year.

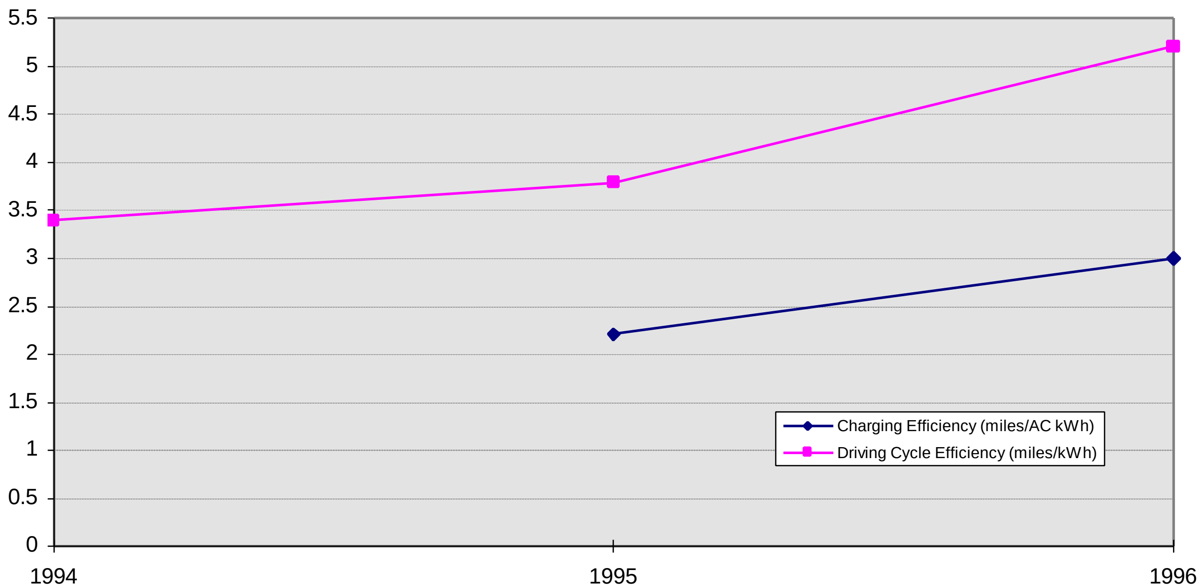


Figure EVA-2. EV America energy efficiency results for the charging efficiency test and the SAE J1634 driving cycle test. The plotted results are the average test results for all vehicles tested during each respective year. The charging efficiency test was not performed on the 1994 tested vehicles.

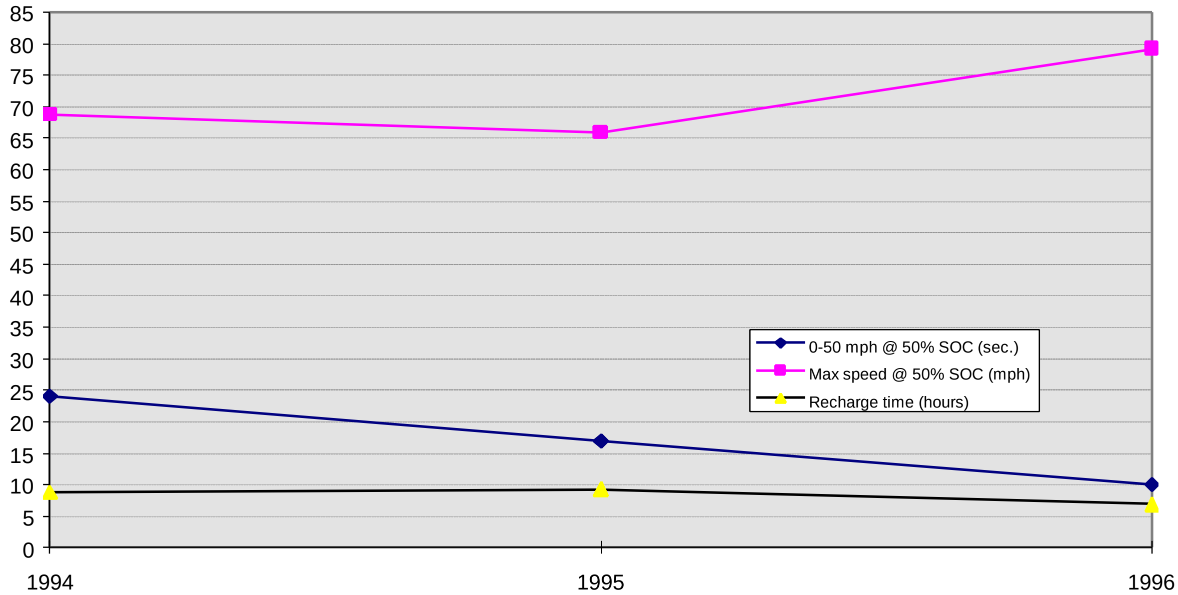


Figure EVA-3. EV America test results for acceleration in seconds and maximum speed in mph at 50% state of charge (SOC), and recharge time in hours. The plotted results are the average test results for all vehicles tested during each respective year.

Test Results Reported on Vehicle Fact Sheets

The following fact sheets summarize the test results for each vehicle in the Site Operator Program. Results in regular type indicate the results met the performance standards. Results in bold type indicate the vehicle did not meet the standard for that performance category.

EVAMERICA	USDOE	PERFORMANCE STATISTICS

ACCELERATION 0-50 mph
At 100% SOC: 6.3 sec
At 50% SOC: 6.7 sec
Max. Power: 116.4 kW
Performance Goal: 13.5 sec at 50% SOC

MAXIMUM SPEED @ 50% SOC
At 1/4 Mile: 78.9 mph
At 1 Mile: 80.4 mph
Performance Goal: 70 mph in one mile

CONSTANT SPEED RANGE @ 45 mph
Range: 135.2 miles
Energy Used: 15.58 kWh
Average Power: 5.19 kW
Efficiency: 115 Wh/mile
Specific Energy: 31.9 Wh/kg

GENERAL MOTORS EV1
VEHICLE SPECIFICATIONS

PURPOSE-BUILT VEHICLE
Base Vehicle: 1997 EV1
VIN: 4g5px2250t0100009
Seatbelt Positions: Two
Standard Features:

- Heat Pump Climate Control System
- Cruise Control
- Power Door Locks, Power Windows
- Power Steering
- Dual Air Bags
- Front Disc Brakes
- Anti-Lock Brakes
- Front Wheel Drive
- Regenerative Braking
- Daytime Running Lights
- AM/FM Stereo w/Cassette and CD Player w/4 Speaker System
- ElectiClear Windshield
- Check Tire Pressure System
- High Voltage Isolation Assurance
- Welded & Bonded Aluminum Alloy Body
- Electronic Key Pad Entry/Vehicle Activation System
- 110V 1.2 kW Convenience Charger

BATTERY
Manufacturer: Delphi
Type: Valve Regulated Lead-acid
Number of Modules: 26
Weight of Module: 18.8 kg
Weight of Pack(s): 1175 kg

BATTERY
Pack Locations: T-Pack Integral
Nominal Module Voltage: 12 V
Nominal System Voltage: 312 V
Nominal Capacity (1C): 53 Ah

WEIGHTS
Design Curb Weight: 2970 lb
Delivered Curb Weight: 2922 lb
Distribution F/R: 53/47 %
GVWR: 3410 lb
GAWR F/R: 1705/1705 lb
Payload: 440 lb
Performance Goal: 400 lb

DIMENSIONS
Wheelbase: 98.9 inches
Track F/R: 57.9/49.0 inches
Length: 169.7 inches
Width: 69.5 inches
Height: 50.5 inches
Ground Clearance: **4.2 inches at GVWR**
Performance Goal: 5.0 inches at GVWR

CHARGER
Location: Off-Board
Type: Delco Electronics Inductive 6.6 kW
Input Voltages: 156 to 260 VAC

TIRES
Tire Mfg: Michelin
Tire Model: Proxima RR Radial
Tire Size: P175/65R14
Tire Pressure F/R: 50/50 psi
Spare Installed: No; Self-Sealing Tires

CONSTANT SPEED RANGE @ 60 mph
Range: 89.1 miles
Energy Used: 14.58 kWh
Average Power: 9.79 kW
Efficiency: 164 Wh/mile
Specific Energy: 29.8 Wh/kg

DRIVING CYCLE RANGE
Range per SAE J1634: 78.2 miles
Energy Used: 12.84 kWh
Average Power: 4.06 kW
Efficiency: 164 Wh/mile
Specific Energy: 26.3 Wh/kg
Performance Goal: 60 miles

BRAKING FROM 60 mph
Controlled Dry: 171.0 ft
Controlled Wet: 214.8 ft
Panic Wet: 211.9 ft
Course Deviation: 0.0 ft

HANDLING
Avg Time @ 90% SOC: 55.8 sec
Avg Time @ 50% SOC: 55.4 sec
Avg Time @ 20% SOC: 55.4 sec
Avg ICE Full Size Time: 54.62 sec

GRADEABILITY (Calculated)
Maximum Speed @ 3%: 79.0 mph
Maximum Speed @ 6%: 78.2 mph
Maximum Grade: 53.2%
Time on 3% Grade: 28 min 57 sec
Performance Goal: 15 Min

CHARGING EFFICIENCY
Efficiency: 248 Wh-AC/mile
Energy Cost @ 10 ¢/kWh: 2.48 ¢/mile

TEST NOTES:

1. At various times during these range tests, the Battery Life, Reduced Performance, Service Soon, and Service Now telltales illuminated.
2. Charging time was extended due to high temperature conditions.
3. Specific Energy values were calculated using the number of modules times the module weight.
4. The battery pack data collection voltage signal was reduced 100:1 through a voltage divider installed by General Motors. This was for personnel protection.
5. The Standing Water Test was conducted with a water depth of six inches versus eight inches.

This vehicle meets all EV America Minimum Requirements listed on back

Values in **bold** indicate the Performance Goal was not met. * All Power and Energy values are DC unless otherwise specified.

CHARGER
Max Charger Ground Current: <0.01 mA
Max Battery Leakage Current: <0.01 mA
Max DC Charge Current: 16.83 Amps
Max AC Charge Current: 28.96 Amps
Pwr Factor @ Max Current: 1.00
THD(V)/(I) @ Max Current: 2.78/4.80 %
Peak Demand: 5.93 kW
Time to Recharge: 5 Hrs 18 min
Performance Goal: 8 hours

TOYOTA RAV4 EV
VEHICLE SPECIFICATIONS

PERFORMANCE STATISTICS

ACCELERATION 0-50 mph
At 100% SOC: 13.15 sec
At 50% SOC: 13.3 sec
Max. Power: 58.6 kW
Performance Goal: 13.5 sec at 50% SOC

MAXIMUM SPEED @ 50% SOC
At 1/4 Mile: 64.6 mph
At 1 Mile: 77.9 mph
Performance Goal: 70 mph in one mile

CONSTANT SPEED RANGE @ 45 mph
Range: 81.7 miles
Energy Used: 16.21 kWh
Average Power: 9.01 kW
Efficiency: 198 Wh/mile
Specific Energy: 32.2 Wh/kg

CONVERTED VEHICLE
Base Vehicle: 1996 Toyota RAV4
VIN:327T0220000000000
Seatbelt Positions: Four

Standard Features:
- Air Conditioning (Heat Pump)
- Heating (Heat Pump)
- Front Wheel Drive
- Power Steering
- Power Brakes
- Front Disk Brakes
- Regenerative Braking
- Drivers Side Air Bag
- AM/FM Stereo Radio

BATTERY
Manufacturer: Matsushita Battery
Type: Valve Regulated Lead-acid
Number of Modules: 24
Weight of Module: 21 kg
Weight of Pack(s): 550 kg
Pack Locations: Underbody
Nominal Module Voltage: 12 V
Nominal System Voltage: 288 V
Nominal Capacity (1C): 55 A/H

WEIGHTS
Design Curb Weight: 3329 lb
Delivered Curb Weight: 3364 lb
Distribution F/R: 48/52 %
GVWR: 3990 lb
GAWR F/R: 1929/2061 lb
Payload: 626 lb
Performance Goal: 600 lb

DIMENSIONS
Wheelbase: 86.4 inches
Track F/R: 57.6/56.7 inches
Length: 146.6 inches
Width: 67.2 inches
Height: 62.5 inches
Ground Clearance: **4.1 inches at GVWR**

Performance Goal: 5.0 inches at GVWR

CHARGER
Location: On-board
Type: High Frequency Resonant Converter
Input Voltages: 90-264 VAC

TIRES
Tire Mfg: Yokohama
Tire Model: AVS E100 Radial
Tire Size: 195/80R16
Tire Pressure F/R: 44/44 psi
Spare Installed: Yes

CONSTANT SPEED RANGE @ 60 mph
Range: 54.7 miles
Energy Used: 15.82 kWh
Average Power: 17.16 kW
Efficiency: 289 Wh/mile
Specific Energy: 31.4 Wh/kg

DRIVING CYCLE RANGE
Range per SAE J1634: 68.2 miles
Energy Used: 16.05 kWh
Average Power: 6.44 kW
Efficiency: 235 Wh/mile
Specific Energy: 31.8 Wh/kg
Performance Goal: 60 miles

BRAKING FROM 60 mph
Controlled Dry: 140.1 ft
Controlled Wet: 196.3 ft
Panic Wet: 260.1 ft
Course Deviation: 3 ft

HANDLING
Avg Time @ 90% SOC: 56.67 sec
Avg Time @ 50% SOC: 55.68 sec
Avg Time @ 20% SOC: 55.08 sec
Avg Dodge Neon Time: 54.62 sec

GRADEABILITY (Calculated)
Maximum Speed @ 3%: 75.6 mph
Maximum Speed @ 6%: 69.3 mph
Maximum Grade: 29.1%

Time on 3% Grade: 28 min 24 sec
Performance Goal: 15 Min

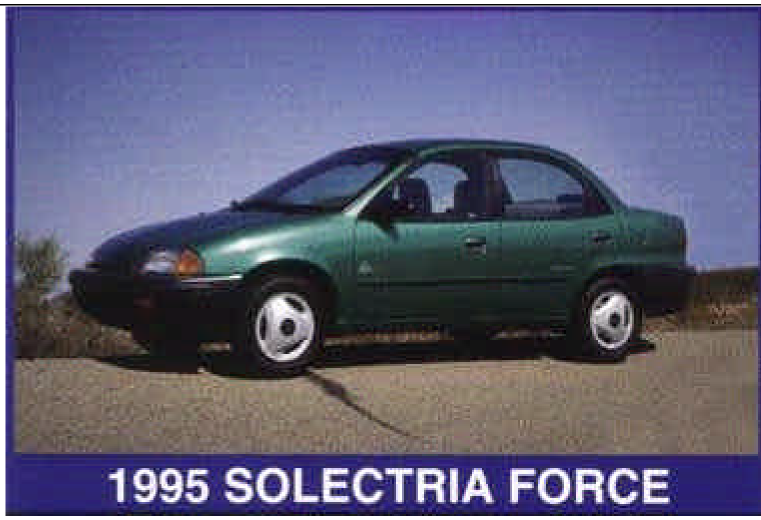
CHARGING EFFICIENCY
Efficiency: 412 Wh-AC/mile
Energy Cost @ 10¢/kWh: 4.12 ¢/mile

CHARGER
Max Charger Ground Current: <0.01 mA
Max Battery Leakage Current: **1.24 mA**
Max DC Charge Current: 13.48 Amps
Max AC Charge Current: 24.01 Amps
Pwr Factor @ Max Current: 1.00
THD(V)(I) @ Max Current: 4.51/4.73%
Peak Demand: 4.15 kW
Time to Recharge: **8 Hrs 29 min**
Performance Goal: 8 hours

TEST NOTES:

1. The Battery Leakage Current measured during the 8-in. standing water test exceeded the Maximum Allowable under EV America Technical Specifications (1.24 mA vs. 1.0 mA required).
2. Contrary to the requirements of EV America Technical Specification 8.1, the charger does not cycle to maintain the battery in a fully charged condition.
3. Contrary to the requirements of EV America Technical Specification 8.1, The battery charger will not initiate a full algorithm charge unless the battery SOC is =< 90 %.
4. The vehicle provided to EV America was a Prototype. Some information was not provided and/or not available from Toyota. The specifics are noted in the Manufacturer's Proposal Review Checklist in the Test Report.
5. Specific Energy calculations were completed using the aggregate weight of the battery modules only.
6. The auxiliary battery was replaced due to an apparent internal fault.
7. This vehicle did not have FMVSS Certification at the time of testing.

Values in **bold** indicate the Performance Goal was not met.
All Power and Energy values are DC unless otherwise specified.



1995 SOLECTRIA FORCE
VEHICLE SPECIFICATIONS

PERFORMANCE STATISTICS

ACCELERATION 0-50 mph
At 100% SOC: 18.3 sec
At 50% SOC: **18.5 sec**
Max. Power: 34.4 kW
Performance Goal: 13.5 sec at 50% SOC
MAXIMUM SPEED @ 50% SOC
At 1/4 Mile: 57.8 mph
At 1 Mile: **69.9 mph**
Performance Goal: 70 mph in one mile
CONSTANT SPEED RANGE @ 45 mph
Range: 105.9 miles
Energy Used: 14.53 kWh
Average Power: 6.13 kW
Efficiency: 137 Wh/mile
Specific Energy: 57.2 Wh/kg

CONVERTED VEHICLE
Base Vehicle: 1995 Geo Metro
VIN:2C1MR529XS6783464
Seatbelt Positions: **Three**
Standard Features:

Power Brakes
Front Disk Brakes
Front Wheel Drive
Dual Air Bags
AM/FM Stereo w/Cassette
Electric Heater

Options as Tested:
None

BATTERY
Manufacturer: GM Ovonic
Type: 13.2EV85 Nickel-metal Hydride
Number of Modules: 14
Weight of Module: 18 kg
Weight of Pack(s): 254 kg
Pack Locations: Undertrunk/Underhood
Nominal Module Voltage: 13.2 V
Nominal System Voltage: 185 V
Nominal Capacity (1C): 85 Ah

WEIGHTS
Design Curb Weight: 2246 lb
Delivered Curb Weight: 2304 lb
Distribution F/R: 50/50 %
GVWR: 2755 lb
GAWR F/R: 1432/1366 lb
Payload: **451 lb**
Performance Goal: 664 lb
DIMENSIONS
Wheelbase: 93.5 inches
Track F/R: 53.9/53.9 inches
Length: 164.1 inches
Width: 62.5 inches
Height: 54.6 inches
Ground Clearance: > 5 inches
CHARGER
Location: Trunk
Type: Solectria 3 kW Conductive
Input Voltages: 208-240 VAC
TIRES
Tire Mfg: Goodyear
Tire Model: Invicta GL Radial
Tire Size: P165/70R13
Tire Pressure F/R: 44/44 psi
Spare Installed: Yes - behind driver seat

CONSTANT SPEED RANGE @ 60 mph
Range: 70.9 miles
Energy Used: 14.07 kWh
Average Power: 11.72 kW
Efficiency: 199 Wh/mile
Specific Energy: 55.4 Wh/kg
DRIVING CYCLE RANGE
Range per SAE J1634: 84.5 miles
Energy Used: 14.59 kWh
Average Power: 4.26 kW
Efficiency: 173 Wh/mile
Specific Energy: 57.4 Wh/kg
Performance Goal: 60 miles
BRAKING FROM 60 mph
Controlled Dry: 180.3 ft
Controlled Wet: 318.8 ft
Panic Wet: 287.4 ft
Course Deviation: 0.0 ft
HANDLING
Avg Time @ 90% SOC: 58.5 sec
Avg Time @ 50% SOC: 58.0 sec
Avg Time @ 20% SOC: 60.5 sec
Avg Dodge Neon Time: 54.6 sec

TEST NOTES:

1. Full charge may not occur when charging in ambient temperatures of >100°F
2. To charge in less than 12 hours, charging should occur in ambient temperatures <100°F
3. When operating on wet surfaces,(rain, standing water, ice, snow, etc.) the regenerative braking selector must be set in the "Snow & Ice" position
4. The vehicle cannot be parked or operated in standing water > 6 in.
5. The left rear passenger door would not open, and was repaired by the manufacturer.
6. The left rear seat is not a designated seating position (may not be used for seating).
7. The vehicle exhibited front-end shudder at high speeds and was repaired by the manufacturer.
8. The vehicle's amp-hour meter required repair during the Test Program.
9. Charger Test was completed with ambient temperatures of 94°F < temp < 98°F.
10. Vehicle was removed from the Test Program for repair for one 24-hour period.

Values in **bold** indicate the Performance Goal was not met. All Power and Energy values are DC unless otherwise specified.

GRADEABILITY (Calculated)
Maximum Speed @ 3%: 65.1 mph
Maximum Speed @ 6%: 54.3 mph
Maximum Grade: 19.3%Time on 3% Grade: 25 min 25 sec
Performance Goal: 15 Min

CHARGING EFFICIENCY
Efficiency: 318 Wh-AC/mile
Energy Cost @ 10¢/kWh: 3.18 ¢/mile

CHARGER
Max Charger Ground Current: <0.01 mA
Max Battery Leakage Current: <0.01 mA
Max DC Charge Current: 14.1 Amps
Max AC Charge Current: 14.0 Amps
Pwr Factor @ Max Current: 0.99
THD(V)/(I) @ Max Current: 3.39/3.97%
Peak Demand: 2.84 kW
Time to Recharge: **8 Hrs 57 min**
Performance Goal: 8 hours

1995 SOLECTRIA E10
VEHICLE SPECIFICATIONS

PERFORMANCE STATISTICS

ACCELERATION 0-50 mph
At 100% SOC: 14.8 sec
At 50% SOC: 17.4 sec
Max. Power: 71.6 kW
Performance Goal: 13.5 sec at 50% SOC

MAXIMUM SPEED @ 50% SOC
At 1/4 Mile: 55.4 mph
At 1 Mile: 67.9 mph
Performance Goal: 70 mph in one mile

CONSTANT SPEED RANGE @ 45 mph
Range: 80.8 miles
Energy Used: 18.49 kWh
Average Power: 9.99 kW
Efficiency: 229 Wh/mile
Specific Energy: 32.3 Wh/kg

CONVERTED VEHICLE
Base Vehicle: 1995 Chevrolet S-10 Pickup
VIN:1GCCS144XSK175700
Seatbelt Positions: Two

Standard Features:
- Power Steering
- Power Brakes
- Front Disk Brakes
- Rear Anti-Lock Brakes
- Driver Side Air Bags
- AM/FM Stereo Radio w/Cassette
- Electric Heater

Options as Tested:
None

BATTERY
Manufacturer: Hawker
Type: G12V38Ah10C Sealed Lead-acid
Number of Modules: 36
Weight of Module: 16 kg
Weight of Pack(s): 573 kg
Pack Locations: Underhood/Underbed
Nominal Module Voltage: 12 V
Nominal System Voltage: 144 V
Nominal Capacity (1C): 30 Ah

WEIGHTS
Design Curb Weight: 3790 lb
Delivered Curb Weight: 3959 lb
Distribution F/R: 48/52 %
GVWR: 4600 lb
GAWR F/R: 2500/2700 lb
Payload: 641 lb
Performance Goal: 632 lb

DIMENSIONS
Wheelbase: 110.0 inches
Track F/R: 54.6/54.6 inches
Length: 188.7 inches
Width: 68.0 inches
Height: 61.8 inches
Ground Clearance: 4.7 inches

CHARGER
Location: Underhood
Type: Solectria 3 kW Conductive
Input Voltages: 208-240 VAC

TIRES
Tire Mfg: Goodyear
Tire Model: Invicta GS Radial
Tire Size: P215/70R15
Tire Pressure F/R: 44/44 psi
Spare Installed: No

CONSTANT SPEED RANGE @ 60 mph
Range: 49.9 miles
Energy Used: 15.59 kWh
Average Power: 17.85 kW
Efficiency: 312 Wh/mile
Specific Energy: 27.2 Wh/kg

DRIVING CYCLE RANGE
Range per SAE J1634: 55.1 miles
Energy Used: 15.59 kWh
Average Power: 6.87 kW
Efficiency: 283 Wh/mile
Specific Energy: 27.3 Wh/kg
Performance Goal: 60 miles

BRAKING FROM 60 mph
Controlled Dry: 184.2 ft
Controlled Wet: 259.4 ft
Panic Wet: 316.0 ft
Course Deviation: 1.0 ft

HANDLING
Avg Time @ 90% SOC: 56.1 sec
Avg Time @ 50% SOC: 56.8 sec
Avg Time @ 20% SOC: 58.7 sec
Avg ICE S-10 Time: 58.3 sec

TEST NOTES:

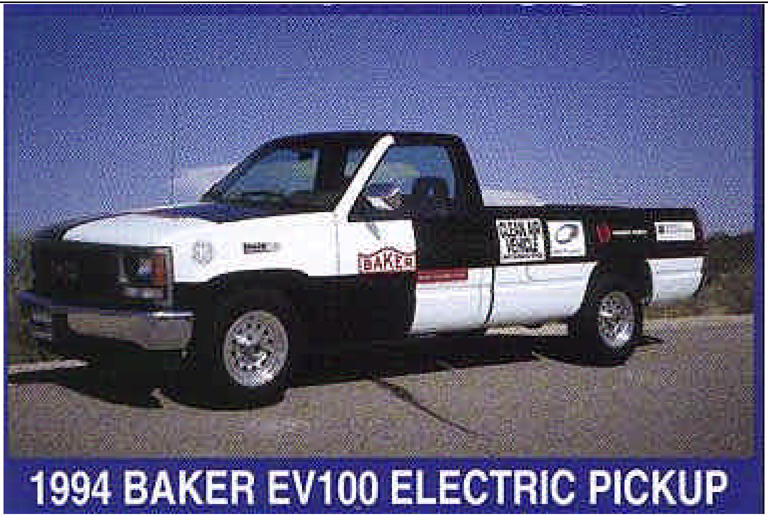
1. The charge algorithm was modified twice during the Test Program.
2. The amp-hour meter showed continuous discharge, even when vehicle was charging.
3. During the "55 mph at 3% Grade Test," the vehicle stopped with no apparent cause.
4. Full charge may not occur when charging at ambient temperatures of >100°F.
5. To charge in less than 12 hours, charging should occur in ambient temperatures <100°F.
6. Vehicle was removed from the Test Program for repair for three 24-hour periods.
7. The Charger Test was completed with ambient temperatures of 82°F < temp < 90°F.
8. The vehicle charger tripped the GFI feeder breaker routinely during the Test Program.

Values in bold indicate the Performance Goal was not met. All Power and Energy values are DC unless otherwise specified.

GRADEABILITY (Calculated)
Maximum Speed @ 3%: 59.4 mph
Maximum Speed @ 6%: 48.5 mph
Maximum Grade: 28.2%
Time on 3% Grade: 12 min 47 sec
Performance Goal: 15 Min

CHARGING EFFICIENCY
Efficiency: 317 Wh-AC/mile
Energy Cost @ 10 ¢/kWh: 3.17 ¢/mile

CHARGER
Max Charger Ground Current: <0.01 mA
Max Battery Leakage Current: <0.01 mA
Max DC Charge Current: 21.0 Amps
Max AC Charge Current: 14.5 Amps
Pwr Factor @ Max Current: 0.99
THD(V)/(I) @ Max Current: 4.23/4.05 %
Peak Demand: 2.92 kW
Time to Recharge: 11 Hrs 11 min
Performance Goal: 8 hours



1994 BAKER EV100 ELECTRIC PICKUP
VEHICLE SPECIFICATIONS

CONVERTED VEHICLE
Base Vehicle: 1994 GMC Full Size Pickup
VIN: 1GTFC24Z6RZ562287
Seatbelt Positions: Three

Standard Features:
- Power Steering
- Power Brakes
- Front Disk Brakes
- Rear Anti-Lock Brakes
- Driver Side Air Bag
- AM/FM Stereo Radio
- Diesel Fuel Fired Heater

Options as Tested:
- Air Conditioning

BATTERY
Manufacturer: GM Ovonic
Type: 13EV85 Nickel-metal Hydride
Number of Modules: 25
Weight of Module: 18 kg
Weight of Pack(s): 450 kg
Pack Locations: Cargo Bed
Nominal Module Voltage: 13.2 V
Nominal System Voltage: 330 V
Nominal Capacity (1C): 85 Ah

WEIGHTS
Design Curb Weight: 5132 lb
Delivered Curb Weight: 5481 lb
Distribution F/R: 50/50 %
GVWR: 7200 lb
GAWR F/R: 3150/4670 lb
Payload: 1719 lb
Performance Goal: 632 lb

DIMENSIONS
Wheelbase: 131.5 inches
Track F/R: 62.8/64.0 inches
Length: 218.4 inches
Width: 77.1 inches
Height: 69.1 inches
Ground Clearance: >5 inches

CHARGER
Location: Off-Board
Type: Hughes 6.6kW Inductive
Input Voltages: 165 to 260 VAC

TIRES
Tire Mfg: General
Tire Model: Amber 550 AS Radial
Tire Size: P225/75R16
Tire Pressure F/R: 40/65 psi
Spare Installed: No

PERFORMANCE STATISTICS

ACCELERATION 0-50 mph
At 100% SOC: 12.9 sec
At 50% SOC: **14.9 sec**
Max. Power: 102.2 kW
Performance Goal: 13.5 sec at 50% SOC

MAXIMUM SPEED @ 50% SOC
At 1/4 Mile: 59.8 mph
At 1 Mile: 71.1 mph
Performance Goal: 70 mph in one mile

CONSTANT SPEED RANGE @ 45 mph
Range: 61.2 miles
Energy Used: 21.40 kWh
Average Power: 15.33 kW
Efficiency: 350 Wh/mile
Specific Energy: 47.6 Wh/kg

CONSTANT SPEED RANGE @ 60 mph
Range: 31.5 miles
Energy Used: 15.36 kWh
Average Power: 25.78 kW
Efficiency: 487.6 Wh/mile
Specific Energy: 34.1 Wh/kg

DRIVING CYCLE RANGE
Range per SAE J1634: **56.6 miles**
Energy Used: 25.67 kWh
Average Power: 11.32 kW
Efficiency: 453.5 Wh/mile
Specific Energy: 57.0 Wh/kg
Performance Goal: 60 miles

BRAKING FROM 60 mph
Controlled Dry: 199.9 ft
Controlled Wet: 238.5 ft
Panic Wet: 281.2 ft
Course Deviation: 2.5 ft

HANDLING
Avg Time @ 90% SOC: 59.9 sec
Avg Time @ 50% SOC: 60.4 sec
Avg Time @ 20% SOC: 60.9 sec
Avg ICE Full Size Time: 58.3 sec

GRADEABILITY (Calculated)
Maximum Speed @ 3%: 67.1 mph
Maximum Speed @ 6%: 56.8 mph
Maximum Grade: 31.5%
Time on 3% Grade: 26 min 36 sec
Performance Goal: 15 Min

TEST NOTES:

1. Vehicle was delivered with a non-functional amp-hour meter. It remained non-functioning throughout the Test Program.
2. The charge algorithm was modified after the 45 mph and 60 mph range tests.
3. The Start-Up Sequence allows the vehicle to be operated without functioning power steering and power assisted brakes.
4. The "Limit Light" warning light did not provide useful information to the driver due to multiple inputs.
5. Oil leaks on the drive motor were repaired.
6. The Battery Pack Management (BPM) switch required repair.
7. Vehicle was removed from the Test Program for repair for one 24-hour period.

Values in **bold** indicate the Performance Goal was not met.
All Power and Energy values are DC unless otherwise specified.

CHARGING EFFICIENCY
Efficiency: 715 Wh-AC/mile
Energy Cost @ 10 ¢/kWh: 7.15 ¢/mile

CHARGER
Max Charger Ground Current: <0.01 mA
Max Battery Leakage Current: 0.31 mA
Max DC Charge Current: 16.33 Amps
Max AC Charge Current: 30.65 Amps
Pwr Factor @ Max Current: 1.00
THD(V)/(I) @ Max Current: 3.40/4.47 %
Peak Demand: 6.53 kW
Time to Recharge: 7 Hrs 50 min
Performance Goal: 8 hours

VEHICLE SPECIFICATIONS

VEHICLE TYPE
Conversion Of: Geo Metro
VIN: 2C1MR24G5R6799793
Seating Capacity: **2 Adults**
Features: Heater, Front Wheel Drive, Front Disk Brakes

DIMENSIONS
Wheelbase: 88.9 inches
Track F/R: 55/54 inches
Length: 147.5 inches
Width: 62.4 inches
Height: 52.4 inches
Ground Clearance: >50 mm
Cargo Space: **Battery Pack Displaces Rear Seat and original equipment manufacturer (OEM) Cargo Well.**

WEIGHT
Curb Weight: 2719 lb
Test Weight: 2719 lb
Distribution F/R: 43/57 %
Conversion GVWR: 3040 lb
OEM GVWR: 2447 lb
Payload: **321 lb**

WHEELS & TIRES
Wheel Size: 13 inch
Tire Mfg: Goodyear Invicta
Tire Size: P175/70R13
Tire Pressure F/R: 44/44 psi
Spare Installed: No

DRIVE SYSTEM
Drive Type: Brush DC
Motor Mfg: Advanced DC

DRIVE SYSTEM
Controller Mfg: Curtis PMC
Transmission: **3 Speed Automatic**

BATTERY
Manufacturer: Optima
Type: **Prototype Deep Cycle**
Number of Modules: 22
Total Traction Voltage: 132 Volts
Battery Pack Weight: 858 lb
Locations In Vehicle: Rear Seat & Trunk

CHARGER
Location: **Off-Board**
Input Voltage(s): **N/A**
Input Current(s): **N/A**

INTERLOCKS
Key Removable When Off Only: Yes
Key Off In Park Only: Yes
Start In Park Only: Yes
Start Blocked By Accelerator: **No**
Start Blocked On Charge: **No**

REQUIREMENTS
Manual Disconnect Present & Operational: **No**
Batteries Sealed or Valve Regulated: Yes
Charger Automatic Control: **No**
SOC Indicator: Yes
Battery Voltage Indicator: **No**
Battery Current Indicator: Yes
Regenerative Current Indicator: N/R
Transmission Single Speed: Yes
Transmission Parking Pawl: Yes
No Open Access to High Voltage: **No**
All High Voltage Clearly Marked: **No**
Control Efforts Similar To OEM: Yes

PERFORMANCE STATISTICS

ACCELERATION AT 90% SOC *
Zero to 30 mph: 7.1 sec
Zero to 40 mph: 11.5 sec
Zero to 50 mph: 17.0 sec
Zero to 60 mph: 23.8 sec
Performance Goal: 13.5 seconds; 0 to 60 mph

ACCELERATION AT 50% SOC *
Zero to 30 mph: 6.6 sec
Zero to 40 mph: 10.9 sec
Zero to 50 mph: 16.5 sec
Zero to 60 mph: 23.0 sec
Performance Goal: 13.5 seconds; 0 to 60 mph

MAXIMUM SPEED
At 50% SOC: 81 mph
Performance Goal: 70 mph

CONSTANT SPEED RANGE
45 mph Distance: 47.1 miles
45 mph Energy Used: 11.3 kWh
45 mph Efficiency: 0.240 kWh/mile
45 mph Specific Energy: 0.0132 kWh/lb
60 mph Distance: 39.6 miles
60 mph Energy Used: 7.1 kWh
60 mph Efficiency: 0.180 kWh/mile
60 mph Specific Energy: 0.0083 kWh/lb

DRIVING CYCLE RANGE
77°F Distance: 37.9 miles
77°F Energy Used: 13.24 kWh
77°F Efficiency: 0.349 kWh/mile
77°F Specific Energy: 0.0154 kWh/lb
19°F Distance: 27.6 miles
19°F Energy Used: 10.13 kWh
19°F Efficiency: 0.367 kWh/mile
19°F Specific Energy: 0.0118 kWh/lb

Performance Goal: 60 miles

GRADEABILITY *
Maximum Grade: 32%
Performance Goal: 25%
Speed At 3% Grade: >70 mph
Performance Goal: 55 mph
Speed At 6% Grade: 57 mph
Performance Goal: 45 mph

HANDLING COURSE
Avg Time @ 90% SOC: 60.3 sec
Avg Time @ 50% SOC: 59.5 sec
Avg Time @ 20% SOC: 58.4 sec
Avg Dodge Neon (ICE) Time: 54.62 sec
Average Chevrolet S-10 Time: 58.29 sec

BRAKING STABILITY
Controllability: No Stability Problems
Distance Dry/Wet: 208.8/323.6 ft

TEST EXCEPTIONS
Prototype batteries
Payload 379 lb less than required
No onboard charger
Test weight greater than OEM GVWR
OEM GVWR re-rated (not certified) by converter
Required battery module replacement
Testing delayed by high battery temperature
Offboard charger fuse failure

Test Date: October 1994
Notes: Bold - Results did not meet EV America Performance Goal

* - Tested at gross vehicle weight
N/R - No regenerative braking

CHARGER
Ground Current During Charge: 8 mA
Battery Leakage Current: 0.01 mA
Charger Efficiency: **N/A**
Average Power Factor: **N/A**
Performance Goal: 0.95
Average THD: **N/A**
Performance Goal: 5%
Time From 80% DOD: **N/A**
Performance Goal: <8 hours

EV America

VEHICLE SPECIFICATIONS

PERFORMANCE STATISTICS

ACCELERATION AT 90% SOC *
Zero to 30 mph: 8.7 sec
Zero to 40 mph: 15.3 sec
Zero to 50 mph: 17.7 sec
Zero to 60 mph: 35.5 sec
Performance Goal: 13.5 seconds; 0 to 60 mph

ACCELERATION AT 50% SOC *
Zero to 30 mph: 9.4 sec
Zero to 40 mph: 16.5 sec
Zero to 50 mph: 26.0 sec
Zero to 60 mph: 43.0 sec
Performance Goal: 13.5 seconds; 0 to 60 mph

MAXIMUM SPEED
At 50% SOC: 67 mph
Performance Goal: 70 mph

VEHICLE TYPE
Conversion Of: Geo Metro
VIN: 2C1MR2466N6766568
Seating Capacity: 2 Adults
Features: Power Brakes, Front Wheel Drive, Front Disk Brakes & Heater

DIMENSIONS
Wheelbase: 89.4 inches
Track F/R: 54.3/53.8 inches
Length: 148.3 inches
Width: 62.4 inches
Height: 52.0 inches
Ground Clearance: >50 mm
Cargo Space: **Battery Pack Displaces Rear Seat and OEM Cargo Well.**

WEIGHT
Curb Weight: 2560 lb
Test Weight: 2582 lb
Distribution F/R: 49/51 %
Conversion GVWR: 2910 lb
OEM GVWR: 2447 lb
Payload: 328 lb

WHEELS & TIRES
Wheel Size: 13 inch
Tire Mfg: Goodyear Invicta
Tire Size: P175/70R13
Tire Pressure F/R: 44/44 psi
Spare Installed: No

DRIVE SYSTEM
Drive Type: Brush DC
Motor Mfg: Advanced DC Motors
Controller Mfg: Curtis PMC
Transmission: **5 Speed Manual**

BATTERY
Manufacturer: Trojan
Type: **T145 Flooded Lead-acid**
Number of Modules: 13
Total Traction Voltage: 78 Volts
Battery Pack Weight: 923 lb
Locations In Vehicle: Rear Seat & Trunk

CHARGER
Location: Behind Driver Seat
Input Voltage(s): 120 volts AC
Input Current(s): 13 amperes AC

INTERLOCKS
Key Removable When Off Only: Yes
Key Off In Park Only: No
Start In Park Only: No
Start Blocked By Accelerator: No
Start Blocked On Charge: No

REQUIREMENTS
Manual Disconnect Present & Operational: No
Batteries Sealed or Valve Regulated: No
Charger Automatic Control: Yes
SOC Indicator Present: Yes
Battery Voltage Indicator: No
Battery Current Indicator: Yes
Regenerative Current Indicator: N/R
Transmission Single Speed: No
Transmission Parking Pawl: No
No Open Access to High Voltage: No
All High Voltage Clearly Marked: No
Control Efforts Similar To OEM: Yes

CONSTANT SPEED RANGE
45 mph Distance: 88.4 miles
45 mph Energy Used: 14.5 kWh
45 mph Efficiency: 0.164 kWh/mile
45 mph Specific Energy: 0.0157 kWh/lb
60 mph Distance: 51.6 miles
60 mph Energy Used: 11.3 kWh
60 mph Efficiency: 0.219 kWh/mile
60 mph Specific Energy: 0.0122 kWh/lb

DRIVING CYCLE RANGE
77°F Distance: 49.50 miles
77°F Energy Used: 11.64 kWh
77°F Efficiency: 0.235 kWh/mile
77°F Specific Energy: 0.0126 kWh/lb
19°F Distance: 33.20 miles
19°F Energy Used: Not Measured
19°F Efficiency: Not Measured
19°F Specific Energy: Not Measured

Performance Goal: 60 miles

GRADEABILITY*
Maximum Grade: 42%
Performance Goal: 25%
Speed At 3% Grade: 56 mph
Performance Goal: 55 mph
Speed At 6% Grade: 42 mph
Performance Goal: 45 mph

HANDLING COURSE
Avg Time @ 90% SOC: 60.9 sec
Avg Time @ 50% SOC: 61.3 sec
Avg Time @ 20% SOC: 64.5 sec
Avg Dodge Neon (ICE) Time: 54.62 sec
Average Chevrolet S-10 Time: 58.29 sec

BRAKING STABILITY
Controllability: No Stability Problems
Distance Dry/Wet: 177.2/272.8 ft

TEST EXCEPTIONS
Payload 372 lb less than required
Test weight greater than OEM GVWR
OEM GVWR re-rated by converter (not certified)
Flooded electrolyte batteries
Testing delayed by high battery temperature
Testing delayed by charge times > 8 hours

Test Date: October 1994
Notes: Bold - Results did not meet EV America Performance Goal
* - Tested at gross vehicle weight
N/R - No regenerative braking

CHARGER
Ground Current During Charge: 3 mA
Battery Leakage Current: 0.01 mA
Charger Efficiency: 93 %
Average Power Factor: 0.54
Performance Goal: 0.95
Average THD: 91.1 %
Performance Goal: 5%
Time From 80% DOD: 10 hours 40 minutes
Performance Goal: <8 hours

EV America

VEHICLE SPECIFICATIONS

VEHICLE TYPE
Conversion Of: Ford Ranger
VIN: 1FTCRIOU1PPA36115
Seating Capacity: 2 Adults
Features: AM/FM Stereo, Power Brakes, Tilt Wheel, Front Disc Brakes & Anti-lock Brakes

DIMENSIONS
Wheelbase: 114.8 inches
Track F/R: 56.9/57.4 inches
Length: 198.1 inches
Width: 69.6 inches
Height: 63.5 inches
Ground Clearance: >50 mm
Cargo Space: 10 cu ft of OEM cargo space lost due to placement of battery box.

WEIGHT
Curb Weight: 4000 lb
Test Weight: 4354 lb
Distribution F/R: 47/53 %
Conversion GVWR: 4700 lb
OEM GVWR: 4260 lb
Payload: 346 lb

WHEELS & TIRES
Wheel Size: 14 inch
Tire Mfg: Goodyear Invicta
Tire Size: P215/75R14
Tire Pressure F/R: 35/35 psi
Spare Installed: No

DRIVE SYSTEM
Drive Type: Brush DC
Motor Mfg: General Electric

DRIVE SYSTEM
Controller Mfg: General Electric
Transmission: **5 Speed Manual**

BATTERY
Manufacturer: Trojan
Type: **T145 Flooded Lead-acid**
Number of Modules: 21
Total Traction Voltage: 126 Volts
Battery Pack Weight: 1491 lb
Locations In Vehicle: Cargo Bed & Under Hood

CHARGER
Location: **Off-Board**
Input Voltage(s): **N/A**
Input Current(s): **N/A**

INTERLOCKS
Key Removable When Off Only: Yes
Key Off In Park Only: No
Start In Park Only: No
Start Blocked By Accelerator: Yes
Start Blocked On Charge: No

REQUIREMENTS
Manual Disconnect Present & Operational: No
Batteries Sealed or Valve Regulated: No
Charger Automatic Control: No
SOC Indicator: Yes
Battery Voltage Indicator: No
Battery Current Indicator: Yes
Regenerative Current Indicator: N/R
Transmission Single Speed: No
Transmission Parking Pawl: No
No Open Access to High Voltage: No
All High Voltage Clearly Marked: No
Control Efforts Similar To OEM: Yes

PERFORMANCE STATISTICS

ACCELERATION AT 90% SOC *
Zero to 30 mph: 9.7 sec
Zero to 40 mph: 17.6 sec
Zero to 50 mph: 29.8 sec

Performance Goal: 13.5 seconds; 0 to 50 mph

ACCELERATION AT 50% SOC *
Zero to 30 mph: 10.0 sec
Zero to 40 mph: Not Achieved
Zero to 50 mph: Not Achieved
Performance Goal: 13.5 seconds; 0 to 50 mph

MAXIMUM SPEED
At 50% SOC: Not Achieved
Performance Goal: 70 mph

CONSTANT SPEED RANGE
45 mph Distance: 55.4 miles
45 mph Energy Used: 17.8 kWh
45 mph Efficiency: 0.321 kWh/mile
45 mph Specific Energy: 0.0119 kWh/lb

60 mph Distance: 44.0 miles
60 mph Energy Used: 16.6 kWh
60 mph Efficiency: 0.378 kWh/mile
60 mph Specific Energy: 0.0111 kWh/lb

DRIVING CYCLE RANGE
77°F Distance: 21.14 miles
77°F Energy Used: 9.21 kWh
77°F Efficiency: 0.436 kWh/mile
77°F Specific Energy: 0.0062 kWh/lb
19°F Distance: 9.40 miles
19°F Energy Used: 4.37 kWh
19°F Efficiency: 0.465 kWh/mile
19°F Specific Energy: 0.0029 kWh/lb

Performance Goal: 60 miles

GRADEABILITY*
Maximum Grade: 37%
Performance Goal: 25%

Speed At 3% Grade: 29 mph
Performance Goal: 55 mph

Speed At 6% Grade: 19 mph
Performance Goal: 45 mph

HANDLING COURSE
Avg Time @ 90% SOC: 65.5 sec
Avg Time @ 50% SOC: 66.6 sec
Avg Time @ 20% SOC: 70.9 sec
Avg Dodge Neon (ICE) Time: 54.62 sec
Average Chevrolet S-10 Time: 58.29 sec

BRAKING STABILITY
Controllability: No Stability Problems
Distance Dry/Wet: 151.6/201.6 ft

TEST EXCEPTIONS
Payload 304 lb less than required OEM
GVWR re-rated (not certified) by converter
Flooded electrolyte batteries
No onboard charger
Auxiliary battery replaced
Required 12 volt connector repair
Removed from testing to add BAT Catalyst
Testing delayed by high battery temperature
Shock absorbers replaced

Test Date: October 1994
Notes: Bold - Results did not meet EV America Performance Goal
* - Tested at gross vehicle weight
N/R - No regenerative braking

CHARGER
Ground Current During Charge: 9 mA
Battery Leakage Current: 1.7 mA
Charger Efficiency: **N/A**
Average Power Factor: **N/A**
Performance Goal: 0.95
Average THD: **N/A**
Performance Goal: 5%
Time From 80% DOD: **N/A**
Performance Goal: <8 hours

EV America

VEHICLE SPECIFICATIONS

PERFORMANCE STATISTICS

ACCELERATION AT 90% SOC *
Zero to 30 mph: 11.1 sec
Zero to 40 mph: 19.9 sec
Zero to 50 mph: 30.7 sec
Zero to 60 mph: **70.0 sec**
Performance Goal: 13.5 seconds; 0 to 60 mph

ACCELERATION AT 50% SOC *
Zero to 30 mph: 12.9 sec
Zero to 40 mph: 20.8 sec
Zero to 50 mph: 33.9 sec
Zero to 60 mph: **80.0** sec
Performance Goal: 13.5 seconds; 0 to 60 mph

MAXIMUM SPEED
At 50% SOC: **62 mph**
Performance Goal: 70 mph

VEHICLE TYPE
Conversion Of: Dodge Caravan
VIN: 2B4GH25945R100022
Seating Capacity: 5 Adults

Features: A/C, AM/FM Radio, Heater, Power Steering, Power Brakes, Front Wheel Drive & Front Disc Brakes

DIMENSIONS
Wheelbase: 112.4 inches
Track F/R: 60.5/62.3 inches
Length: 177.7 inches
Width: 72.7 inches
Height: 68.0 inches
Ground Clearance: >50 mm
Cargo Space: No Intrusion on OEM Space

WEIGHT
Curb Weight: 5150 lb
Test Weight: 5138 lb
Distribution F/R: 50/50 %
Conversion GVWR: 5950 lb
OEM GVWR: 5950 lb
Payload: 812 lb

WHEELS & TIRES
Wheel Size: 15 inches
Tire Mfg: Goodyear Momentum
Tire Size: P205/75R15
Tire Pressure F/R: 50/50 psi
Spare Installed: Yes

DRIVE SYSTEM
Drive Type: 54 kW Brush DC
Motor Mfg: General Electric
Controller Mfg: General Electric
Transmission: **2 Speed Manual**

BATTERY
Manufacturer: Eagle-Picher
Type: NIF - 200 - 5 Nickel-Iron
Number of Modules: 30
Total Traction Voltage: 180 volts
Battery Pack Weight: 1685 lb
Locations In Vehicle: Beneath Vehicle

CHARGER
Location: Under Hood
Input Voltage(s): **208/240 volts AC**
Input Current(s): 40 amperes AC

INTERLOCKS
Key Removable When Off Only: Yes
Key Off In Park Only: **No**
Start In Park Only: **No**
Start Blocked By Accelerator: Yes
Start Blocked On Charge: Yes

REQUIREMENTS
Manual Disconnect Present & Operational: **No**
Batteries Sealed or Valve Regulated: **No**
Charger Automatic Control: Yes
SOC Indicator: Yes
Battery Voltage Indicator: **No**
Battery Current Indicator: **No**
Regenerative Current Indicator: **No**
Transmission Single Speed: **No**
Transmission Parking Pawl: Yes
No Open Access to High Voltage: Yes
All High Voltage Clearly Marked: **No**
Control Efforts Similar To OEM: Yes

CONSTANT SPEED RANGE
45 mph Distance: 86.4 miles
45 mph Energy Used: 27.4 kWh
45 mph Efficiency: 0.317 kWh/mile
45 mph Specific Energy: 0.0163 kWh/lb
60 mph Distance: 57.0 miles
60 mph Energy Used: 23.78 kWh
60 mph Efficiency: 0.417 kWh/mile
60 mph Specific Energy: 0.0141 kWh/lb

DRIVING CYCLE RANGE
77°F Distance: **51.40 miles**
77°F Energy Used: 21.88 kWh
77°F Efficiency: 0.426 kWh/mile
77°F Specific Energy: 0.0130 kWh/lb
19°F Distance: **48.60 miles**
19°F Energy Used: 21.89 kWh
19°F Efficiency: 0.450 kWh/mile
19°F Specific Energy: 0.0130 kWh/lb

Performance Goal: 60 miles

GRADEABILITY*
Maximum Grade: **16%**
Performance Goal: 25%
Speed At 3% Grade: **48 mph**
Performance Goal: 55 mph
Speed At 6% Grade: **37 mph**
Performance Goal: 45 mph

HANDLING COURSE
Avg Time @ 90% SOC: 66.0 sec
Avg Time @ 50% SOC: 63.9 sec
Avg Time @ 20% SOC: 118 sec
Avg Dodge Neon (ICE) Time: 54.62 sec
Average Chevrolet S-10 Time: 58.29 sec

BRAKING STABILITY
Controllability: No Stability Problems
Distance Dry/Wet: 207.2/355.1 ft

TEST EXCEPTIONS
No 110 volt charging
Charger replaced
Motor and controller replaced
Batteries require watering
Controller tuning required to meet max.speed
Charger battery temperature inhibit bypassed
Electrolyte reservoir leak during charge

Test Date: October 1994
Notes:
Bold - Results did not meet EV America Performance Goal
* - Tested at gross vehicle weight

CHARGER
Ground Current During Charge: Not Measured
Battery Leakage Current: 1.7 mA
Charger Efficiency: 98.8%
Average Power Factor: **0.93**
Performance Goal: 0.95
Average THD: **45.0%**
Performance Goal: 5%
Time From 80% DOD: 5 hours 7 minutes
Performance Goal: <8 hours

EV America

VEHICLE SPECIFICATIONS

PERFORMANCE STATISTICS

ACCELERATION AT 90% SOC *
Zero to 30 mph: 8.5 sec
Zero to 40 mph: 12.6 sec
Zero to 50 mph: 18.4 sec
Zero to 60 mph: **27.0 sec**
Performance Goal: 13.5 seconds; 0 to 60 mph

ACCELERATION AT 50% SOC *
Zero to 30 mph: 9.4 sec
Zero to 40 mph: 14.2 sec
Zero to 50 mph: 21.5 sec
Zero to 60 mph: **34.1** sec
Performance Goal: 13.5 seconds; 0 to 60 mph

MAXIMUM SPEED
At 50% SOC: 70 mph
Performance Goal: 70 mph

VEHICLE TYPE
Conversion Of: Geo Metro
VIN: 2CIMR5299567000106
Seating Capacity: 4 Adults

Features: AM/FM Radio, Heater, Battery Thermal Management, Power Steering, Power Brakes, Front Wheel Drive, Front Disc Brakes & Anti-Lock Brakes

DIMENSIONS
Wheelbase: 93.0 inches
Track F/R: 55.0/53.9 inches
Length: 164.3 inches
Width: 62.0 inches
Height: 54.5 inches
Ground Clearance: >50 mm
Cargo Space: No Intrusion on OEM Space

WEIGHT
Curb Weight: 2290 lb
Test Weight: 2424 lb
Distribution F/R: 49/51 %
Conversion GVWR: 2800 lb
OEM GVWR: 2800 lb
Payload: **376 lb**

WHEELS & TIRES
Wheel Size: 13 inches
Tire Mfg: Goodyear Invicta
Tire Size: P165/70R13
Tire Pressure F/R: 44/44 psi
Spare Installed: No

DRIVE SYSTEM
Drive Type: 35 kW AC Induction
Motor Mfg: Solectria

DRIVE SYSTEM
Controller Mfg: Solectria
Transmission: Single Speed

BATTERY
Manufacturer: Hawker Energy
Type: G12V26Ah10C Sealed Lead-acid
Number of Modules: 30
Total Traction Voltage: 180 volts
Battery Pack Weight: 690 lb
Locations In Vehicle: Under Trunk & Engine Compartment

CHARGER
Location: Trunk
Input Voltage(s): 120/208/240 volts AC
Input Current(s): 15/14.4/12.5 amperes AC

INTERLOCKS
Key Removable When Off Only: Yes
Key Off In Park Only: Yes
Start In Park Only: Yes
Start Blocked By Accelerator: **No**
Start Blocked On Charge: Yes

REQUIREMENTS
Manual Disconnect Present & Operational: **No**
Batteries Sealed or Valve Regulated: Yes
Charger Automatic Control: Yes
SOC Indicator: Yes
Battery Voltage Indicator: **No**
Battery Current Indicator: **No**
Regenerative Current Indicator: **No**
Transmission Single Speed: Yes
Transmission Parking Pawl: Yes
No Open Access to High Voltage: Yes
All High Voltage Clearly Marked: Yes
Control Efforts Similar To OEM: Yes

CONSTANT SPEED RANGE
45 mph Distance: 49.5 miles
45 mph Energy Used: 7.2 kWh
45 mph Efficiency: 0.171 kWh/mile
45 mph Specific Energy: 0.0104 kWh/lb
60 mph Distance: 26.6 miles
60 mph Energy Used: 5.3 kWh
60 mph Efficiency: 0.199 kWh/mile
60 mph Specific Energy: 0.0077 kWh/lb

DRIVING CYCLE RANGE
77°F Distance: **45.4 miles**
77°F Energy Used: 7.77 kWh
77°F Efficiency: 0.145 kWh/mile
77°F Specific Energy: 0.0113 kWh/lb
19°F Distance: **43.5 miles**
19°F Energy Used: 7.75 kWh
19°F Efficiency: 0.178 kWh/mile
19°F Specific Energy: 0.0112 kWh/lb
Performance Goal: 60 miles

GRADEABILITY *
Maximum Grade: **15.2%**
Performance Goal: 25%
Speed At 3% Grade: 60 mph
Performance Goal: 55 mph
Speed At 6% Grade: 47 mph
Performance Goal: 45 mph

HANDLING COURSE
Avg Time @ 90% SOC: 58.6 sec
Avg Time @ 50% SOC: 58.3 sec
Avg Time @ 20% SOC: 58.1 sec
Avg Dodge Neon (ICE) Time: 54.62 sec
Average Chevrolet S-10 Time: 58.29 sec

BRAKING STABILITY
Controllability: No Stability Problems
Distance Dry/Wet: 164.4/214.4 ft

TEST EXCEPTIONS
Prototype vehicle
Payload 324 lb less than required
Required charger adjustment
Required battery module replacement

Test Date: October 1994
Notes: Bold - Results did not meet EV America Performance Goal
* - Tested at gross vehicle weight

CHARGER
Ground Current During Charge: <0.01 mA
Battery Leakage Current: <0.01 mA
Charger Efficiency: 95.2%
Average Power Factor: **0.937**
Performance Goal: 0.95
Average THD: **29.0%**
Performance Goal: 5%
Time From 80% DOD: 3 hours 54 minutes
Performance Goal: <8 hours

EV America

VEHICLE SPECIFICATIONS

VEHICLE TYPE
Conversion Of: Chevrolet S10
VIN: 1GCCS1448SK100655
Seating Capacity: 2 Adults

Features: AM/FM Stereo,
Battery Thermal Management,
Power Steering, Power Brakes,
Front Disc Brakes & Anti-Lock Brakes

DIMENSIONS
Wheelbase: 109.0 inches
Track F/R: 54.2/54.5 inches
Length: 189.7 inches
Width: 68.1 inches
Height: 62.3 inches
Ground Clearance: >50 mm
Cargo Space: No Intrusion on OEM Cargo Bed

WEIGHT
Curb Weight: 3790 lb
Test Weight: 3991 lb
Distribution F/R: 47/53 %
Conversion GVWR: 4600 lb
OEM GVWR: 4600 lb
Payload: **609 lb**

WHEELS & TIRES
Wheel Size: 15 inch
Tire Mfg: Goodyear Momentum
Tire Size: P205/75R15
Tire Pressure F/R: 50/50 psi
Spare Installed: No

DRIVE SYSTEM
Drive Type: Dual AC Induction
Motor Mfg: Solectria
Controller Mfg: Solectria
Transmission: Single Speed

BATTERY
Manufacturer: Hawker Energy
Type: G12V38Ah10C Sealed Lead-acid
Number of Modules: 36
Total Traction Voltage: 144 volts
Battery Pack Weight: 1260 lb
Locations In Vehicle: Under Cargo Bed & Under Hood

CHARGER
Location: Behind Seat in Cab
Input Voltage(s): 110/208/220 volts AC
Input Current(s): 15/14.4/12.5 amperes AC

INTERLOCKS
Key Removable When Off Only: Yes
Key Off In Park Only: **No**
Start In Park Only: Yes
Start Blocked By Accelerator: **No**
Start Blocked On Charge: Yes

REQUIREMENTS
Manual Disconnect Present & Operational: **No**
Batteries Sealed or Valve Regulated: Yes
Charger Automatic Control: Yes
SOC Indicator: Yes
Battery Voltage Indicator: Yes
Battery Current Indicator: Yes
Regenerative Current Indicator: Yes
Transmission Single Speed: Yes
Transmission Parking Pawl: **No**
No Open Access to High Voltage: Yes
All High Voltage Clearly Marked: Yes
Control Efforts Similar To OEM: Yes

PERFORMANCE STATISTICS

ACCELERATION AT 90% SOC *
Zero to 30 mph: 7.0 sec
Zero to 40 mph: 11.5 sec
Zero to 50 mph: **18.8 sec**
Performance Goal: 13.5 seconds; 0 to 50 mph

ACCELERATION AT 50% SOC *
Zero to 30 mph: 7.1 sec
Zero to 40 mph: 12.2 sec
Zero to 50 mph: **21.7 sec**
Performance Goal: 13.5 seconds; 0 to 50 mph

MAXIMUM SPEED
At 50% SOC: **66 mph**
Performance Goal: 70 mph

CONSTANT SPEED RANGE
45 mph Distance: 72.8 miles
45 mph Energy Used: 16.7 kWh
45 mph Efficiency: 0.229 kWh/mile
45 mph Specific Energy: 0.0132 kWh/lb
60 mph Distance: 39.5 miles
60 mph Energy Used: 14.2 kWh
60 mph Efficiency: 0.359 kWh/mile
60 mph Specific Energy: 0.0113 kWh/lb

DRIVING CYCLE RANGE
77°F Distance: **57.86 miles**
77°F Energy Used: 21.09 kWh
77°F Efficiency: 0.364 kWh/mile
77°F Specific Energy: 0.0167 kWh/lb
19°F Distance: **53.80 miles**
19°F Energy Used: 18.09 kWh
19°F Efficiency: 0.336 kWh/mile
19°F Specific Energy: 0.0144 kWh/lb

Performance Goal: 60 miles

GRADEABILITY*
Maximum Grade: 26%
Performance Goal: 25%
Speed At 3% Grade: **53 mph**
Performance Goal: 55 mph
Speed At 6% Grade: **42 mph**
Performance Goal: 45 mph

HANDLING COURSE
Avg Time @ 90% SOC: 57.8 sec
Avg Time @ 50% SOC: 57.2 sec
Avg Time @ 20% SOC: 57.1 sec
Avg Dodge Neon (ICE) Time: 54.62 sec
Average Chevrolet S-10 Time: 58.29 sec

BRAKING STABILITY
Controllability: No Stability Problems
Distance Dry/Wet: 172.4/258.2 ft

TEST EXCEPTIONS
Battery charging delayed by high temperature
Charger output fuse replaced
Required charger adjustment
Payload 41 lb less than required

Test Date: October 1994
Notes:
Bold - Results did not meet EV America Performance Goal
* - Tested at gross vehicle weight

CHARGER
Ground Current During Charge: <0.01 mA
Battery Leakage Current: 0.02 mA
Charger Efficiency: 96.2%
Average Power Factor: **0.943**
Performance Goal: 0.95
Average THD: **19.4%**
Performance Goal: 5%
Time From 80% DOD: 6 hours 52 minutes
Performance Goal: <8 hours

VEHICLE SPECIFICATIONS

PERFORMANCE STATISTICS

ACCELERATION AT 90% SOC *
Zero to 30 mph: 10.9 sec
Zero to 40 mph: 18.4 sec
Zero to 50 mph: **30.9 sec**
Performance Goal: 13.5 seconds; 0 to 50 mph

ACCELERATION AT 50% SOC *
Zero to 30 mph: 10.8 sec
Zero to 40 mph: 18.3 sec
Zero to 50 mph: **30.3 sec**
Performance Goal: 13.5 seconds; 0 to 50 mph

MAXIMUM SPEED
At 50% SOC: 70 mph
Performance Goal:70 mph

VEHICLE TYPE
Conversion Of: Ford Ranger
VIN: 1FTCR10AXRPB48159
Seating Capacity: 2 Adults
Features: A/C, AM/FM Stereo, Power Brakes, Power Steering, Front Disc Brakes & Anti-Lock Brakes

DIMENSIONS
Wheelbase: 114.1 inches
Track F/R: 57.4/57.5 inches
Length: 197.8 inches
Width: 70.0 inches
Height: 63.0 inches
Ground Clearance: >50 mm
Cargo Space: No Intrusion on OEM Space

WEIGHT
Curb Weight: 4000 lb
Test Weight: 4589 lb
Distribution F/R: 50/50 %
Conversion GVWR: 4700 lb
OEM GVWR: 4700 lb
Payload: **111 lb**

WHEELS & TIRES
Wheel Size: 14 inch
Tire Mfg: Firestone
Tire Size: P225/70R14
Tire Pressure F/R: 35/35 psi
Spare Installed: No

DRIVE SYSTEM
Drive Type: 32 kW Brushless DC Motor
Motor Mfg: UQM
Controller Mfg: UQM
Transmission: **5 Speed Manual**

BATTERY
Manufacturer: Optima
Type: **Prototype Deep Cycle**
Number of Modules: 30
Total Traction Voltage: 180 volts
Battery Pack Weight: 1170 lb
Locations In Vehicle: Under Cargo Bed & Under Cab

CHARGER
Location: Under Cargo Bed
Input Voltage(s): **240 volts AC**
Input Current(s): 25 amperes AC

INTERLOCKS
Key Removable When Off Only: Yes
Key Off In Park Only: **No**
Start In Park Only: **No**
Start Blocked By Accelerator: Yes
Start Blocked On Charge: Yes

REQUIREMENTS
Manual Disconnect Present & Operational: Yes
Batteries Sealed or Valve Regulated: Yes
Charger Automatic Control: Yes
SOC Indicator: Yes
Battery Voltage Indicator: Yes
Battery Current Indicator: Yes
Regenerative Current Indicator: Yes
Transmission Single Speed: **No**
Transmission Parking Pawl: **No**
No Open Access to High Voltage: Yes
All High Voltage Clearly Marked: **No**
Control Efforts Similar To OEM: Yes

CONSTANT SPEED RANGE
45 mph Distance: 53.5 miles
45 mph Energy Used: 17.74 kWh
45 mph Efficiency: 0.332 kWh/mile
45 mph Specific Energy: 0.0152 kWh/lb
60 mph Distance: 38.3 miles
60 mph Energy Used: 11.47 kWh
60 mph Efficiency: 0.299 kWh/mile
60 mph Specific Energy: 0.0098 kWh/lb

DRIVING CYCLE RANGE
77°F Distance: **43.30 miles**
77°F Energy Used: 18.51 kWh
77°F Efficiency: 0.427 kWh/mile
77°F Specific Energy: 0.0158 kWh/lb
19°F Distance: **29.80 miles**
19°F Energy Used: 12.09 kWh
19°F Efficiency: 0.406 kWh/mile
19°F Specific Energy: 0.0103 kWh/lb

Performance Goal: 60 miles

GRADEABILITY *
Maximum Grade: 30%
Performance Goal: 25%
Speed At 3% Grade: **51 mph**
Performance Goal: 55 mph
Speed At 6% Grade: **36 mph**
Performance Goal: 45 mph

HANDLING COURSE
Avg Time @ 90% SOC: 62.1 sec
Avg Time @ 50% SOC: 61.6 sec
Avg Time @ 20% SOC: 62.0 sec
Avg Dodge Neon (ICE) Time: 54.62 sec
Average Chevrolet S-10 Time: 58.29 sec

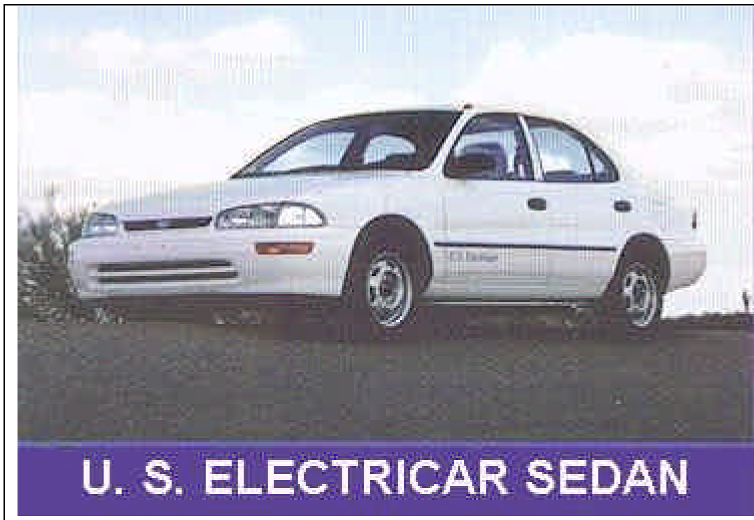
BRAKING STABILITY
Controllability: No Stability Problems
Distance Dry/Wet: 157.8/190.0 ft

TEST EXCEPTIONS
Prototype vehicle
Payload 539 lb less than required
Traction battery fuse replaced after battery short
Charger not operable from GFCI protected circuit
Testing delayed by charge times > 8 hours
Removed from testing to check for failed battery

Test Date: October 1994
Notes:
Bold - Results did not meet EV America Performance Goal
* - Tested at gross vehicle weight

CHARGER
Ground Current During Charge: <0.01 mA
Battery Leakage Current: 0.42 mA
Charger Efficiency: 96.8%
Average Power Factor: **0.53**
Performance Goal: 0.95
Average THD: **33.1%**
Performance Goal: 5%
Time From 80% DOD: **10 hours 50 minutes**
Performance Goal: <8 hours

EV America



VEHICLE SPECIFICATIONS

PERFORMANCE STATISTICS

ACCELERATION AT 90% SOC *
Zero to 30 mph: 6.5 sec
Zero to 40 mph: 9.6 sec
Zero to 50 mph: 14.3 sec
Zero to 60 mph: 21.0 sec
Performance Goal: 13.5 seconds; 0 to 60 mph

ACCELERATION AT 50% SOC *
Zero to 30 mph: 7.0 sec
Zero to 40 mph: 10.6 sec
Zero to 50 mph: 16.2 sec
Zero to 60 mph: **24.9 sec**
Performance Goal: 13.5 seconds; 0 to 60 mph

MAXIMUM SPEED
At 50% SOC: 81 mph
Performance Goal: 70 mph

VEHICLE TYPE
Conversion Of: Geo Prizm
VIN: 1YSK5304RZ092279
Seating Capacity: 4 Adults

Features: AM/FM Radio, Power Steering, Power Brakes, Front Wheel Drive & Front Disc Brakes

DIMENSIONS
Wheelbase: 96.8 inches
Track F/R: 57.5/56.7 inches
Length: 173.1 inches
Width: 66.6 inches
Height: 55.2 inches
Ground Clearance: >50 mm
Cargo Space: No Intrusion on OEM Space

WEIGHT
Curb Weight: 3420 lb
Test Weight: 3445 lb
Distribution F/R: 55/45 %
Conversion GVWR: 4060 lb
OEM GVWR: 3510 lb
Payload: **615 lb**

WHEELS & TIRES
Wheel Size: 14 inches
Tire Mfg: Firestone
Tire Size: P185/765R14
Tire Pressure F/R: 35/35 psi
Spare Installed: No

DRIVE SYSTEM
Drive Type: 50 kW AC Induction
Motor Mfg: Hughes
Controller Mfg: Hughes
Transmission: Single Speed

BATTERY
Manufacturer: Hawker Energy
Type: G12V26Ah10C Sealed Lead-acid
Number of Modules: 50
Total Traction Voltage: 300 volts
Battery Pack Weight: 1150 lb
Locations In Vehicle: Below The Passenger Compartment

CHARGER
Location: Under Hood
Input Voltage(s): 110/220 volts AC
Input Current(s): 15/30 amperes AC

INTERLOCKS
Key Removable When Off Only: Yes
Key Off In Park Only: **No**
Start In Park Only: **No**
Start Blocked By Accelerator: Yes
Start Blocked On Charge: Yes

REQUIREMENTS
Manual Disconnect Present & Operational: Yes
Batteries Sealed or Valve Regulated: Yes
Charger Automatic Control: Yes
SOC Indicator: Yes
Battery Voltage Indicator: **No**
Battery Current Indicator: **No**
Regenerative Current Indicator: **No**
Transmission Single Speed: Yes
Transmission Parking Pawl: Yes
No Open Access to High Voltage: Yes
All High Voltage Clearly Marked: **No**
Control Efforts Similar To OEM: Yes

CONSTANT SPEED RANGE
45 mph Distance: 59.3 miles
45 mph Energy Used: 12.4 kWh
45 mph Efficiency: 0.209 kWh/mile
45 mph Specific Energy: 0.0108 kWh/lb
60 mph Distance: 41.5 miles
60 mph Energy Used: 11.7 kWh
60 mph Efficiency: 0.282 kWh/mile
60 mph Specific Energy: 0.0102 kWh/lb

DRIVING CYCLE RANGE
77°F Distance: **45.90 miles**
77°F Energy Used: 11.93 kWh
77°F Efficiency: 0.260 kWh/mile
77°F Specific Energy: 0.0104 kWh/lb
19°F Distance: **32.20 miles**
19°F Energy Used: 9.57 kWh
19°F Efficiency: 0.296 kWh/mile
19°F Specific Energy: 0.0083 kWh/lb

Performance Goal: 60 miles

GRADEABILITY*
Maximum Grade: **23%**
Performance Goal: 25%
Speed At 3% Grade: 66 mph
Performance Goal: 55 mph
Speed At 6% Grade: 53 mph
Performance Goal: 45 mph

HANDLING COURSE
Avg Time @ 90% SOC: 55.0 sec
Avg Time @ 50% SOC: 55.0 sec
Avg Time @ 20% SOC: 57.6 sec
Avg Dodge Neon (ICE) Time: 54.62 sec
Average Chevrolet S-10 Time: 58.29 sec

BRAKING STABILITY
Controllability: No Stability Problems
Distance Dry/Wet: 157.6/203.9 ft

TEST EXCEPTIONS
Payload 85 lb less than required
Requires offboard transformer for charging
Charger/Controller GFI trips inadvertently
OEM GVWR re-certified by converter
Charge Complete Indicator lights prematurely

Test Date: October 1994
Notes:
Bold - Results did not meet EV America Performance Goal
* - Tested at gross vehicle weight

CHARGER
Ground Current During Charge: <0.01 mA
Battery Leakage Current: <0.01 mA
Charger Efficiency: 95.8%
Average Power Factor: **0.937**
Performance Goal: 0.95
Average THD: **15.5%**
Performance Goal: 5%
Time From 80% DOD: **8 hours 12 minutes**
Performance Goal: <8 hours

EV America

PERFORMANCE STATISTICS

ACCELERATION AT 90% SOC *
Zero to 30 mph: 7.9 sec
Zero to 40 mph: 12.2 sec
Zero to 50 mph: **18.7 sec**
Performance Goal: 13.5 seconds; 0 to 50 mph

ACCELERATION AT 50% SOC *
Zero to 30 mph: 8.2 sec
Zero to 40 mph: 12.8 sec
Zero to 50 mph: **20.1 sec**
Performance Goal: 13.5 seconds; 0 to 50 mph

MAXIMUM SPEED
At 50% SOC: 71 mph
Performance Goal: 70 mph

VEHICLE SPECIFICATIONS

VEHICLE TYPE
Conversion Of: Chevrolet S10
VIN: 1GCCS1443R8203148
Seating Capacity: 2 Adults

Features: A/C, Power Steering
AM/FM Stereo, Power Brakes,
Battery Thermal Management,
Anti-Lock Brakes & Heater

DIMENSIONS
Wheelbase: 117.4 inches
Track F/R: 54.7/55.0 inches
Length: 200.0 inches
Width: 68.2 inches
Height: 61.4 inches
Ground Clearance: >50 mm
Cargo Space: No Intrusion
on OEM Space

WEIGHT
Curb Weight: 4730 lb
Test Weight: 4862 lb
Distribution F/R: 49/51 %
Conversion GVWR: 5400 lb
OEM GVWR: 4600 lb
Payload: **538 lb**

WHEELS & TIRES
Wheel Size: 15 inch
Tire Mfg: Uniroyal
Tire Size: P205/75R15
Tire Pressure F/R: 35/35 psi
Spare Installed: No

DRIVE SYSTEM
Drive Type: 50 kW Induction
Motor Mfg: Hughes
Controller Mfg: Hughes
Transmission: Single Speed

BATTERY
Manufacturer: Hawker Energy
Type: G12V38Ah10C Sealed Lead-acid
Number of Modules: 52
Total Traction Voltage: 312 volts
Battery Pack Weight: 1820 lb
Locations In Vehicle: Under Cab
& Cargo Bed

CHARGER
Location: Under Hood
Input Voltage(s): 110/220 volts AC
Input Current(s): 50/30 amperes AC

INTERLOCKS
Key Removable When Off Only: Yes
Key Off In Park Only: Yes
Start In Park Only: **No**
Start Blocked By Accelerator: Yes
Start Blocked On Charge: Yes

REQUIREMENTS
Manual Disconnect Present & Operational: Yes
Batteries Sealed or Valve Regulated: Yes
Charger Automatic Control: Yes
SOC Indicator: Yes
Battery Voltage Indicator: **No**
Battery Current Indicator: **No**
Regenerative Current Indicator: **No**
Transmission Single Speed: Yes
Transmission Parking Pawl: Yes
No Open Access to High Voltage: Yes
All High Voltage Clearly Marked: **No**
Control Efforts Similar To OEM: Yes

CONSTANT SPEED RANGE
45 mph Distance: 70.7 miles
45 mph Energy Used: 20.9 kWh
45 mph Efficiency: 0.296 kWh/mile
45 mph Specific Energy: 0.0115 kWh/lb
60 mph Distance: 47.3 miles
60 mph Energy Used: 19.1 kWh
60 mph Efficiency: 0.404 kWh/mile
60 mph Specific Energy: 0.0105 kWh/lb

DRIVING CYCLE RANGE
77°F Distance: 68.8 miles
77°F Energy Used: 20.90 kWh
77°F Efficiency: 0.304 kWh/mile
77°F Specific Energy: 0.0115 kWh/lb
19°F Distance: **55.24 miles**
19°F Energy Used: 18.90 kWh
19°F Efficiency: 0.342 kWh/mile
19°F Specific Energy: 0.0104 kWh/lb

Performance Goal: 60 miles

GRADEABILITY*
Maximum Grade: **19%**
Performance Goal: 25%

Speed At 3% Grade: 59 mph
Performance Goal: 55 mph
Speed At 6% Grade: 45 mph
Performance Goal: 45 mph

HANDLING COURSE
Avg Time @ 90% SOC: 59.8 sec
Avg Time @ 50% SOC: 59.8 sec
Avg Time @ 20% SOC: 60.8 sec
Avg Dodge Neon (ICE) Time: 54.62 sec
Average Chevrolet S-10 Time: 58.29 sec

BRAKING STABILITY
Controllability: No Stability Problems
Distance Dry/Wet: 163.6/214.2 ft

TEST EXCEPTIONS
Payload 112 lb less than required
Requires offboard transformer for charging
Testing delayed by charge times > 8 hours
Charge Complete Indicator lights prematurely
Charger/Controller GFI trips inadvertently
OEM GVWR re-certified by converter
Driveline contact during hard cornering & rough road

Test Date: October 1994
Notes: Bold - Results did not meet EV America Performance Goal
* - Tested at gross vehicle weight

CHARGER
Ground Current During Charge: <0.01 mA
Battery Leakage Current: 1.2 mA
Charger Efficiency: 95.2%
Average Power Factor: **0.893**
Performance Goal: 0.95
Average THD: **19.5%**
Performance Goal: 5%
Time From 80% DOD: **15 hours 40 minutes**
Performance Goal: <8 hours

EV America

ENERGY ECONOMICS

This section compares the energy economics of electric vehicles to the energy costs of vehicles fueled by internal combustion engines (ICE). The energy costs are discussed for five types of vehicles: two gasoline-powered ICEs that get 18 miles per gallon (mpg), and 22 mpg, respectively; and three electric vehicles that go 2, 3, and 4 miles per kWh of electricity, respectively. The last Site Operator's Quarterly Report originally touched on this subject, but this discussion has been expanded, with dynamic comparisons of electricity efficiencies and variable fuel costs (for electricity on a per-kWh basis and for a gallon of gasoline). The use of an ICE truck that gets 18 mpg has been included as this is the type of vehicle that a utility would most likely replace with an electric vehicle pickup or minivan from an original equipment manufacturer (OEM) or a vehicle converter. An electric vehicle that gets 2 miles/kWh has also been included, given that this is probably the bottom range for energy efficiency that a new electric vehicle pickup/minivan would experience.

While there are other variables that affect the total life-cycle costs of electric vehicles, 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 electric vehicles. For instance, should the cost of GM's EV1/Impact be compared to an ICE that has similar range, similar luxury, or similar handling and acceleration?

Assumptions

To perform the energy economics comparison, several assumptions must be used that 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 hopefully reasonable.

An Energy Information Agency publication[1] lists the 1992 United States automobile average efficiency of 21.6 mpg, 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 mpg. However, utility use vehicles usually have low mpg characteristics, so the 22-mpg and 18-mpg ICE vehicle profiles are included.

An electric vehicle baseline efficiency value of 3 miles/kWh is assumed for the analysis. There is no strong historical basis for electric vehicle fleet efficiency, given the continuous increases in electric vehicle technology over short periods of time and the relatively short history of OEM-built electric vehicle availability. However, some miles/kWh information is available, including the GM EV1/Impact, which exhibited an energy efficiency of over 6 miles/kWh in the SAE J1634 test performed under the DOE/EV America Program. With the exception of the Baker pickup (of which only a very limited number were built), the other four 1995 and 1996 EV America performance tested electric vehicles all obtained greater than 3 miles/kWh. In fact, 8 of the 14 electric vehicles tested by EV America exceeded the 3 miles/kWh value, and 5 electric vehicles exceeded 4 miles/kWh, as did both of the 1996 test vehicles.

The next assumption is the cost of gasoline. Based on the February 23rd 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 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 reports cited examples of gasoline approaching $2.00 per gallon. The analysis uses a cost of gasoline for an ICE as ranging between $1.20 to $2 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 kWh of use. However, the national average for residential customers is known, and through December of 1995, the kWh rate for the year was averaging about 8.5 cents/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/kWh. All of these rates are residential, which assumes at-home charging. The other types of rates include commercial (7.75 cents/kWh), industrial (4.73 cents/kWh), and others (6.70 cents/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/kWh for residential electric vehicle consumption in California. Because of possible rates associated with different charging scenarios, a range of 3 cents to 40 cents/kWh is used for the analysis. Each of the four electric vehicles, with energy efficiencies of 2, 3, and 4 miles/kWh, use the 3 to 40 cents/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 of gasoline by the number of miles per gallon, 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 graphed for comparison in Figure EE-1. To understand the relationships between the costs, the graph is read as follows.

The solid thick line labeled "22 miles/gallon" represents the fuel cost per mile for a gasoline powered vehicle that gets 22 mpg. At $1.30 per gallon, the per-mile energy cost is determined by where the vertical line bisects the bottom scale (5.9 cents/mile; see point B). The per gallon cost of gasoline uses the right scale (Gasoline cost per gallon). At $1.40 per gallon, the per-mile energy cost shifts to about 6.4 cents, and at $1.50 per gallon, the per-mile energy cost is about 6.8 cents.

The dotted line, labeled "EV 3 miles/kWh" represents the fuel cost per-mile (2.8 cents) for an electric vehicle that has an energy efficiency of 3 miles/kWh. To read the graph, find Point A, the point at which the 3 miles/kWh line bisects 8.5 cents/kWh (left scale), and follow the vertical line down to the Energy cost per-mile X-axis (2.8 cents/mile). For the 3-mi/kWh EV, At 5 cents/kWh (left scale), the per-mile energy cost (bottom scale) is about 1.7 cents/mile; at 20 cents/kWh, the per-mile energy cost is about 6.7 cents; and at 30 cents/kWh, the per-mile energy cost is about 10 cents.

The other lines can be read in a similar manner to determine the fuel costs per mile. For instance, the line labeled "EV 4 miles/kWh" represents the fuel cost per mile for an electric vehicle that has an energy efficiency of 4 miles/kWh. Using the left scale (Electricity cost per kWh), one can compare the electricity cost per kWh and the cost per mile. At 6 cents/kWh (left scale), the per-mile energy cost is 1.5 cents (bottom scale); at 10 cents/kWh, the per-mile energy cost is 2.5 cents; and at 16 cents/kWh, the per-mile energy cost is about 4 cents.

The reader can compare the per-mile energy costs for electric vehicles and ICEs for each of the energy efficiencies and at various energy costs. For instance, the 22 mpg ICE profile at $1.40 per gallon has a per-mile gasoline cost of about 6.4 cents. Using the national average cost of about 8 cents for a kWh of electricity, the 3 miles/kWh electric vehicle has an energy cost of 2.7 cents/mile, significantly lower than the ICE vehicle. To further the discussion, the 4 miles/kWh electric vehicle will always have lower per-mile energy costs than the 18 mpg ICE vehicle when the cost of electricity is lower than 21 cents/kWh and the cost of gasoline is at $1.30 per gallon or higher. If the electric vehicle owner has the option of charging her electric vehicle at night with California off-peak charging rates under 4 cents/kWh, the cost per mile for electricity is 0.5 to 1 cent for all three electric vehicles.

As seen in the graph (Figure EE-1), the per-mile cost to fuel an electric vehicle can be significantly lower than the cost to fuel an ICE. The consumer has the ability to control his/her behavior to fuel the EV, provided of course that the consumer does not try to exceed the vehicle's maximum 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.

Other electric vehicle 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 electric vehicles 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 electric vehicles will have maintenance costs that are unique to electric vehicles. It may be difficult to quantify some electric vehicle 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.

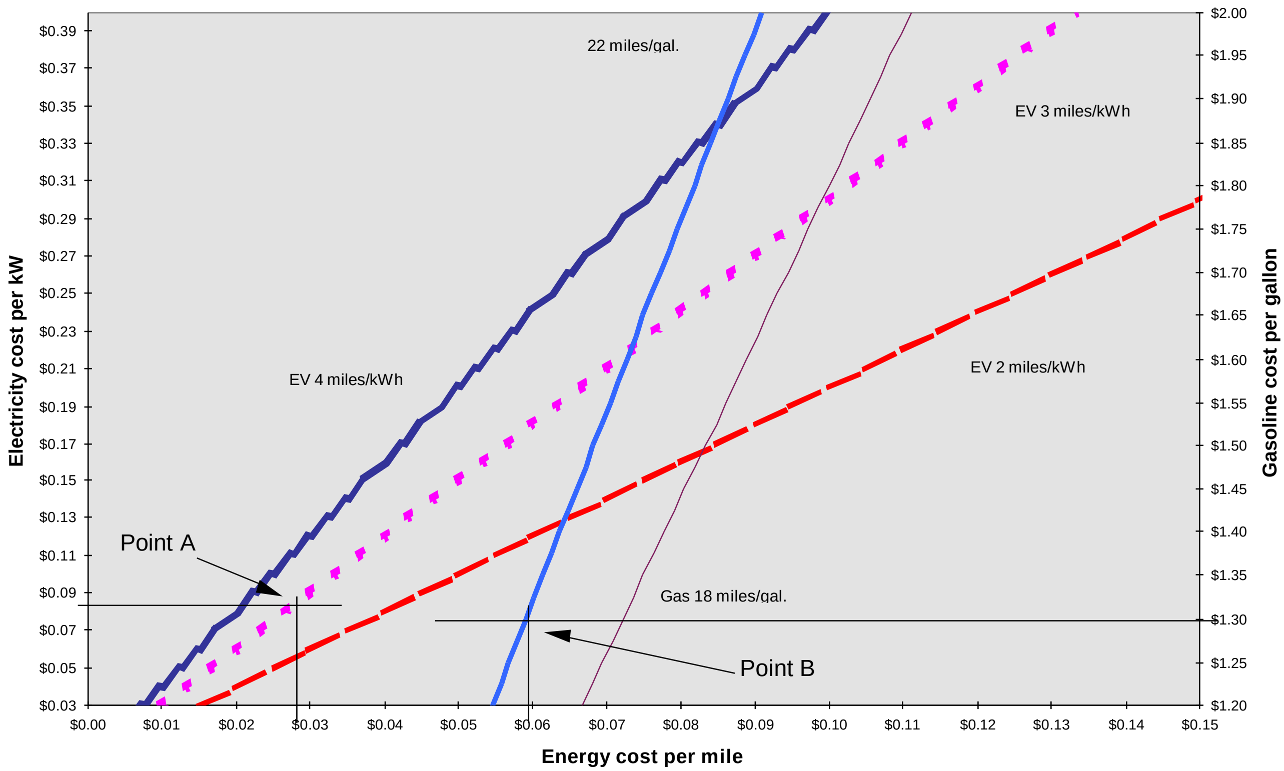


Figure EE-1. Comparison of the cost of running electric vehicles versus ICEs.

ARIZONA PUBLIC SERVICE

Fleet Testing

The Arizona Public Service (APS) electric vehicle fleet accumulated 235,000 miles during the 5 years (1991 through 1996) APS was a member of the Site Operator Program. The APS fleet (Table APS-1) began the decade of the 1990s with DC drives, series-wound motors, manual multigear transmissions, and classical battery charging. By 1996, most of the APS fleet vehicles were AC drive, single-speed transmissions with advanced regeneration braking, and rechargeable to 80% state of charge in less than 15 minutes. The APS operational electric vehicle fleet was kept at about 20 vehicles during the 5-year period, with older vehicles donated or sold into the greater Phoenix area.

The Old Fleet

The APS "Old Fleet" vehicles were powered by DC drives (except the Solectrias) with some of the battery systems being flooded electrolyte. The old fleet vehicles were driven 130,000 miles (Figure APS-1) during APS' s 5-year participation in the Site Operator Program. All of these vehicles encountered problems early in their use, which created fleet-use reliability problems. However, most of these reliability problems were overcome by APS and the vehicles were acceptable for limited applications. The vehicles did show significant variability in their energy efficiencies (Figure APS-2) as well as in their operating costs (Figure APS-3).

Five carryover vehicles from the 1980s (two Unique Sedans and three Soleq EVcorts) were part of the APS fleet in 1991. These vehicles were powered with DC motors and 4-speed manual transmissions. The Unique Sedans were dropped from fleet use by the mid-1990s due to their low power, high maintenance requirements, unreliability, and dissatisfaction by fleet operators. The EVcorts initial performance was limited due to poor battery life. The gel batteries (Sonnenschein) in the EVcorts were adversely affected by high ambient temperatures. Once steps were taken to limit temperature exposure, the EVcorts exhibited good reliability and acceptable and consistent ranges of 35 miles. However, the EVcorts suffered from extremely poor acceleration. During 1996, all of the EVcorts were sold and continue to operate in the Phoenix area by non-APS entities.

In 1991, APS purchased four G-Vans. These were 3/4-ton GMC vans, converted to electric power by Conceptor of Canada, with support from the Electric Power Research Institute (EPRI). The vans had chloride-flooded, lead-acid batteries, DC drives with single-speed transmissions, and regenerative braking. The G-Vans had been crashed tested by the manufacturer, which had not been performed on any previous electric vehicles. The G-Vans met recognized minimum safety criteria for internal combustion vehicles. Initial field testing of the G-Vans identified numerous problems, such as leaks in the battery watering system, breakdowns in the drive train transfer case, and short battery life. In addition, their slow speed (52–54 mph), large size (GMC full size van), high weight (approximately 8,100 pounds), low payload (750 pounds), and low power (Chloride DC drive with Nelco motor 30-hp continuous and 60-hp peak) provided the G-Vans with an unacceptable performance envelope for APS fleet applications. The G-Vans were all sold by 1996.

Table APS-1. Arizona Public Service electric vehicle fleet.

APS vehicle No.	Type	Manufacturer	Model year	No. of modules	System voltage	Controller inverter
100	Unique Sedan	Unique	1981	16	96	Soleq
298	Unique Sedan	Unique	1981	16	96	Soleq
101	Detroit Sedan	Detroit	1915	14	84	Detroit
104	Solectria Force	Solectria	1991	12	144	Solectria
105	Electric Colt	Solar Car	1991	10	120	Curtis
300	EVcort Sedan	Soleq	1988	18	108	Soleq
301	EVcort Sedan	Soleq	1988	18	108	Soleq
302	EVcort Sedan	Soleq	1988	18	108	Soleq
102	G-Van (cargo)	Conceptor	1991	36	216	Chloride
103	G-Van (cargo)	Conceptor	1991	36	216	Chloride
3045	G-Van (passenger)	Conceptor	1991	36	216	Chloride
3051	G-Van (passenger)	Conceptor	1991	36	216	Chloride
107	Honda CRX	DEMI	1991		150	Curtis
109	Saturn SC	Motorola/DEMI	1992	15	180	Motorola
114	S-10 DC drive (GE)	DTS	1995	20	120	GE/DC
115	Electric S-10	Motorola	1995	25	300	Motorola
116	TEVan	Chrysler	1993	30	180	GE/DC
124	Solectria Force	Solectria	1995	15	180	Solectria
130	ES10	Solectria	1995	36	144	Solectria
131	ES10	Solectria	1995	36	144	Solectria
132	ES10	Solectria	1995	36	144	Solectria
133	ES10	Solectria	1995	36	144	Solectria
134	ES10	Solectria	1995	36	144	Solectria
135	ES10	Solectria	1995	36	144	Solectria
136	Electric S-10	Spartan/GE	1995	24	288	GE/AC
137	Electric S-10	US Electricar	1995	52	312	Hughes
138	Electric S-10	US Electricar	1995	52	312	Hughes
139	Electric S-10	US Electricar	1995	52	312	Hughes
	Phoenix Shuttle Bus	Specialty Vehicle	1994	27x4	216	Nelco
	X-11	Lola/Brawner	1985	16	192	Soleq
	X-12	Lola/Brawner	1986	275	360	Motorola

APS purchased the first Solectria Force produced (a GEO Metro conversion) and an early Solar Colt (Dodge Colt conversion). Both cars were powered by 12 Sears Die Hard batteries. The Force had a single-speed transmission and air conditioning. The Solar Car featured photovoltaic panels on its roof and hood, giving the illusion of off-grid charging. Both vehicles exhibited short battery life, low range, and poor reliability. Powered by their Die Hard batteries, both vehicles exhibited impressive performance through the first few battery charge cycles, but drive range dropped off linearly with charge cycles to less than 10 miles per charge at approximately 2,500 miles on each pack. The vehicles were fun to drive but due to reliability issues and having to replace the packs at 2,500 miles, the vehicles were never operated in the fleet. The vehicles were used for exhibits and ride-n-drives. The Solar Car was sold with 5,000 miles and the Force was sold at 15,000 miles.

The Chrysler prototype TEVan began operating at APS during 1994. The TEVan, part of an EPRI program, was the first electric vehicle sold by a major car manufacturer and it was considered as a development step, both for Chrysler as the manufacturer, and electric utilities as the future infrastructure builders. The TEVan had Saft nickel cadmium (NiCad) batteries (requiring watering), General Electric DC motor and controller, manual 2-speed transmission, and a 10-kW Martin Marietta battery charger. The TEVan complied with NTHSA safety standards and it had undergone safety testing by Chrysler. Chrysler introduced fast charging (25 to 30 minutes) of the NiCad battery, using a Norvik Charger. After overcoming early problems with the motor and controller, the TEVan performed well in fleet use and was charged almost exclusively with a Norvik fast charger.

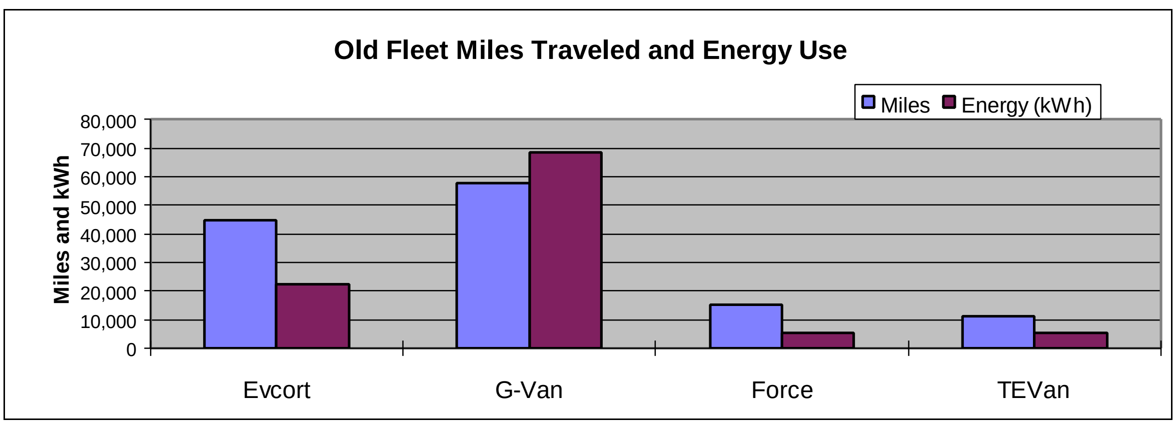


Figure APS-1. Old Fleet total mileage and energy use (kWh) for four EVcorts, four G-Vans, one Solectria Force, and one TEVan.

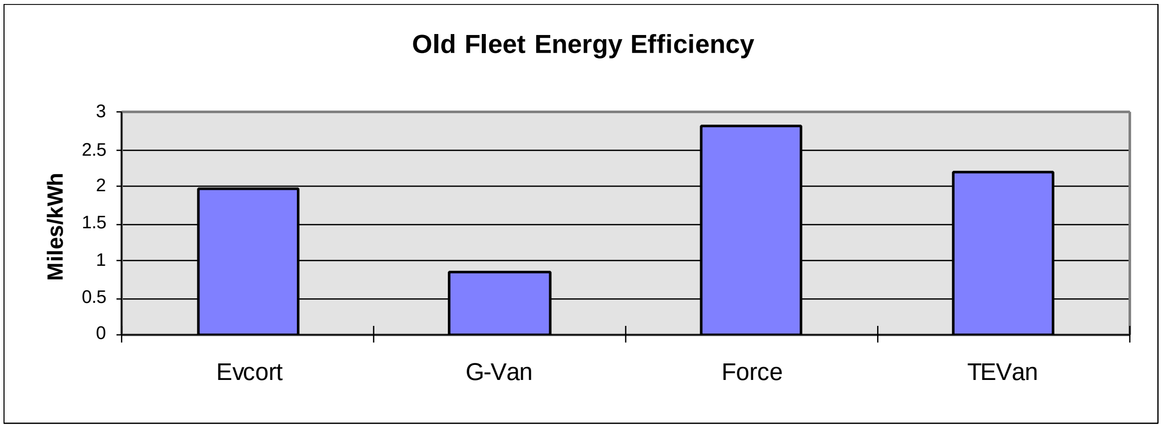


Figure APS-2. Old Fleet average energy efficiencies for four EVcorts, four G-Vans, one Solectria Force, and one TEVan.

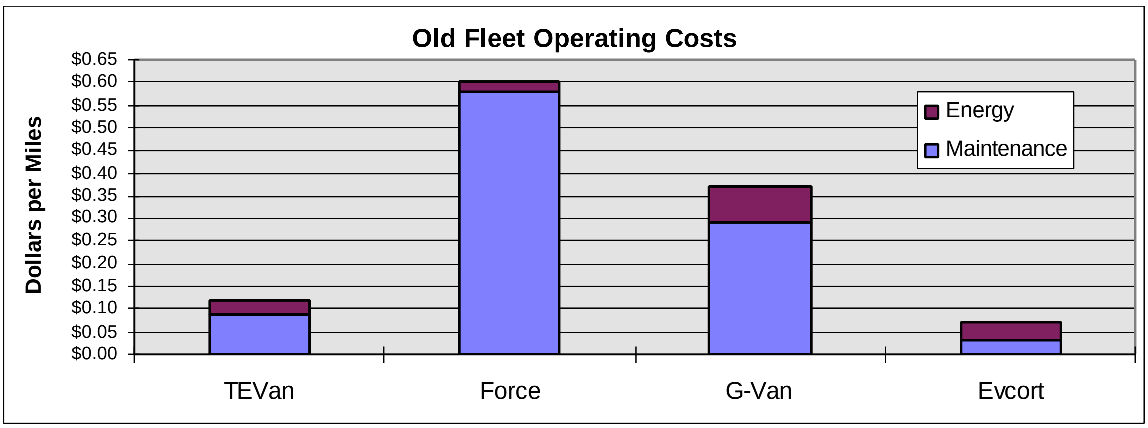


Figure APS-3. Old Fleet average operating costs for four EVcorts, four G-Vans, one Solectria Force, and one TEVan.

The New Fleet

APS' s "New Fleet" is defined to be those vehicles that were purchased after the establishment of the EV America program (1994). After the first year of EV America testing, APS purchased three US Electricar S10 pickup conversions and three Solectria S10 pickup conversions. These vehicles all had AC drives. After the second phase of EV America performance testing in 1995, APS purchased three additional Solectria pickup conversions and one Solectria Force sedan which was powered by a GM Ovonics Nickel Metal Hydride battery. APS also acquired one Spartan S10 pickup conversion manufactured by Spartan Motors of Lansing, Michigan. The Spartan S10 had an advanced GE AC drive system (motor and inverter package). The Spartan was specifically built for the Site Operator Program.

The new fleet accumulated over 100,000 miles (Figure APS-4) during 1995 and 1996. Both the Solectria and US Electricar pickup conversions encountered severe charger problems that later caused premature battery failures. The US Electricar pickups suffered from a design flaw in the driveline bushing, which caused failure of the bushing and at times, the carrier bearing. Failures of the auxiliary motors in the Solectria pickups were routine, occurring about every 5,000 miles. Most of these vehicles exhibited similar energy efficiencies of about 3 miles/kWh (Figure APS-5). The exception was the Solectria Force sedan, with its nickel-metal hydride battery pack; its energy efficiency approached 6 miles/kWh. Similarly, most of the vehicles had operating costs exceeding 30 cents per mile, except the Force, whose only reported operating costs were for energy (Figure APS-6).

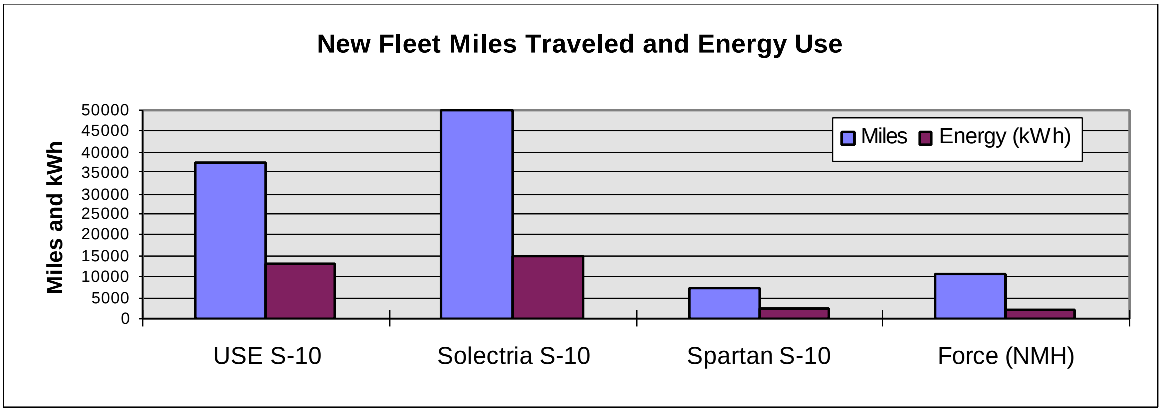


Figure APS-4. New Fleet total mileage and energy use (kWh) for three US Electricar S10 conversions, six Solectria S10 conversions, one Solectria Force sedan with a Nickel-Metal Hydride battery from GM Ovonics, and one Spartan S10 conversion.

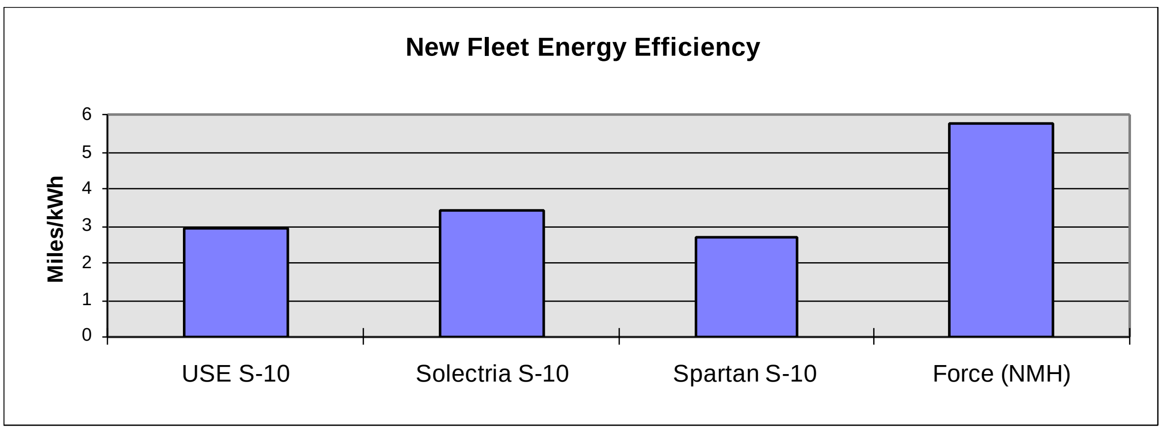


Figure APS-5. New Fleet average energy efficiencies (miles/kWh) for three US Electricar S10 conversions, six Solectria S10 conversions, one Solectria Force sedan with a Nickel-Metal Hydride battery from GM Ovonics, and one Spartan S10 conversion.

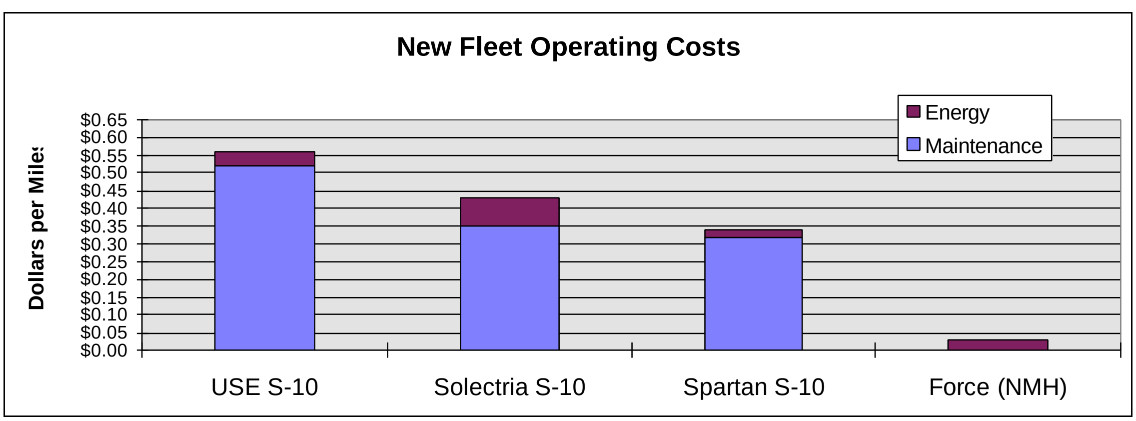


Figure APS-6. New Fleet average operating costs per mile for three US Electricar S10 conversions, six Solectria S10 conversions, one Solectria Force sedan with a Nickel Metal Hydride battery from GM Ovonics, and one Spartan S10 conversion.

Battery Field Testing

The first round of EV America performance testing concluded in November 1994. Among the numerous bench mark performance data collected was vehicle range at a constant speed of 45 mph (SAE 227A), constant speed at 60 mph (SAE 227A), and range per fuel efficiency drive cycle (SAE J1634). Over 225 electric vehicles (Solectria pickups and sedans, and US Electricar pickups and sedans) were purchased during the first phase of the EV America program by utilities and government agencies. All of these vehicles were powered by Hawker Genesis 38 amp-hour VRLA AGM batteries, model G190W. In use, these early vehicles reported a significant loss in range, at low battery cycles. Proving ground range testing (45 mph constant speed, SAE 227A) in Phoenix, confirmed an approximate 50% range reduction in a US Electricar S-10, and a 37% range reduction in a Solectria E-10.

An evaluation by Hawker Energy Products concluded that an undercharge condition existed in the batteries. The US Electricar S-10 was equipped with a 2-kW integral charger, which charged a 52 module, 21-kWh pack. However, Hawker concluded that a minimum 12-kW charging rate was required. The Solectria ES-10 was equipped with a 2-kW charger, which charged a 36-module, 16-kWh pack. Hawker concluded that a 8-kW charging rate was required.

Phase I Battery/Charger Testing. A field test program was initiated in 1995 for the purpose of evaluating the performance of the Hawker Genesis batteries with a variety of chargers. This Phase I testing evaluated the following conductive chargers: 150-kW Norvik Minit charger, 2-kW Solectria charger, and a 3-kW Solectria Charger. A 6.6-kW Delco inductive charger was also evaluated. Six electric pickup trucks were selected for field testing. None of these vehicles were equipped with a battery energy management system to monitor modules during charging. Thermal management of the batteries was limited to a few small oven fans in half the vehicles. The test program began in May 1995 and terminated in January 1996. The vehicles were driven in the Phoenix area, where summer daytime temperatures can reach 120°F.

Table APS-2 describes the alignment of chargers and total charge cycles accumulated at the end of pack life. The Norvik Minit charger was used to fast charge two vehicles at an arbitrarily chosen rate of 3C (3 times the one-hour discharge rating of the Hawker batteries). The vehicles charged by the Norvik charger required periodic equalize charges. Only vehicle 138 (US Electricar S-10) was equalized periodically with the Norvik charger. Norvik charging used 2.45 volts per cell for the Genesis battery and equalization was based upon 2.65 volts per cell. Vehicle 137 (another US Electricar S-10) was equalized with the Delco inductive charger. The Delco charger conducted the main charge routine with 2.45 volts per cell and the equalization routine was based upon 2.56 volts per cell. The Solectria onboard conductive chargers used a 2.45 volts per cell routine and cell equalization was accomplished with extensive overcharging.

Table APS-3 provides a summary of the battery pack performances and battery module failure causes. Although the batteries were the same make and model in each vehicle, there is significant variability is the number of charge cycles and pack miles that may be attributable to chargers and charge algorithms. In considering the battery performance in this test, it was evident that the Hawker Genesis battery can be damaged by low-power charging and the battery performs better as charge power is increased. The summer heat in Phoenix did not appear to have any impact on battery performance with high rate charging. One of the vehicles had a pack fire (vehicle 138) that appeared to be caused by loose battery interconnections. The pack fire reinforced the importance of following proper procedures for assembling battery packs.

Table APS-2. Phase I electric vehicle chargers and charge cycles. The ES10 models are all Solectria pickups and the S-10 models are all US Electricar pickups. "Cyc" is the number of cycles on the battery pack.

Vehicle		Norvik Fast Charge		Overnight Delco	Overnight Solectria		Equalization	
No.	Make	Rate	Cyc	Cyc	Rate	Cyc	Type	Cyc
133	ES10				3kW	197		
134	ES10				2kW	52		
135	ES10	2C	59		2kW	54		
137	S-10	3C	240				6kW	120
138	S-10	3C	140				Norvik	
139	S-10			120				

Table APS-3. Vehicle, battery pack charge cycles and miles, and the pack failure reason for the six vehicles in the Phase I electric vehicle chargers field test. The ES10 models are all Solectria pickups and the S-10 models are all US Electricar pickups.

Vehicle No.	Make	Charge cycles	Pack miles	Cause of module failure
133	ES10	197	7,500	Corrosion, 12 modules
134	ES10	52	1,200	Thermal run away, 12 modules
135	ES10	103	3,573	Thermal run away, 36 modules
137	S-10	360	16,500	Corrosion, 8 modules
138	S-10	140	4,250	Pack fire due to loose connection, 52 modules
139	S-10	120	3,878	Corrosion, 17 modules

From the results of the Phase I field testing and the autopsy of the modules from the vehicles, it was concluded that the Norvik 3C charging provided the optimal vehicle performance and the longest battery cycle life. The abrupt failure of the 17 modules in the number 139 vehicle (which were caused by grid corrosion) was hypothesized to be the result of equalization or overcharge at the elevated voltage portion of the implemented algorithm. Coincidentally, after the same number of equalization cycles on vehicle 137, which was charged by the Norvik charger and equalized by the Delco charger, a similar failure mechanism occurred in 8 modules. The Solectria 2-kW chargers produced battery failures due to thermal run away early in battery life (vehicles 134 and 135). The Solectria 3-kW charger produced failure via grid corrosion (vehicle 133).

Phase II Battery/Charger Testing. Significant cycle life extension has been achieved using high charging rates in laboratory testing. It has been demonstrated that sealed VRLA batteries can be rapidly charged with higher energy efficiencies than traditional charging, without detrimental effect to the battery, and with significantly extended cycle lives. It has also been shown that VRLA batteries in laboratory testing given five to ten rapid partial-charge cycles can fully recover their capacity.

For years, laboratory testing has been performed to determine the effects of charging methods on battery performance in electric vehicle applications. Parameters such as battery capacity life and grid corrosion have been examined. Results of laboratory testing to date have indicated that the charging scheme utilized has a direct effect on battery performance. However, testing within laboratories, even when simulated drive cycles are used for charge and discharge test cycles, does not completely represent the environmental rigors of fleet use. Fleet vehicles do not operate under controlled sets of conditions, rather, traffic conditions, ambient temperature, and operator usage are just a few of the variant conditions impacting battery performance.

Table APS-4 describes the field test fleet used for the Phase II testing. Vehicles 130, 136, 137, 114, and 333 were given multiple fast charges each day and the vehicles were operated by dedicated drivers. This method of accelerated aging of the vehicles compresses the testing time. The other vehicles were driven arbitrary routes with arbitrary charge routines. These vehicles were driven by APS employees while performing normal work missions. Vehicles 131 and 134 were driven by meter readers and at the end of the work shift, vehicles 131 and 134 were charged by the Delco inductive charger. Twice per month, vehicles 131 and 134 were given a 3C charge on the Norvik fast charger.

Table APS-4. Phase II battery charger field test vehicles and charging scenarios.

Vehicle No.	Model	Make	Modules in pack	Battery manufacturer	Norvik charge rate	Overnight charger
114	S10	DTS	42	Hawker	9C	Martin M
333	S10	Solectria	36	Hawker	9C	
137	S10	USE	52	Hawker	5C	Delco
136[a]	S10	Spartan	24	Optima	5C	
136[a]	S10	Spartan	24	GNG	3C	
130	S10	Solectria	36	Hawker	3C	Solectria
131	S10	Solectria	36	Hawker	3C	Delco
133	S10	Solectria	36	Hawker	3C	Solectria
134	S10	Solectria	36	Hawker	3C	Delco
135	S10	Solectria	36	Hawker	3C	Solectria
124	Geo	Solectria	15	GMO		Solectria
116	TEVan	Chrysler	30	Saft	3C	Martin M

a. The 136 vehicle was used twice in the Phase II test with battery parts from two manufacturers.

The electric vehicles used for the Phase II testing did not have battery energy management systems or battery module monitoring equipment installed. The amount of thermal management equipment varied among the vehicles. The two vehicles (333 and 114) charged at 9C rates were equipped with module cooling systems. The 333 vehicle was equipped with high air velocity manually initiated module cooling. The 114 vehicle was equipped with a Phase Change material provided by Shape. The 124, 130, 131, 133, 134, and 135 vehicles had small oven fans to ventilate ambient air across the packs and were activated by battery temperatures. Vehicle 116, the TEVan equipped with Nickel Cadmium batteries from Saft, was nearly 100% fast charged with minimal equalizations. The 124 vehicle, the Solectria sedan with the GM Ovonics nickel-metal hydride battery pack, was charged by a Solectria 3-kW charger and it was given very frequent opportunity charges in its fleet mission. On 6–8 week intervals, the vehicles were taken to a local proving ground and given the 60-mile, constant-speed range test (SAE 227 A) to evaluate pack capacity.

The accelerated aging group required extensive use of fast charging. Fast charging occurred at the 3C, 5C, and 9C rates. Daily fast charge cycles varied in number from 1 to 5. Battery equalizations were varied from every third to every tenth cycle, depending upon the specific vehicle. Hence, the majority of vehicle charging and operations were with partial charge cycles including the overnight charging. Equalization cycles were minimized because of the grid corrosion found during the Phase I battery autopsy.

Table APS-5 provides a description of the Phase II testing through December 1, 1996. The 333 and 114 vehicles were primarily charged at the 9C rate. Vehicle 333 was equalized every sixth cycle by the Norvik charger, while the 114 vehicle was charged overnight by the Martin Marietta 10-kW charger and equalized every fifth charge cycle by the Martin Marietta charger, which incorporates a manually initiated equalization cycle. Equalization voltage on the Martin Marietta charger was 2.5 volts per cell for the Hawker Genesis batteries. During the overnight cycle on the 114 vehicle, the Shape Phase Change material used for pack thermal stability was frozen using a standard window air-conditioning unit to circulate air through the battery pack. Although a relatively large number of battery modules were lost by these high-rate charges, fast charging was deemed to by very promising due to the large number of modules which survived without benefit of individual module charge control. Typical 9C charge rate module failures were observed to have a hot high-rate venting of a module cell, which was detected by the Norvik charger and the charge was terminated.

Vehicles 137 and 136 were charged at the 5C rate. The 137 vehicle carried Hawker Genesis batteries and it was charged over night by the Delco inductive charger. During every third Delco charge, the battery was equalized at 2.56 volts per cell. The Delco charger permitted programming for automated charge equalization on a specific cycle interval. The 136 vehicle carried Optima batteries and it was equalized every sixth cycle by the Norvik charger. The 137 vehicle operated extremely well, incurring over 100 miles daily (two partial 5C charges daily). At just under 10,000 miles, without any previous battery maintenance, a single module failed. At this point, the test on the 137 vehicle was terminated. The 136 vehicle suffered problems with battery module interconnections, which caused arcing and battery damage.

Table APS-5. Phase II battery charger performance results through December 1, 1996.

Vehicle No.	Model	Make	Days of operation	Pack miles	Pack cycles	End of life	Module failures
114	S10	DTS	78	1,772	108	no	2
333	S10	Solectria	165	4,607	200	no	9
137	S10	USE	247	9,984	251	yes	1
136[a]	S10	Spartan (GNB)	279	3,927	97	yes	
136[a]	S10	Spartan (Optima)	175	2,658	137	no	4
130	S10	Solectria	367	11,192	399	no	1
131	S10	Solectria	414	3,744	140	no	0
133	S10	Solectria	610	11,355	427	yes	9
134	S10	Solectria	368	8,969	344	no	12
135	S10	Solectria	321	6,125		no	0
124	Geo	Solectria	473	12,143	379	no	
116	TEVan	Chrysler	1,120	11,937	367	no	0

a. The 136 vehicle was used twice in the Phase II test with battery parts from two manufacturers.

The 130 vehicle, which was predominately charged at the 3C rate, performed very successfully. Overnight charges were accomplished with the Solectria 3kW charger. The 130 vehicle showed no significant deterioration in range up to the time of its first module failure at 11,134 miles. The test protocol for the 130 vehicle was based upon the 137 vehicle test protocol during the Phase I testing, were the 137 vehicle operated successfully at the 3C charge rate and it was overnight charged by the Delco charger. The 137 vehicle achieved about 16,500 miles during the Phase I testing and the 130 vehicle achieved over 11,000 miles during the Phase II testing and 399 charge cycles. All of the fast charge cycles achieved 80% state of charge within 15 minutes. In both cases, the 130 and 137 vehicles did well without thermal management or battery energy management systems, which, if added to the vehicles, should increase their performance.

The 131 and 134 vehicles were driven in meter reading duty missions of about 20 to 25 miles per day during the Phase II testing. The 134 vehicle was part of the Phase I testing and it used a Solectria 2-kW charger when it lost 12 battery modules due to thermal run away. The 12 modules were replaced and the battery pack underwent numerous fast charge cycles at the 3C rate. It was then moved into the Phase II test program. Both the 131 and 134 vehicles were charged with the Delco charger at the end of the work day, with equalizations occurring every fifth cycle. These vehicles were fast charged once every other weekend with the Norvik fast charger at the 3C rate. Over the test period, their range continued to decrease, until during the early part of November 1996, the ranges dropped to about 23 miles at a constant speed of 60 mph. The 133 vehicle was also continued from the Phase I into the Phase II program. In Phase I, the 133 vehicle accumulated about 7,800 miles on the pack while being charged by the Solectria 3-kW charger, at which point the range had fallen to about 25 miles. At this point, the 133 vehicle was only charged by the Norvik charger at the 3C rate. The 133 vehicle's range improved significantly and it was returned to fleet duty where it continued to operate until abrupt pack death at 11,355 miles.

KANSAS STATE UNIVERSITY

Kansas State University (KSU) is the Program Manager for the Kansas Electric Utilities Research Program (KEURP). The KEURP is an alternative fuel research partnership, responsible for developing a regional Alternative Fuel Vehicle Test and Evaluation Center. The members of the program are:

- KG&E, A Western Resources Company
- KPL, A Western Resources Company
- Kansas City Power & Light Company
- Midwest Energy, Inc.
- WestPlains Energy
- Sunflower Electric Power Corporation
- The Empire District Electric Company.

The Test and Evaluation Center will research, design, develop, produce, and support the most advanced technology alternative fuel vehicles manufactured in America. The KSU Test and Evaluation Center will serve as the genesis of a long-term process, a process that will replace petroleum-based vehicles as America’ s primary individual transportation systems. While maintaining a position of fuel neutrality, the University will make every effort to assist the development of electric drive technology while working to find flexible fuel and energy systems to power the high efficiency electric drive trains that will be an integral part of any advanced technology vehicle.

Transportation Design and Manufacturing (TDM), a major supplier to the domestic automobile industry, has established a research, development, and manufacturing base in Manhattan, Kansas. KSU expects TDM’ s new Alternative Fuel Vehicle Production Facility to serve as the cornerstone in establishing the region as a leader in the development of advanced vehicles.

Field Data Collection and Vehicle Operations

KSU, in partnership with TDM, has been collecting data on both of KSU’ s Ford EVcorts, and a TDM Ford Ranger electric vehicle.

EVcorts

The 1993 Ford EVcorts are Ford Escorts that were converted to electric vehicles by the Soleq Corporation, of Chicago, Illinois. These two vehicles, except for minor component failures (such as battery cables or system fuses) have been routinely operated without incident since initial purchase. The vehicles have been involved in a number of serious collisions, and, although significant body damage occurred, the vehicles were available for use once body repairs were completed. One of the EVcorts has been transferred to Kansas City Power and Light for use in their demonstration program, and the other EVcort was transferred to the West Plains Energy Company.

The Soleq EVcorts have proven to be highly reliable vehicles, with limited range and high initial costs. The EVcorts were operated over 3 years, and except for minor maintenance problems that could be fixed in less than two hours once parts were available, were 100%

operational. The Soleq vehicles have proven to be excellent prototype vehicles, but they will not likely ever see commercial production. The two vehicles were driven a total of almost 13,000 miles during the 3 years and they have had an average energy efficiency of 1.56 miles/kWh (Tables KSU-1 & KSU-2).

Table KSU-1. Operating miles and energy totals for the EVcort number 151. The quarterly data is for June 1995 through June 1996, and the total is accumulated 3-year vehicle totals.

Quarter	End Date	Miles	Daily Miles	Charges	Miles/ Charge	kWh	Miles/ kWh
1st	09/30/95	888	11.1	80	11.1	479	1.9
2nd	12/13/95	1,387	16.1	86	16.1	951	1.5
3rd	03/31/96	300	6.0	50	6.0	306	1.0
4th	06/30/96	220	7.9	28	7.9	141	1.6
3-year Totals		9,182	16.3	585	16.3	5,827	1.6

Table KSU-2. Operating miles and energy totals for the EVcort number 152. The quarterly data is for June 1995 through June 1996, and the total is accumulated 3-year vehicle totals.

Quarter	End Date	Miles	Daily Miles	Charges	Miles/ Charge	kWh	Miles/ kWh
1st	09/30/95	403	6.1	66	6.1	189	2.1
2nd	12/13/95	449	7.1	63	7.1	428	1.0
3rd	03/31/96	447	6.0	68	6.0	287	1.6
4th	06/30/96	268	8.3	32	8.3	161	1.7
3-year Totals		3,616	12.0	445	12.0	2,387	1.5

TDM Ford Ranger

The 1996 Ford Ranger Electric was the first conversion prototype produced by TDM. As should be expected, there was a large number of “rough edges” on the vehicle. A significant amount of time was spent repairing components, installing systems necessary for proper operation, or modifying system capability to maintain the vehicle’ s operations. The only reported operations data is displayed in Table KSU-3, and it includes the vehicle’ s energy use of 2.3 miles/kWh.

KSU reported on several operations and maintenance issues with the vehicle; in summary, these include the following issues and problems. It must be remembered that this vehicle was the first prototype constructed and some or all of these problems may be of a singular nature.

- Main controller board defect causing auxiliary battery charging failures
- Electronic speedometer failures
- Wiring harness circuit failure

- Poor quality fuse used in the charger requiring replacement with a higher quality fuse
- Defective oil cooling pump
- AC induction motor upgraded from 65 to 95 horsepower
- High battery pack temperatures (exceeding 150°F), caused by chemical reactions during both charging and discharging. The charging time is increased and the pack life will be decreased. However, the vehicle range is dramatically increased resulting in a round trip of almost 150 miles.

Table KSU-3. Operating miles and energy totals for the TDM converted Ford Ranger electric vehicle number A5. The quarterly data is for October 1995 through June 1996, and the total is for the 3 quarters. (Because this vehicle is not equipped to directly record kWh supplied to the vehicle while charging, the data is interpolated from other information.)

Quarter	**End Date**	**Miles**	**Daily Miles**	**Charges**	**Miles/ Charge**	**kWh**	**Miles/kWh**
1st	--	--	--	--	--	--	--
2nd	12/13/95	250	8.3	30	8.3	120	2.1
3rd	03/31/96	2,190	27	82	27	920	2.4
4th	06/30/96	1,947	46	42	46	837	2.3
Accumulated Totals		4,387	27	154	27	1,877	2.3

LOS ANGELES DEPARTMENT OF WATER AND POWER

Introduction

The Los Angeles Department of Water and Power (LADWP) is a municipal utility serving the citizens of Los Angeles, California. The LADWP has promoted the use of electric transportation for more than 8 years, both as part of Los Angeles' overall air quality improvement effort and as a means of improving the region's economic competitiveness through the creation of new industries.

LADWP's electric transportation program continues to extend beyond vehicle deployment to include infrastructure and public transit development, public education and awareness, and legislative and regulatory activities.

Vehicle Operations and Activities

LADWP has maintained and operated 20 electric vehicles since the fourth quarter of 1994. These vehicles consisted of six G-Vans, four Chrysler TEVans, five U.S. Electricar pickup trucks, and five U.S. Electricar Prizms.

U.S. Electricar Pickup Trucks

LADWP took delivery of the five U.S. Electricar pickups during the fourth quarter of FY 1994. Real-world driving tests performed on the vehicles showed a range of 50 to 60 miles under normal driving conditions. A complete charge consistently requires approximately 21 kWh of energy and 7 hours of charging time. The vehicles have logged almost 20,000 miles since their delivery.

During LADWP's involvement with the Site Operator Program, several issues were addressed with the pickups, including the following:

- *Ground Fault Circuit Interrupter Incompatibility.* All U.S. Electricar vehicles showed a basic inability to charge on an outlet protected by a ground fault circuit interrupter (GFCI). This incompatibility causes the GFCI on the 220-volt receptacle to trip while the vehicle is charging. U.S. Electricar has never resolved this problem, and all of the charging stations used to charge the pickups had to be retrofitted with the "G-FIX" device manufactured by EVI. The "G-FIX" cancels out electrical noise generated by the electric vehicle controller during charging. The vehicles cannot be successfully charged on GFCI equipped receptacles without this device.
- *Defective Battery Modules.* Soon after vehicle delivery, some of the pickups exhibited inadequate ranges due to defective battery modules. The LADWP replaced battery modules in several of the battery packs. Premature module failure was attributed to the integrated charger under-charging the battery packs. The charging algorithm was modified to fix this problem.

The U.S. Electricar pickups exhibited sluggish performance, especially on hills and when carrying a load. Because of this, one of the trucks was retrofitted with an automatic transmission, and two other trucks were retrofitted with 5-speed manual transmissions. These modifications improved performance considerably. The pickup retrofitted with the automatic transmission showed a slight decrease in range (under 5 miles), while the trucks with manual transmissions showed no range reduction over the stock vehicle. Air conditioning units were also installed on two of the pickups. Mobile Data Acquisition System (MDAS) units were installed in three of the trucks.

The MDAS units operated somewhat unreliably. In some cases, they caused the auxiliary batteries in the vehicles to fail after overnight charging, because the MDAS units sometimes would not shut down when battery pack charging was completed. The data would also often be corrupted, making evaluation impossible. Some of the data errors were caused by floppy disks that were damaged during use. Because of the problems with the MDAS units, LADWP decided to install hard cards to replace the often unreliable floppy discs used for data storage. Since the hard cards stay with the MDAS unit, confusion was eliminated concerning configuration files, which are often a problem when using multiple floppy disks on multiple vehicles.

After installation of the hard cards on the MDAS units, the problem of unexpected unit failures still persisted until the first quarter of 1997. At that time LADWP discovered, per discussions with the main processor board manufacturer, that bad memory chips had been installed on some boards back in 1995 when the units were delivered. These chips would fail intermittently when they heated up during normal vehicle operations. The memory chips were immediately replaced and no unexpected failures have occurred since.

Chrysler TEVans

LADWP has logged over 15,000 miles on four Chrysler TEVans since the fourth quarter of 1994, but use of these vehicles has been limited due to their very poor reliability. The vehicles have experienced significant problems from the first day that LADWP received them, with most of the problems being of a repetitive nature and related to design flaws. Several problems were encountered early, but most have been corrected. One of the problems was the inability to charge the vehicle from a GFCI-equipped, single-phase outlet. These safety devices are required by the City of Los Angeles Building Code on all electric vehicle charging facilities. Other problems included repeated failures of the motor controller units and auxiliary power units.

U.S. Electricar Sedans

The five U.S. Electricar sedans were driven under a variety of conditions. The sedans generally continued to maintain a 50- to 55-mile range under city/highway conditions, sometimes dropping to 40 miles when the battery packs had started to deteriorate. One of the vehicles was used daily as an employee car pool vehicle. A full charge takes 6 to 8 hours, requiring 17 kWh of energy. The sedans logged a total of 35,000 miles since delivery during the first quarter of 1995. The following problems were encountered with the U.S. Electric sedans:

It was determined that the charging algorithm provided with the sedans was undercharging the batteries. As a result, one battery pack was damaged and subsequently replaced. LADWP, with input from the manufacturer, modified the charging algorithm on another sedan.

LADWP service technicians adjusted the state-of-charge gage to increase its accuracy. The gauge is still inaccurate when the batteries are nearly exhausted; the gauge can show as much as one-quarter of usable battery capacity remaining while the vehicle has already gone into a reduced-performance mode.

Hill climbing ability for the sedans is adequate for most areas in Los Angeles, however, there are some hills that can only be climbed very slowly, and in one extreme case cannot be climbed at all.

Other Electric Vehicles

LADWP continued to support the maintenance and operation of six G-Vans. Two of the G-Vans are being operated at the Los Angeles International Airport, and the other four are currently operating in LADWP's fleet.

The Unique Mobility minivan is not operational.

ORCAS POWER AND LIGHT

Introduction

The Orcas Power and Light Company (OPALCO) is a rural electric distribution cooperation serving 19 islands in San Juan County, Washington. The county has a population of 12,000 and a two-lane road system with speed limits between 25 and 40 miles per hour. In 1995, the Sustainable Technology Center was completed. This campus incorporates several state-of-the-art technologies aimed at reducing building and tenant costs. Electric Transportation is included as a feature of the Center. Seventy-two percent of the electric distribution system in San Juan County is underground. At one electric vehicle for every 750 internal combustion engine (ICE) vehicles, San Juan County boasts the highest ratio of electric vehicles to ICE vehicles of any county in the United States. Early in 1991, the Board of Directors encouraged OPALCO management to explore the possibility of operating electric vehicles in San Juan County. OPALCO joined the Site Operator Program in 1991, with the intent of purchasing and operating electric vehicles. OPALCO also documented their experiences and educated the public on electric vehicle operation.

Operations Results

OPALCO owned and operated three electric vehicles as part of the Site Operator Program. The vehicles were a General Motors G-Van, which is a full-size, 1-ton General Motors Van conversion; a Jet Escort, which is a Jet Industries conversion of a Ford Escort; and a Solectria Force, which is a GEO Metro glider that has electric vehicle components added by the Solectria Company of Arlington, Massachusetts. Information about each vehicle is provided below.

General Motors G-Van

This vehicle was selected for its large space and seating capacities. The G-Van was a dependable vehicle with a consistent range. This vehicle was traded for the Jet Escort. The G-Van did have a few problems, including the following:

- The motor and controller were replaced because of a motor failure
- Intermittent starting required relay replacements
- The 4 x 4 x 4-ft, 300-lb off-board charger did not allow any opportunity charging in the course of a trip
- Some drivers, used to driving compacts on Orcas Island, had difficulty with the size and weight of the van.

Solectria Force

This automatic AC-drive vehicle is the vehicle of choice among drivers, and has highest use when measured by quarterly miles driven (Figure OCR-1). The Solectria is also the most energy efficient of the three vehicles, averaging 2.7 miles/kWh over the 5-year program period (Table OCR-1). The Solectria also had the best energy efficiency on a quarter-by-quarter basis of the three vehicles in the program (Figure OCR-2). However, an inadequate heater and defroster, and regenerative braking on ice make it less desirable to drive during the winter months. The Force’ s relative light weight, 2,400 lb, makes it responsive and lively. After two battery pack replacements, OPALCO concluded that charging at every opportunity and keeping the battery pack topped off is best for the life of the lead-acid batteries. The battery pack life has averaged from 2,500 to 7,000 miles. The vehicle has had some equipment changes, including the following:

- Replacing motor mounts
- Replacing one battery charger
- Upgrading the controller
- Replacing the two battery packs.

The maintenance and operation costs (excluding batteries) of the Solectria are approximately equal to a comparable gasoline vehicle. Because of the abundance of hydropower, the fuel costs per mile favors the electric vehicle in the Pacific Northwest. The Solectria averages 1.8 cents/mile for electricity, the gasoline counterpart about 4 cents/mile.

Jet Industries Escort

York Technical College updated the Escort before OPALCO received it. The Escort has a Curtis controller, a manual transmission, and it operates at 108 volts DC. The age of the vehicle and the eighteen 6-volt batteries make it a heavy vehicle, with a weight of 3,400 lb. The vehicle's maximum range was 47 miles and the battery pack was replaced once during the 5-year program. The vehicle uses a gasoline-fired heater to provide adequate heat. The Escort is left on the charger while parked, and its onboard smart charger cycles the battery pack as required to maintain a full charge. The Escort has performed adequately.

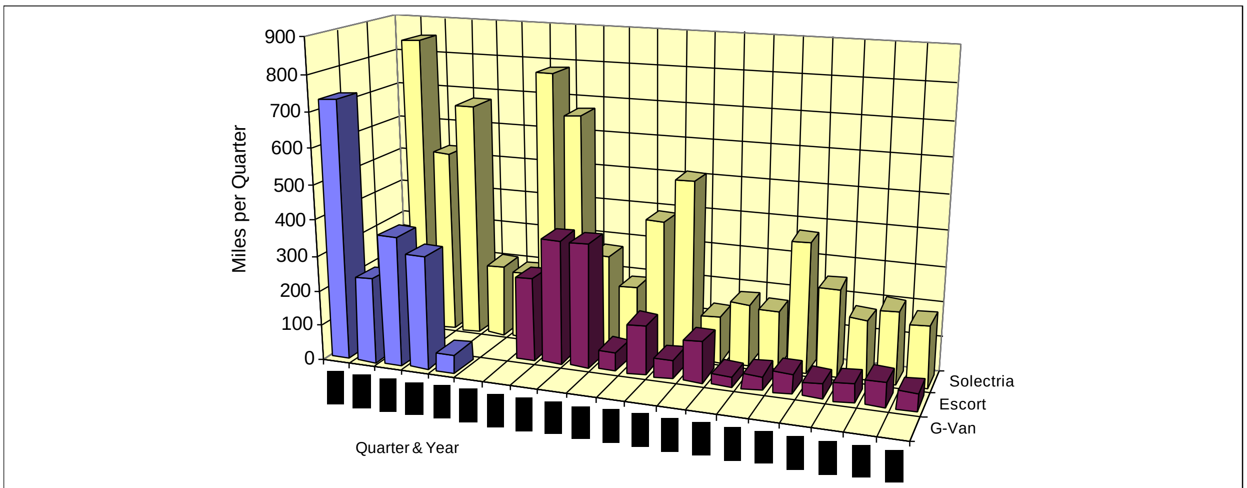


Figure OCR-1. Quarterly mileage for each of Orcas Island's three electric vehicles.

Table OCR-1. Total mileage and energy use for Orcas Island's three electric vehicles.

	Total miles	Miles/ day	Miles/ month	Average miles/kWh
GM G-Van	1,714	14.8	115	0.6
Solectria Force	7,170	12.5	150	2.7
Jet Industries Escort	1,645	7.7	40	0.8
Total	10,529			

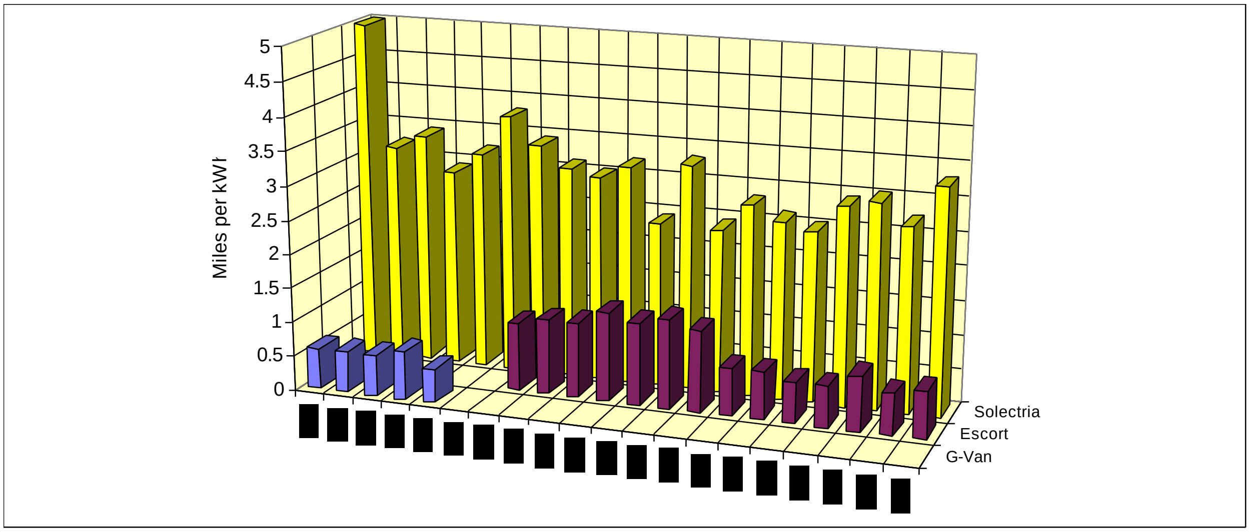


Figure OCR-2. Miles/kWh for each of Orcas Island's three electric vehicles. The data is displayed by quarter years.

Public Activities

Getting the public behind the wheel of an electric vehicle was an important goal of the OPALCO electric vehicle program. In addition to the numerous ride and drive events, San Juan County residents have a standing invitation to stop by and drive an electric vehicle anytime. Residents' responses generally fall in the following categories:

- Is it running?
- It's so quiet!
- You really have to push on the brakes
- It's not too peppy.

Regular drivers are those who are using or have used an electric vehicle on a daily basis for at least thirty days. In addition to initial responses similar to those above, these drivers commented as follows:

- A back-of-the-mind worry about running out of fuel
- Negative effects of cold weather, reduction of range, and inability to heat/defrost
- Grew to enjoy "one-footed" driving of regenerative braking

- Made a game of seeing how few amp hours a specific trip could be accomplished with
- A sense of contributing towards the improvement of the environment
- Considered distance of trip, state of charge, and availability of charging at the destination.

Other opportunities to reach the public have included OPALCO employee education, local media, country fairs, Seattle Auto Show, Earth Day celebrations, state legislative rallies, high school driver training classes, Fourth of July parades, and merely driving the vehicles that are clearly marked "Electric Vehicle." Numerous feature stories on the electric vehicle program in local newspapers and the novelty of the charging stations caused predictable small town conversations. As a result, over 75% of the adult population of San Juan County is aware that OPALCO operates electric vehicles. Another measure of the public's response to the OPALCO/DOE electric vehicle program is the number of electric vehicles operating in San Juan County. Since the beginning of the program, 11 electric vehicles have taken to the roads of San Juan County.

PACIFIC GAS AND ELECTRIC CO.

Pacific Gas and Electric (PG&E) is actively supporting the use of electric vehicles, and its expanding electric vehicle program is addressing the following :

- Vehicle development and demonstration
- Vehicle technology assessment
- Infrastructure evaluation
- Participation and support of various electric vehicle organizations and events.

The PG&E electric vehicle program had 18 vehicles in its traditional light-duty electric vehicle fleet during 1996. These included 10 active vehicles that were driven a total of 18,755 miles between January and October 1996.

Vehicle Operations

Ford Ecostars

PG&E operated five Ecostars during the first half of 1996. The Ecostars were returned to Ford during June 1996. The Ecostars were used throughout the service territory by meter readers, customer service representatives, electrical inspectors, parts delivery personnel, and staff commuters. They were typically charged at the PG&E service center at 240 volts, although the Ecostars were occasionally slow-charged at home by employees at 110 volts. The 90+ miles range and 70 mph top speed have made the Ecostars very popular vehicles with employees. The five Ecostars were not all used during each month (Figure PGE-1), but they did accumulate over 5,000 miles total during the first 6 months of 1996.

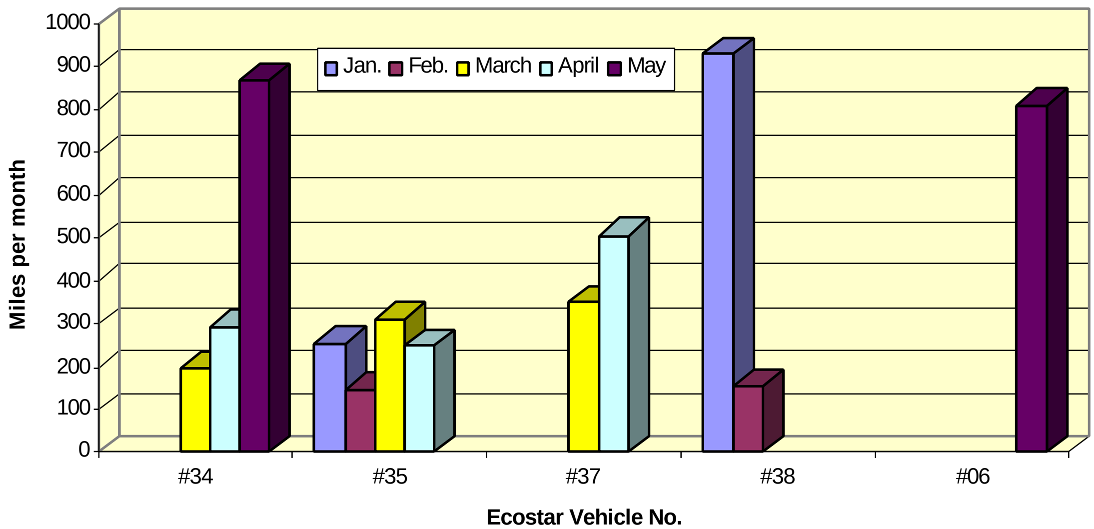


Figure PGE-1. Mileage per month for the five Ecostar minivans in Pacific Gas & Electric's electric vehicle fleet.

Honda Civics

PG&E only operated three Honda Civics at any one time. However, a total of four Civics were in PG&E's possession during 1996; two of the vehicles were switched and this is reflected in vehicles #13 and #17 only reporting miles driven for parts of 1996 (Figure PGE-2). The Honda Civic fleet was driven 8,843 miles during the reported 10-month period. The Civics exhibited ranges of 35-40 miles per charge with their lead-acid battery packs. The Civics did not have any failures, only requiring scheduled preventative maintenance. Vehicle #16 received a nickel-metal hydride battery pack during 1996. The monthly average miles driven went from 389 miles with the lead-acid battery pack to 570 miles per month with the nickel-metal hydride pack, a 47% increase.

Toyota RAV4

Since the first quarter 1996 arrival of the RAV4, it has been driven a total of 4,844 miles (Figure PGE-3) and has been used regularly for demonstrations and fleet applications without any problems.

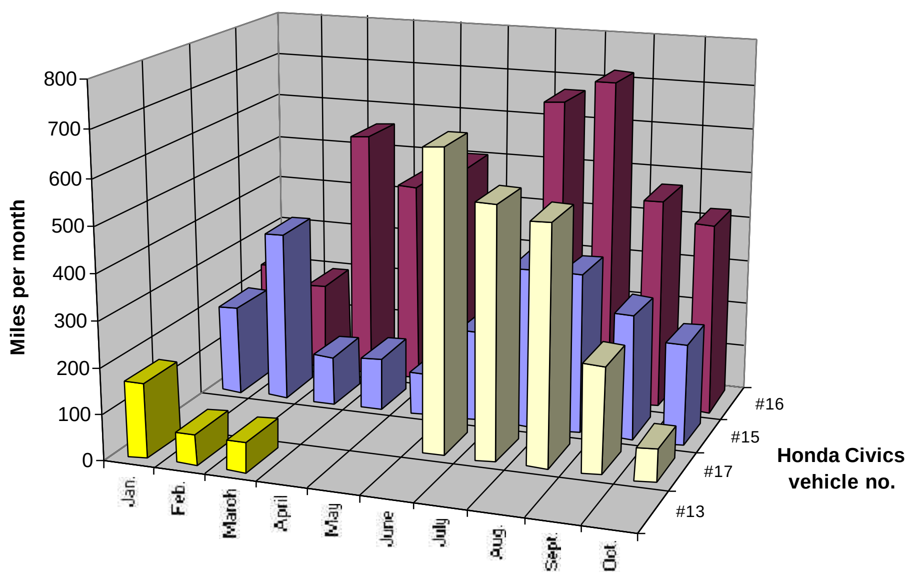


Figure PGE-2. Monthly mileage for PG&E' s four Honda Civic electric vehicles.

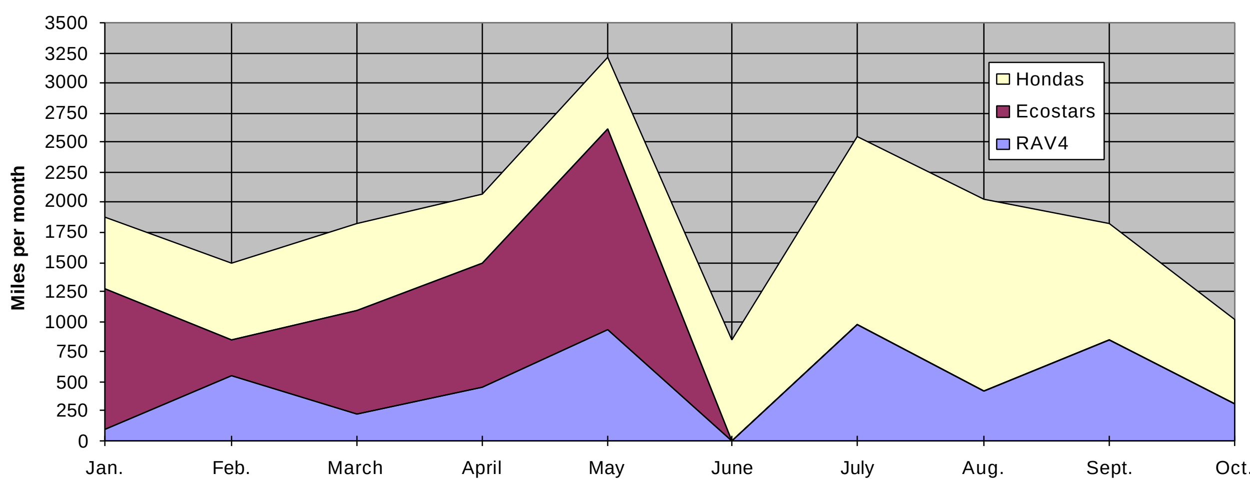


Figure PGE-3. Monthly mileage totals by car type for PG&E' s electric vehicles. PG&E had one RAV4, four Honda Civics, and five Ford Ecostars. The Ecostars were not driven after May.

U.S. Electricar Chevy S-10s

PG&E has in its possession five U.S. Electricar conversions of the Chevy S-10. These vehicles have not operated in the past in a satisfactory manner and they were scheduled for the following component changes:

- A Wavedriver controller/charger was to be installed in one pickup, but due to operational difficulties, the system could not successfully recognize the battery technology. Various software and E-Prom problems were experienced as well.
- A 5-kW Coherent Power charger, designed to recondition onboard batteries, was to be installed on a second vehicle, however, the circuitry had to be redesigned to prevent the charger from overcharging the batteries.
- The Hawker batteries were to be replaced in a third pickup with an Electrosource Horizon battery pack and a Badicheq battery management system with the intention of modifying the technology to accept power from a Wavedriver charger. Technical difficulties required sending the Badicheq system back to the manufacturer for repair. A new E-Prom was installed.
- The fourth pickup is scheduled to receive a new Hughes charger.

Other Vehicles

PG&E is in the process of transferring its three G-Vans to Cal Poly State University and the City of Santa Rosa.

PG&E is a partner in a project to develop a Narrow Lane Vehicle, allowing a single lane to be divided into two traffic lanes; and a project to develop a Fleet Electric Vehicle for use as an in-town delivery vehicle. PG&E is also supporting a 22-vehicle station car demonstration using a Norwegian Citi car for commuting to and from train stations. The station car test is scheduled to include 40 vehicles.

PG&E is supporting the use of 31-ft (Specialty Vehicle) and 35-ft (APS Systems) electric buses in Yosemite National Park. Both of the buses use Trojan quick-charge battery packs. A second electric bus project is the Berkeley demonstration project, which is using seven 22-ft U.S. Electricar shuttle buses.

PLATTE RIVER POWER AUTHORITY

This Program participant did not provide input to the final report.

POTOMAC ELECTRIC POWER COMPANY

Introduction

The Potomac Electric Power Company (PEPCO) is an investor-owned electric utility servicing approximately 2 million people in the Maryland and Washington, D.C. area. The majority of PEPCO's service area has been classified as a serious ozone non-attainment area and is part of the Northeast Ozone Transport Region. Amendments to the Clean Air Act require both the District of Columbia and the state of Maryland to take significant steps to reduce ozone emissions over the next 10 years. In addition, as an alternative fuel provider under the Energy Policy Act, PEPCO is purchasing electric vehicles to meet the requirements for fleet conversion to alternative fuel vehicles. PEPCO formed its electric vehicle program in 1992 and subsequently became a member of the Site Operator Program.

PEPCO has established special electric vehicle rates for both of its jurisdictions. For the District of Columbia, the experimental electric vehicle time-of-use rate is 2.795 cents per kWh in the summer and 2.705 cents per kWh in the winter. In Maryland, the experimental time-of-use rate is 2.512 cents per kWh. A dedicated meter is installed to measure the energy used to charge electric vehicles. The PEPCO electric vehicle program is focused on three objectives: revenue, environment, and technology.

Revenue

PEPCO is committed to encouraging the commercialization of electric vehicles as a source of future revenue growth. During the last few years, PEPCO has played a key role in developing national commercialization strategies for electric vehicles through PEPCO's leadership in EV America and the Electric Transportation Coalition. EV America is an organization of utilities that PEPCO helped establish in order to develop common technical specifications and vehicle testing procedures to ensure that only quality, road-worthy vehicles are brought to the marketplace. The Electric Transportation Coalition is an organization committed to helping launch the market for electric vehicles across the United States.

Environment

PEPCO is committed to helping reduce mobile source emissions by encouraging the commercialization of electric vehicles. PEPCO intends to purchase a total of 25 new electric vehicles for use in its fleet, to comply with the Energy Policy Act as well as to help stimulate a self-sustaining market for electric vehicles.

Technology

PEPCO expects its involvement with electric vehicles to continue to benefit the company from a technology monitoring point of view. Much of the technology being developed for electric vehicles has direct application to PEPCO's core electricity business, e.g., batteries, flywheels, capacitors, fuel cells, turbines, and advanced power electronics.

Demonstrations

During the spring of 1996, PEPCO worked closely with General Motors in a program called the GM PrEView Drive Program. The PrEView Drive Program was a market research study for electric vehicles using General Motors' prototype vehicle, the *Impact,* for test drives. Sixty of PEPCO's customers were selected to drive Impacts for 2-week trial periods. Through the PrEView Drive Program, General Motors gained valuable information about consumer preferences and driving patterns, consumers learned about electric vehicles, and PEPCO learned a great deal about infrastructure requirements.

An additional success of the PrEView Drive Program was the visibility it received in the Washington D.C. area. During the course of the Program, PEPCO performed over 250 electric vehicle demonstrations with the Impacts. Audiences ranged from high-ranking government officials to school children. Notable demonstrations included: the governor of Virginia, several members of congress, members of the Renewable Energy Caucus, members of the local and national media, as well as local business leaders. In addition, the general public had many opportunities to see the Impacts via sidewalk demonstrations, county fair exhibits and parades, and several television news stories.

PEPCO is committed to helping all of the automobile manufacturers acquaint potential customers with electric vehicles. To facilitate this, PEPCO has hosted joint marketing activities with automobile manufacturers by helping to display electric vehicles to local fleet managers and assisting in the coordination of Ride and Drives for fleet managers and the general public.

Vehicles/Components/Batteries

In 1996, PEPCO operated a total of 15 electric vehicles. Twelve of the vehicles were Impacts, and the other three vehicles were Solectria E-10 pickups. The Solectria E-10s were delivered to PEPCO in 1995 as part of the EV America field test evaluation. Two of these vehicles were 1995 models and the third was a 1994 model. All three of the vehicles were equipped with Mobile Data Acquisition Systems for on-board data acquisition of operating parameters. One of the pickups (number S07) was in service with the Architect of the Capital, the second pickup (S06) was operated as a mail delivery vehicle in PEPCO’ s fleet, and the third vehicle was operated as a commuter and demonstration vehicle.

Vehicle range and performance was measured by operating the vehicles on a ten-mile driving loop on local streets and a highway in the District of Colombia. Through the use of this bench mark, it was determined that the batteries in the S06 vehicle were not providing the expected energy capacity. Through consultation with Solectria, it was determined that the batteries were from different manufacturing runs and they did not have consistent characteristics. The entire pack was replaced under warranty by Solectria. During the course of installing the new pack, one of the connectors was improperly installed and damage occurred to the front portion of the battery pack. The front portion was subsequently replaced with sequential batteries. The trouble-shooting, negotiation, and pack replacement activities covered a span of five months and it was responsible for the low vehicle mileage.

The three pickups were driven a total of 650 miles during 1996 and they used a total of 154 kWh of energy for charging (Figure PEPCO-1). The three vehicles had a combined energy efficiency of 4.2 miles/kWh during 1996 (Figure PEPCO-2).

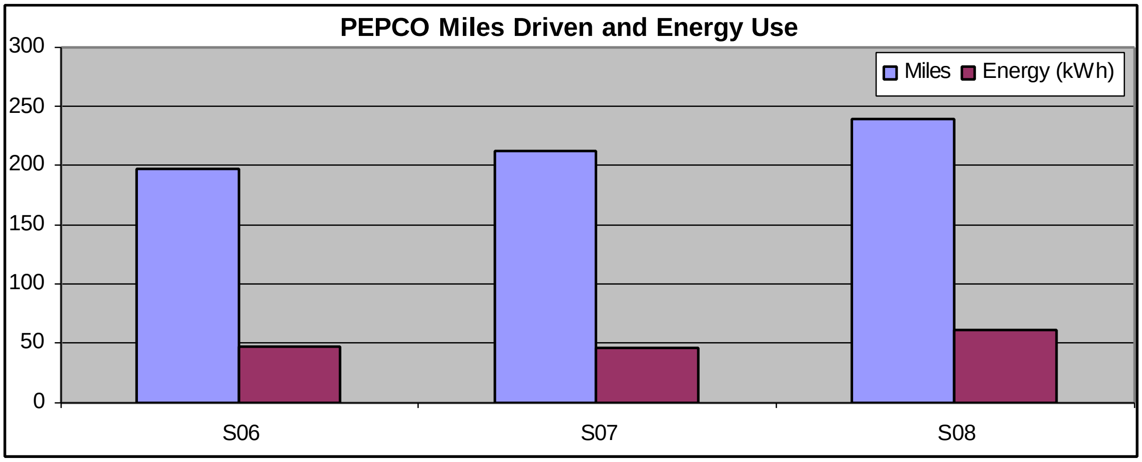


Figure PEPCO-1. Total miles driven and charging energy (kWh) for the three Solectria E-10 pickups in the PEPCO fleet during 1996.

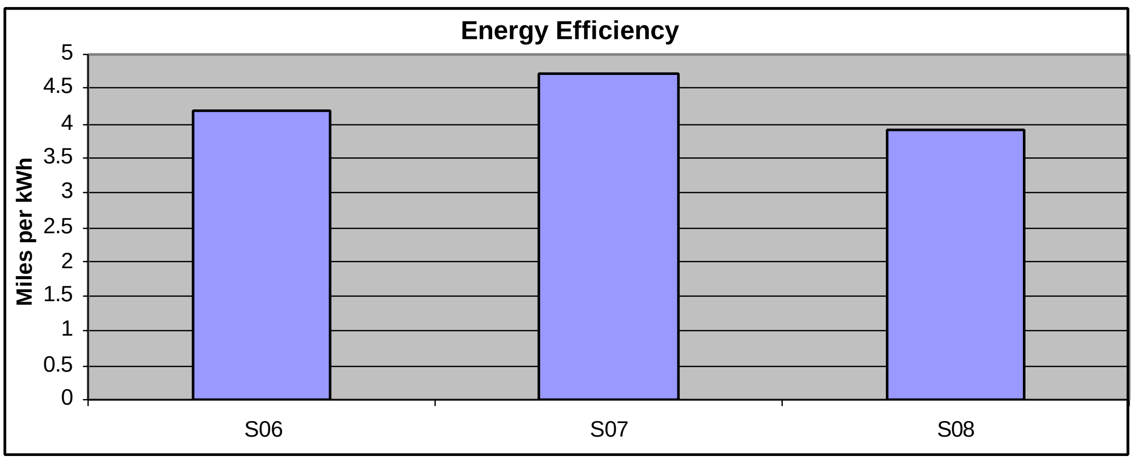


Figure PEPCO-2. Energy efficiencies, in miles/kWh, for the three Solectria E-10 pickups in the PEPCO fleet during 1996.

During 1996, PEPCO' s three Solectria E-10 required a combined total of 110 hours of maintenance (Table PEPCO-1). The three vehicles averaged only 5.9 miles per each hour of maintenance performed. On a per-miles-driven basis, the vehicles incurred 16.9 hours of maintenance for each 100 miles driven. Note that not all the maintenance activities were directly related to electric component maintenance. For example, over 35 hours were required for installing a bed liner, a fire extinguisher, and a bed cap, as well as for vehicle licensing and registration-related inspections.

Table PEPCO-1. The 1996 maintenance requirements for the three Solectria E-10 pickups in the PEPCO fleet.

Vehicle	Date	Description of Work	Labor Hours
S06	03/26	Record serial numbers of batteries	10.50
	05/06	A level preventive maintenance	1.00
	05/28	Replace inoperative PS pump	1.50
	06/25	Remove and reinstall all batteries	6.00
	08/01	Install cap, backup alarm, fire extinguisher	17.40
	08/29	Install brushes in PS motor	0.50
	09/05	Washington D.C. inspection	3.75
	11/13	A level preventive maintenance	2.00
		Total	42.65
S07	02/23	Check and test batteries	12.00
	03/12	Check batteries	4.50
	03/26	Check batteries	8.00
	05/06	A level preventive maintenance, C level p.m. also	1.50
	08/29	Install brushes in PS motor	0.50
	09/05	Washington D.C. inspection	3.75
	09/19	Install bed liner	7.50
		Total	37.75
S08	05/24	Repair emergency brake cable problem	1.00
	05/24	Repair air conditioner, replace bad relay	12.00
	06/14	A level preventive maintenance	1.00
	08/24	Check PS motor for brush fix, not needed	0.50
	09/09	Washington D.C. inspection	4.00
	09/09	Repair A/C, replace relay, repair regen. and wiring	2.00
	11/13	A level preventive maintenance	1.00
	12/05	Replace fuse in 110 charging, repair ground	8.00
		Total	29.50

SANDIA NATIONAL LABORATORY

History

The Sandia electric vehicle fleet was created in 1981, when the DOE supplied Sandia with seven electric vehicles, manufactured by "Jet" Industries of Austin Texas. The seven vehicles were called Electricas, and they were electric vehicle conversions of the two-door Ford Escort sedan (Table SNL-1). Four additional Electricas were obtained in 1986 from the U.S. Navy; these were upgraded before being placed in service. A twelfth Electrica was obtained from the Public Service Company of New Mexico, and it was added to the Sandia fleet after upgrading. During 1990, the entire electric vehicle fleet had state-of-art speed controllers installed.

Table SNL-1. Vehicle specifications for the Sandia fleet of Electricas.

Parameter	Value
Weight	3,300 lb
Model	Ford Escort, 2-door, 4 passenger sedan
Motor	20 HP series D.C., 120 volt
Transmission	4-speed manual
Battery pack	16, 6 volt deep discharge lead-acid batteries
Auxiliary battery	12 volt lead-acid, supplied voltage for controller logic and ancillary equipment
Controller	Solid-state, variable-speed, 80-120 volts D.C., 400 amp. Max
Acceleration	0 to 50 mph, 12 seconds
Range	Up to 40 miles
Top speed	65 mph
Energy efficiency	On-road, 0.8 to 1.3 miles/kWh

A preventive maintenance program was initiated early on to maximize the life of the Electricas. Every 4 to 8 weeks each vehicle was inspected by the electric vehicle maintenance contractor. The batteries were cleaned and watered, and any defective or marginal component was repaired or replaced. The battery packs were replaced as needed, approximately every 2 years. The maintenance contractor also responded to on-road emergency failures. The aggressive maintenance program has resulted in very few on-road failures. The preventative maintenance program has proven to be very effective and the costs have been lower than expected; the annual cost has been $5000–$8,500 for all twelve vehicles, or about $562 per vehicle, per year. In addition to the reasonable maintenance cost, the fleet has been accident-free.

Fleet Problems

The fleet has experienced a variety of problems, including the following:

- Erratic state-of-charge (SOC) indicators, caused by aging electronic components. Due to inoperable SOC meters, the miles per vehicle were not as great as desired, which therefore led to the reluctance of many drivers to use these vehicles. A Curtis Instruments Model 986 SOC system has been evaluated and found satisfactory. It has a current integrator that uses a microprocessor to record both the charge and discharge cycles and displays the battery capacity. The display uses a 10-bar LED to clearly display the state-of-charge. This system has been procured and is being installed in all 12 vehicles.
- Failure of the 12-volt auxiliary battery system, caused by inadequate charger capabilities.
- The emergency pull-out switch (kill switch) is occasionally pulled by drivers thinking it is the parking brake. This is a cause of poor human engineering in component placement.
- Exhaust fan failure, caused by acid vapors destroying the fan impellers.
- Some battery compartments are showing the results of aging and effects of exposure to battery acids.
- Faulty microswitch in the charger receptacle, caused by sand or dirt. This switch prevents moving the vehicle with the charge cable attached.
- Faulty microswitch in power brake vacuum sensing unit. This switch fails in the "on" position, which means the vacuum pump runs continuously, but does not create a safety problem.
- Age of all vehicles is approaching 16 years old, making it difficult to obtain special spare parts and components. None of the air-conditioning units are operating due to old design and unavailability of replacement parts.
- The heaters are VW 8,000 BTU gasoline units. These are difficult to keep operational due to failing logic circuits, fuel pumps, and clogged fuel lines.
- Chargers failing to turn off after reaching traction pack voltage (122 volts), caused by the failure of electronic components in the logic board due to age and heat.

Fleet Performance

As of October 1996, the Sandia electric vehicle fleet had accumulated over 120,000 miles and the fleet energy efficiency for the 12 Electricas was 1.1 miles/kWh (Table SNL-2).

Table SNL-2. Sandia electric vehicle fleet performance as of October 1996.

Vehicle	Odometer	kWh	Miles/kWh
E-22410	10,998	8,752	1.3
E-22411	8,887	9,934	0.9
E-22412	11,153	11,261	1.0
E-22413	15,395	8,142	1.9
E-22414	11,139	11,422	1.0
E-22415	14,300	13,656	1.0
E-22416	6,922	5,793	1.2
E-27433	12,391	10,678	1.2
E-27434	8,570	7,703	1.1
E-27436	8,549	10,464	0.8
E-27440	10,126	10,648	1.0
E-27661	5,744	5,012	1.1
Totals	124,174	113,465	1.1

Lessons Learned and Causes of Failures

- Traction battery failures were caused by:
  - Manufacturing defects
  - Temperature extremes
  - Lack of ventilation
  - Mismatched modules
  - Deep discharge
  - Overcharging
  - Undercharging
  - Low electrolyte level
  - Shock of vibration.
  - The auxiliary battery failures were caused by the above plus the following:
  - Not large enough capacity for auxiliary load
  - Not being charged separately from the traction pack charger.
- The high current cables and battery connectors have fused and or melted down due to the following:
  - Improper size, capacity

- Dirt, corrosion at interconnection causing high resistant contact
- Connections improperly tightened
- Overheated due to high contact resistance
- Inadequate air flow.

- Most battery compartments have fan exhaust systems. It is a must that a negative pressure be maintained in the compartment. As a result, acid vapors are exhausted which destroys the exhaust fans impellers. These fans are replaced every 6–9 months.
- Matching the charger to the required manufacturers' battery signature is one of the most important features to be addressed in an electric vehicle. The Electricas have a 96-volt traction system. The biggest failure is the charger failing to shut off when reaching the traction pack terminal voltage of 122 volts. Also, sometimes the back-up 16-hour mechanical timer fails. The charger failures are caused by aging components (defective) in the logic board. A few diodes have failed but that is rare.
- The original Anderson state-of-charge system on the Electricas were very satisfactory; the accuracy was +/- 10-15%. However, components aged and units became erratic or completely failed.
- There are two different microswitches in the Electricas. One is in the power brake vacuum sensing unit. When this switch fails, it fails in the "on" position and the vacuum pump runs continuously instead of shutting off at a pre-determined vacuum. However, this does not cause a safety problem since the vehicle always has vacuum for the power brakes.

  The other microswitch is located in the charge receptacle (220 volt). With the 220-volt cable attached, it opens up the key circuit for running and prevents the driver from operating the car with the cable attached.
- The heaters are all VW gasoline fueled units. They are very complex and very sensitive to dirt, vibration, heat, etc. and fail frequently.
- Most drivers use "opportunity" charging and usually the battery pack is not down to 80% SOC. As a result, much energy is wasted on converting water into hydrogen, oxygen, and heat. That is obvious when the kWh/mile exceeds 0.900.

Future Program Activities

Sandia will continue to maintain the viability of their electric vehicle fleet by continuing the preventive maintenance program, upgrading components when necessary, and replacing old or marginal battery packs. This will include the evaluation of new battery packs. New Curtis Instruments Model 986 SOC systems are being installed in the 12 Electricas. DC-to-DC converters are being evaluated to replace the current battery charger for the 12-volt auxiliary batteries to help increase vehicle reliability. Smaller, high frequency battery pack chargers will be evaluated for possibly increased energy efficiency and vehicle reliability.

Conclusions

While the Electricas are older vehicles that do not now represent the state-of-the-art, several positive conclusions can be drawn from the Sandia electric vehicle program.

- The Sandia electric vehicle program has proved to be very successful at providing transportation to Sandia personnel.
- The Sandia vehicles have demonstrated that electric vehicles can be a very efficient means of transportation.
- Electric vehicles are reliable and the cost of operation is acceptable: (1) there has never been a run-away condition where the "emergency switch" had to be pulled; (2) the fleet has never had an accident due to electrical components or brake failure due to extra weight; (3) there never has been a motor failure or any need to replace brushes or bearings; (4) the original PMC speed controllers were replaced with the Curtis controllers. Since then, no speed controller failures have occurred; (5) the Electricas passed the Environmental Safety and Health evaluations after safety "high voltage" decals and a fire extinguisher were added to the vehicle; (6) maintenance costs have been lower than predicted at a yearly average of $562.
- Sandia has been part of an effective public awareness program through exhibits, conventions, public programs, and by using the 12 Electricas throughout the city of Albuquerque.

SOUTHERN CALIFORNIA EDISON CO.

Introduction

The Southern California Edison Company (SCE) was a member of the Site Operator Program from 1991until 1996. As of September 1996, the SCE fleet had 65 electric vehicles (Table SCE-1). Some of these vehicles were the newest generation of electric vehicles available. The entire fleet has accumulated well over 500,000 miles. Some of the model-types have accumulated over 100,000 miles each, averaging over 10,000 miles per vehicle (Figure SCE-1). Given the limited range per charge, this per-vehicle mileage is a significant accomplishment.

Table SCE-1. Southern California Edison’ s electric vehicle fleet profile as of September 1996.

Make	Model	Battery	Quantity	Miles
Conceptor	G-Van	Lead-acid	9	140,600
Conceptor	G-Van	Nickel-cadmium	1	14,300
Specialty	Shuttle	Lead-acid	1	21,500
Solectria	Force (Metro)	Lead-acid	7	36,600
Solectria	E-10 (PU)	Lead-acid	2	6,900
US Electricar	ES-10 (PU)	Lead-acid	10	35,100
US Electricar	Sedan (Prizm)	Lead-acid	10	40,400
Ford	Ecostar	Sodium-Sulfur	12	114,200
Honda	CUV4 (Civic)	Lead-acid/Nickel-Metal Hydride	3	26,800
Toyota	RAV4	Lead-acid/Nickel-Metal Hydride	2	10,700
Nissan	Avenir	Lead-acid	1	1,700
Chrysler	TEVan	Lead-acid	1	1,000
Chrysler	TEVan	Nickel-Iron	1	900
TDM	Ranger	Lead-acid	2	3,700
AC Propulsion	CX	Lead-acid	1	6,500
B.A.T.	Metro	Lead-acid	1	1,400
B.A.T.	Ranger	Lead-acid	1	200
Retired electric vehicles	G-Van, etc.	Lead-acid	(12)	115,700
		Totals:	65	578,200

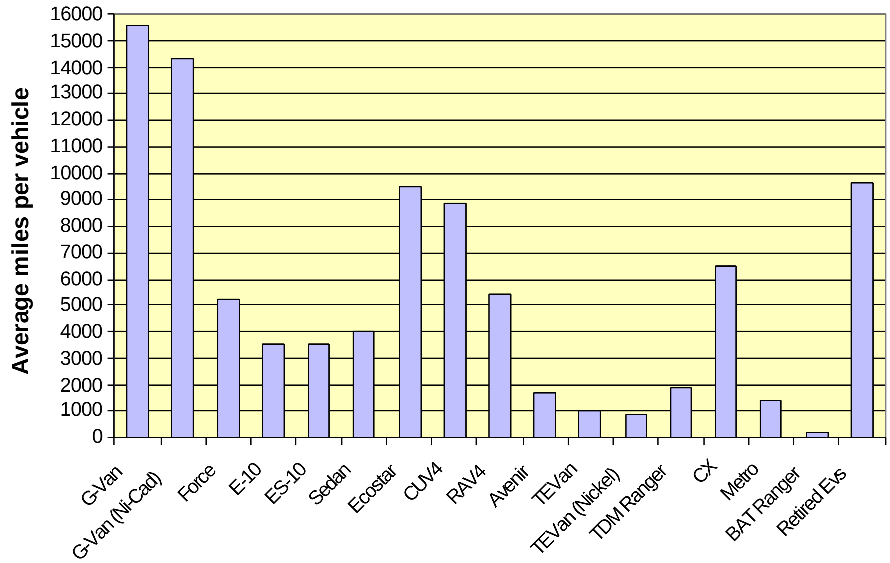


Figure SCE-1. Average miles per vehicle for Southern California Edison's electric vehicle fleet as of September 1996.

Vehicle Development and Testing

SCE had an active electric vehicle program before joining the Site Operator Program, and technology assessment was a major focus of the early SCE electric vehicle program. As part of that early program, SCE received two proof-of-concept G-Vans in 1988 for test and evaluation to support the design and certification of a production version G-Van and the development of a more advanced electric vehicle based on the early Chrysler TEVan platform. The development of a lithium-air battery powered mini-van with significant range potential was also initiated.

Early experience with the G-Vans led Edison to support the improvement of vehicle subsystems such as the air conditioning, battery state-of-charge gauges, and on-broad chargers. Two Solectria electric passenger vehicles and an electric shuttle bus were added to the fleet during 1991.

During 1992, several vehicles were tested and evaluated, including a side-by-side energy efficiency test of a Solectria and its gasoline counterpart (the Geo Metro). Two G-Vans were accepted in the local Federal Express delivery fleet for testing, and a Southern California conversion firm converted two SCE gasoline fleet vehicles to electric vehicles.

The SCE Transportation Research group tested two light-duty pickup trucks, one passenger car, one converted electric school bus, and a full-size van upgraded with nickel-cadmium batteries during 1993. Also during 1993, a Hughes inductive charger was tested in two of SCE's electric vans. One was tested for performance characterization at SCE's facilities, and the other was field tested in conjunction with PG&E.

SCE was able to significantly improve one of the Federal Express-loaned G-Vans by retrofitting it with nickel-cadmium batteries. This project included the design and fabrication of an air-cooled battery tray, the use of a new battery charger and a new state-of-charge gauge. SCE tested several electric vehicles for electromagnetic fields and prepared a fact sheet on electric vehicles and electromagnetic fields. Test protocols for electromagnetic field testing were developed by SCE and project partners EPRI and PG&E.

During 1994, SCE initiated the test and evaluation of the first of twelve Ford Ecostar prototype electric vans; a total of 23 electric vehicles were transferred to fleet operations. A complete electric vehicle technical center was made fully operational when the charging infrastructure was completed and energized. SCE also performed the acceptance testing of the US Electricar S-10 pickups for the Site Operator Program.

During 1995 and 1996, SCE developed and implemented a Fleet Evaluation Program to systematically and consistently document the performance of its electric vehicle fleet.

Energy Storage Development and Testing

SCE's earliest electric vehicle related work was with lead-acid battery testing. The first batteries tested were those in the two proof-of-concept G-Vans in 1988 and subsequent prototype G-Vans from Conceptor, all of which had chloride-flooded lead-acid packs. SCE co-funded the development of a high energy density nickel-iron battery at Eagle-Picher as part of the effort to extend the range of electric vehicles. While successful in producing prototype batteries for incorporation into Chrysler TEVans, the high hydrogen gassing of this battery during recharge contributed to the dropping of attempts to proceed to a pilot-plant stage. A number of sealed bipolar lead-acid battery prototypes were built and tested in 1990 and 1991, but shorts occurred due to mechanical failures and SCE discontinued funding.

A joint project with Electrotek saw a Griffon van with a CSPL sodium sulfur battery achieve 154 miles on a C-Cycle. (The C-Cycle was a simulated driving cycle test procedure developed in the 1980s.) The battery developed internal problems and a replacement battery was built and tested at the Electrotek test track in 1991. The battery demonstrated a range of 130–160 miles. About 15,000 total miles were logged over 170 discharge cycles. The test was terminated when capacity began to drop.

A light-weight, 168-cell zinc-air battery was produced and it has achieved a range of 120 miles in a Chrysler mini-van. A range of 65 miles has been achieved with a 84-cell half-pack. Work continues with the goal of improving the cells to obtain a discharge rate of nearly three times the power of the previous cells to ensure adequate driveability of the van.

In a joint project between Arizona Public Service and SCE, a Honda CRX was equipped with a bipolar zinc-air battery design by Dreisback Electromotive Inc. (DEMI). The vehicle averaged 54 mph for 108 miles while winning the 1991 Solar and Electric 500 race in Phoenix. In another test, the CRX recorded 251 miles on a single charge.

Testing has been performed on several alternative lead-acid batteries; the G-Vans were used to complete tests on battery packs produced by Chloride, Sonnenschein and Trojan. Reviews of battery options such as ARIAS Bipolar and Electrosource lead-acid batteries were completed. A study of battery/fuel cell hybrid combinations suggested that the optimal hybrid combination is a 50/50 battery/fuel cell mix.

SCE provided support to the USABC (United States Advanced Battery Consortium) both financially and through active participation on the Technical Advisory Committee and on other committees. Some of the battery technologies that are being investigated include nickel-metal hydride, lithium polymer, and lithium iron disulfide.

SCE has been able to obtain first-hand information on current technology by testing several battery technologies, including advanced lead-acid and nickel-cadmium batteries, from several different manufacturers. SCE has also monitored the progress of electric vehicle alternative energy storage technologies, including fuel cells, ultracapacitors, and flywheels.

During 1994, two new battery systems were introduced for testing: a valve-regulated spiral would absorb electrolyte from a lead-acid battery pack by Optima, and a nickel-iron battery pack manufactured by Eagle Picher. These new packs underwent initial characterization and equalization in the laboratory, followed by in-vehicle road testing and life cycle testing in the SCE fleet. SCE conducted life cycle tests on maintenance-free valve regulated lead-acid battery packs from Hawker (four packs), Sonnenschein (two packs), East Penn (two packs), and Teledyne (one pack).

SCE has attempted to integrate battery packs with battery chargers produced by different manufacturers such as La Marche, Enerpro, and Soleq. The main goal of this task was to improve overall energy efficiency of electric vehicles by meeting charging regimes as required by battery manufacturers. SCE has also investigated battery pack life and charge acceptance during quick charging using a Norvik fast charger. This charger may allow the recharging of electric vehicle battery packs from a 20% state-of-charger to a 80% state-of-charge (SOC) in as few as 10 minutes.

Infrastructure

In 1992, SCE initiated research, development and demonstration activities to support the creation of an electric vehicle recharging infrastructure. A multi-year research plan was developed and implemented. In the initial years, the plan’ s focus was on electric vehicle recharging load management device testing and evaluation, while projects in the later years developed and tested other recharging equipment, on-site energy storage, and distributed generation concepts that minimize the utility’ s electrical demand. Some of the specific activities included:

- The function of battery chargers and their impacts on a utility electrical system
- Standards for charging connectors
- Communication links between the battery charger and the utility, for load management
- Strategies for effective charging facilities
- Ways to manage (shift) charging loads through on-site energy storage or distributed generation
- Electrical infrastructure requirements of alternative fuels
- Battery charging safety issues
- Billing for charging
- Standards for charging power quality.

Another activity is SCE’ s participation on the Infrastructure Working Council’ s Connectors and Connecting Stations Committee. This is a national committee for establishing electric vehicle charging standards for voltage, current, and time.

SCE has analyzed and tested the Hughes Power Control Systems inductive charger technology. SCE found that this technology has good power quality with a very high power factor and very low harmonics. The inductive paddle was found to be safe and convenient from a users standpoint.

SCE has teamed with many organizations to develop the necessary infrastructure for electric vehicles, as well as to generally advance electric vehicle technology in the United States. Some of those partner organizations have been the following:

South Coast Air Quality Management District	CALSTART
Electric Power Research Institute	APRA
Society of Automotive Engineers	Japanese Electric Vehicle Association
Sacramento Municipal Utility District	York Technical College
Electric Vehicle Association of the Americas	Ovonic Battery Corporation
Saft Battery Company	Grace
Santa Barbara MTA	

Lessons Learned

Vehicles

- Vehicle development is being addressed by small and larger assemblers and the technology is evolving for many powertrain components. However, the size of the manufacturer is not directly relevant to the quality of an electric vehicle.
- Historically, small, unfit firms have failed to continue business operations. Therefore, larger business entities offer the greatest promise for high volume products aimed at building a sustainable market.
- SCE testing of electric vehicles is essential to verify manufacturer vehicle performance data. Even as standardization of testing protocols is obtained, SCE should continue to test electric vehicles for corporate fleet and general ratepayer knowledge.
- Vehicle development support by utilities is a high-risk activity with minimal payback. For example, after numerous years of research and development, and about 100 vehicles built, the G-Van was not able to move into volume production.
- Feedback of utility test data to vehicle and component developers is of high value to ensure that utility fleet and customer needs are recognized and accommodated.

Energy Storage

- Far more than any other component, energy storage remains the technological and commercialization weak point for electric vehicles. No stakeholder, including utilities, should ignore the need to continue development support. Because of the large magnitude of support needed and the typically long time duration required to finish the development process, cooperative efforts among stakeholders are essential.
- Chemical batteries are appropriately receiving a large amount of support for their use in electric vehicles. Many developers continue to make incremental improvements in

near-term batteries, e.g., lead-acid. However, if electric vehicles are to be a sustainable market, there must be technology advancements that meet midterm and long-term performance parameters. Research and development support for a battery type must be continuously evaluated for its commercial cost viability.

- SCE should continue to test promising new chemical batteries at both the prototype and production stages of development. Unanticipated quality problems have occurred as technologies move from the laboratory stage to production.
- About every 10 years, mechanical battery (i.e., flywheel) developers forecast commercial product availability in 5 years. Healthy skepticism should be applied to these forecasts and only when working units are available and acceptable costs verified, should high confidence be assumed for their use in electric vehicles.
- Fuel cells have a potential for use in electric vehicles. Their use in combination with batteries at about a 50/50 mix seems most viable, but not before the mid-2000s.
- Although SCE's program has not been involved in developing and testing hybrid electric vehicles (HEV), electric vehicles are a viable lower emission vehicle. These vehicles put less of a range and cost demand on batteries, since the battery pack can be smaller in size. Range extension is likely to come from combustion engines or turbines.
- Feedback to developers is of high value in efforts to develop products suitable for utility and customer needs. Laboratory and auto manufacturer testing alone is not sufficient. Real-world testing over extended periods in actual user environments has exposed the need for numerous product improvements.

Infrastructure

- Standardization and code accommodation of electric vehicles in the infrastructure segment of the industry has been glaringly deficient. A combined utility and automaker effort under the Infrastructure Working Council has begun and needs to be nurtured to ensure charging infrastructure has a solid base from which to grow.
- Early charging equipment did not meet power quality parameters. Testing revealed undesirable feedback into the utility electrical system; high value was obtained from these tests by identifying improvement needs to suppliers. Equipment tests by neutral parties should be expanded and efforts should be directed to establish industry standards.
- Industry has shown the ability to agree on some parameters for electric vehicle charging, i.e., power levels 1, 2, and 3. However, a major controversy continues to exist between the inductive and conductive charging methods. SCE has tested both approaches with neither emerging as a overwhelming winner. A single method should be identified.

TEXAS A&M UNIVERSITY

Introduction

Texas A&M' s involvement of electric vehicles is through the Center for Electrochemical Systems and Hydrogen Research, which is a department of the Texas Engineering Experiment Station. Texas A&M joined the Site Operator Program in August 1991. The University has been involved in the education, demonstration, research, development and testing of electric vehicles since 1988. Texas A&M continues to be actively involved in the research in new materials for advanced batteries and in proton exchange membrane fuel cells for transportation applications.

Vehicle Operations and Activities

During the first 2 years as a Site Operator Program participant, Texas A&M tested 16 G-Vans and two Jet Industries conversions in field applications. During the following years, nine Chrysler TEVans were added to the fleet. During the final year of the program, three US Electricar Chevrolet S-10 pickups were added to the Texas A&M fleet. The 30 vehicles logged a total of 150,000 miles. Several different electric vehicle projects and studies have occurred as part of the program; some of the titles included:

- Battery Modeling for Electric Vehicle Applications using Neural Networks
- Comparison of Various Battery Technologies for Electric Vehicles (lead-acid, nickel-cadmium, nickel-metal hydride, zinc-bromide)
- Comparison of Advanced Battery Technologies for Electric Vehicles
- A Smart Control System for Electric Vehicle Batteries.

Education and Information

During the course of the 5-year Site Operator Program, Texas A&M personnel made more than 150 electric vehicle presentations and demonstrations; nearly half of these presentations were followed by ride and drive events. Some of the groups that received presentations include the Texas Public Utility Commission, the Texas Energy Policy Alternative Fuels Committee, Governor Richards of Texas, Vice President Al Gore, Secretary of Transportation Federico Pena, Earth Day events, and school groups. An Electric Vehicle Symposium to educate public, private, and government organizations has been held annually.

The program has also helped the research programs and theses projects of graduate students in the areas of electric vehicles, batteries, fuel cells, and hybrids. Electric vehicle mechanics have been trained and specialized electric vehicle tools have been developed through program support. The program has also supported the development of safety procedures for electric vehicle operations, maintenance, and repairs.

Conclusions

The program objectives of education and awareness of electric vehicles have met with total success. Today, electric vehicle awareness is much higher than at the beginning of the program in 1991. This is especially true among younger children and students up to the high school level.

The vehicle evaluation aspect of the Program was not as great a success as the education and awareness objectives. Electric vehicles need more sophistication and the power source (battery) must be greatly improved before electric vehicles will be acceptable and affordable by the general public. Quality control by the early manufacturers and converters of electric vehicles of the vehicles tested was poor. The after-sales treatment of electric vehicle owners was equally poor. This experience deterred electric vehicles purchasers as they became disenchanted with the products and support service.

UNIVERSITY OF SOUTH FLORIDA

Introduction

The University of South Florida (USF), in collaboration with Florida utilities and other organizations, has completed a research and development program for the testing and evaluation of electric vehicles in fleet and commuter operations. One feature of the USF program has been the development of a utility-interconnected photovoltaic system for charging electric vehicles with solar energy. The photovoltaic system consists of a twelve bay parking facility equipped with roof mounted photovoltaic panels. The primary objects of the USF program included the following:

- Gathering electric vehicle performance data under actual commuter and fleet conditions.
- Determining public acceptance of electric vehicles through questionnaires and personal interviews with drivers.
- Determine the maintenance requirements.
- Evaluation of battery performance as a function of vehicle range and driving conditions.
- Determine vehicle ranges for commercially available electric vehicles.
- Evaluate the effect of an air conditioner on electric vehicle range and performance.
- Determine the best role for photovoltaic systems in charging electric vehicles.
- Determine the technical feasibility and economic advantages of returning the extra power generated by the photovoltaic system to the utility grid.

Vehicle Inventory

Eight electric vehicles were purchased with funds received from the DOE, with cost sharing by Tampa Electric Company, Florida Power Corporation, the Florida Energy Office, Hillsborough County, and the City of Tampa. Six of these electric vehicles were located at the USF campus and operated under the guidance of the Electrical Engineering Department. Two electric vehicles were located in downtown Tampa; one was operated by the Hillsborough County Environmental Protection Commission and the second electric vehicle was operated by the Tampa Electric Company. These two electric vehicles were tested in both commuter-type and fleet-type environments. Additional electric vehicles were acquired and operated by the Florida Power Corporation. Data from the Florida Power Corporation electric vehicles were included in a common database with those of the USF fleet. All of the electric vehicles operated in the Tampa-St. Petersburg metropolitan area of Florida. Eight additional operators of electric vehicles contributing to the database were located in the counties of Alachua, Volusia, Pinellas, Dade, Polk, Duval, Brevard, and Orange (Table USF-1).

Table USF-1. Inventory and status of vehicles monitored by the University of South Florida.

Vehicle #	Model	Location	Status
G01	GMC van	USF	Not operational
G02	GMC van	USF	Not operational due to motor failure
S01	Chev S10	USF	Operational, data being collected
S02	Chev S10	USF	Operational, data being collected, noisy charger causing faulty charge readings
M01	Mitsubishi Mirage	USF	Operational, testing
SOL	Solectria Geo Force	USF	Vehicle totaled in accident
S3	Chev S10	Clearwater	Vehicle totaled by fire
S4	Chev S10	Gainesville	Not operational
S5	Chev S10	Jacksonville	Operational, data being collected, little use
S6	Chev S10	Hillsborough	Operational data being collected
S7	Chev S10	Orlando	Not operational
S8	Chev S10	Volusia	Not operational, bad battery pack
S9	Chev S10	Miami	Not operational
S10	Chev S10	Haines City	Not operational, controller failure
FP1	Chev S10	St. Petersburg	Operational, little usage, no data
FP2	Chev S10	St. Petersburg	Operational, little usage, no data
SL1	Chev S10	Tampa	Operational, data being collected

Vehicle Performance

A Mobile Data Acquisition System (MDAS) was developed by USF for installation in electric and alternative fuel vehicles. The MDAS was installed onboard vehicles and they collected performance data such as battery pack voltage, current, and temperature, as well as speed and ambient temperatures. The MDAS units and supporting software have undergone several improvements since the initial use in 1992. The MDAS units are now commercially available by a private company. Table USF-2 gives a summary of performance data derived from the MDAS units that have been used on 14 vehicles monitored by the USF electric vehicle program. This data has been collected over different time intervals since the fourth quarter of 1993.

Driver logs were also used to obtain vehicle driving and charge summaries for four of USF' s electric vehicles. The data from the driver logs represents a longer period of time than does the MDAS-captured data. The operations and charging data (Figure USF-1) is for the second quarter of 1993 to the second quarter of 1996. The four vehicles were driven a total of 22,250 miles (Figure USF-1) during the 3-year reporting period, and the average energy use was 1.1 miles/kWh (Figure USF-2).

Table USF-2. Vehicle performance summaries collected by the Mobile Data Acquisition System developed
South Florida.

Trip Summary												
		Vehicle Number										
Parameter	**Units**	**G01**	**S01**	**S02**	**M01**	**S3**	**S4**	**S5**	**S6**	**S7**	**S10**	**SO**
Days in use	# days	372	408	149	139	10	86	108	114	7	45	1
Trip cycles	#	1526	1274	429	445	15	247	425	450	9	261	5
Total trip time	hours	222	204	56	81	3	49	54	58	6	31	
Total distance	miles	4143	3581	1075	1099	74	630	1006	1208	71	707	8
Avg. speed	mph	22	22	20	18	24	22	18	22	17	26	1
Max. batt. temp.	^oC	65	58	99	99	45	60	42	99	34	99	4
Avg. batt. temp.	^oC	35	31	36	37	40	35	26	42	30	39	3
Total Regen	kWh	74	15	2.5	na	0.04	2	9	4	2	5	
Total A/C energy	kWh	101	30	8	na	3	28	17	7	0.4	na	r
Total discharge	kWh	2368	1183	366	417	26	133	304	410	4	178	2
Net DC energy	mi/kWh	1.8	2.6	3.0	2.9	2.9	4.7	3.3	2.9	2.4	3.9	

Table USF-2 (cont.)

		Vehicle Numbers										
Charge Summary		**G01**	**S01**	**S02**	**M01**	**S3**	**S4**	**S5**	**S6**	**S7**	**S10**	**SO**
Total charges	Number	264	424	136	117	7	66	108	110	3	67	2
Tot. charge time	hours	1540	2736	559	537	62	659	591	911	5	270	9
Max. charge current	A	185	34	137	39	41	53	26	36	16	23	2
Avg. charge current	A	18	8	9	10	5	7	6	13	2	12	
Max batt. temp.	^{o}C	52	75	44	36	52	44	45	45	31	38	5
Avg. batt. temp	^{o}C	27	29	27	20	34	26	27	27	27	25	3
Tot. charge energy	kWh	6883	2962	748	623	47	409	414	1048	2	258	4
Gross DC eff.	mi/kWh	0.6	1.8	1.2	1.4	1.6	1.5	2.4	1.2	5.4	2.7	
Battery pack eff.	%	33	69	40	48	54	32	73	41	225	69	4

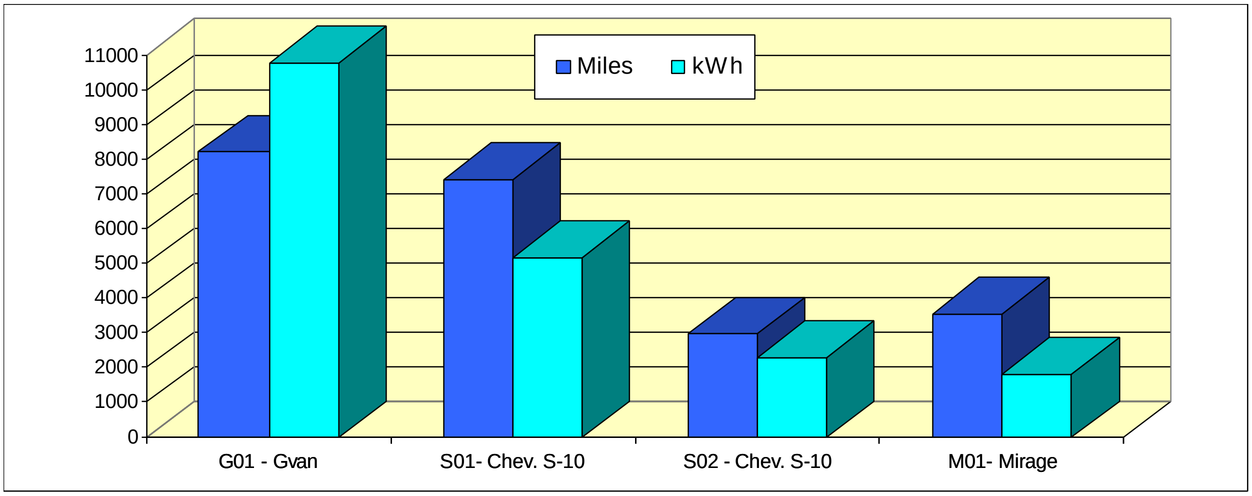


Figure USF-1. Vehicle distance and charge summaries for four of USF's electric vehicles. The data was collected during a 3-year period, from the second quarter of 1993 through the second quarter of 1996. The Chevrolet S-10s are conversion vehicles.

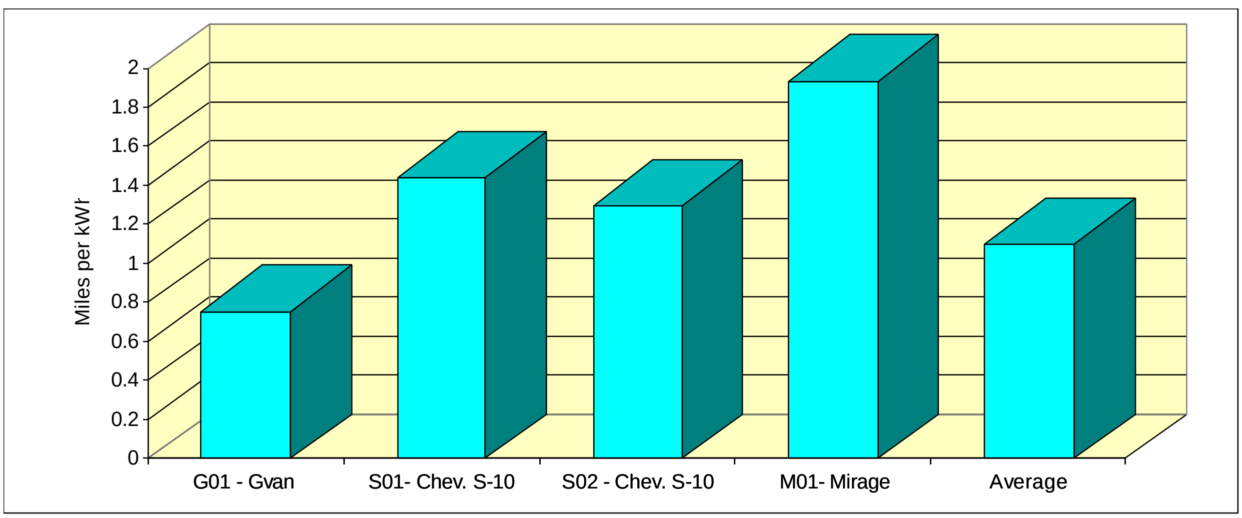


Figure USF-2. Energy use in miles/kWh (AC) for four of USF's electric vehicles. The fifth column, titled Average, is the average miles/kWh for the four vehicles. The data was collected during a 3-year period, from the second quarter of 1993 through the second quarter of 1996. The Chevrolet S-10s are conversion vehicles.

Air Conditioning Performance

A set of sensors were installed on the G01 GVan to monitor air conditioning power requirements. The data was collected from the second quarter of 1995 through the second quarter of 1996. The energy use results were:

Total battery discharge energy	1,161 kWh
Energy consumed by the air conditioner	56 kWh
Percentage of battery discharge consumed by the air conditioner	4.8%

Photovoltaic Solar Power

The USF Photovoltaic Demonstration and Evaluation Program includes a 20-kW (peak) photovoltaic (PV) system. The system includes a 12-bay carport with 20 solar panels forming the carport roof (Figure USF-3). A 6-kW (peak) segment of the PV system can be simultaneously distributed between computer-controlled direct DC-DC charging and power grid interconnection. The DC-DC charger (DC-DAS) controls the charging current of a battery pack with minimal power waste by using computer control of current flow direction for each of the four source circuits. By connecting the modules in series and in parallel, the modules can be interfaced with the electric vehicles directly or through the utility grid. AC-DC chargers are available for charging when solar power is unavailable or insufficient. The photovoltaic panels are tilted south at three different angles. Array #1 has 117 modules angled at 25 degrees, Array #2 has 130 modules angled at 15 degrees, and Array #3 has 130 modules angled at 5 degrees. All the electric power produced by Arrays #2 and #3 is directed to the power grid via microprocessor-controlled inverters, which load the PV circuits at their maximum power voltage by constantly varying the load and monitoring the power.

Figure USF-3. 20-kW solar energy charging station located on the campus of the University of South Flori up to 12 electric vehicles, using 377 Siemens 53-watt solar modules. When not charging vehicles, the electr cells is fed into the local utility grid. (photo 95-943-1-1)

U.S. NAVY

The U.S. Navy has been a member of the Site Operator Program since the late 1970s, and it shared the Program's goals of testing, demonstrating, and evaluating electric vehicles in fleet operations. During the early 1980s, the Navy had as many as four hundred electric vehicles in service throughout the United States. These old-style electric vehicles were conversions of gasoline-powered production vehicles and they were very inefficient in their energy use.

Over the years, the Navy fleet has been reduced to about 60 vehicles. Sixteen of these remaining vehicles are the old style Jet Industries conversions that date from the early 1980s. At one time, 21 Navy bases were using electric vehicles. In 1991, the Navy purchased three new electric G-Vans, which were GMC vans converted by Conceptor Industries. These vehicles are still providing dependable transportation today, but the energy efficiencies of these G-Vans is not of the highest order. During 1994, the Navy was able to acquire 14 electric vehicles converted by Solectria, of Massachusetts, and US Electricar of California. These 14 vehicles were also gasoline-type of production vehicles converted to electric vehicles.

During 1995 and 1996, the Navy received funding to purchase new electric vehicles from original equipment manufacturers (OEM). While there were not any OEM vehicles available during 1995, the Navy was able to issue a request for the purchase of electric vehicles during 1996. The Navy was later able to use the General Services Administration to purchase 68 electric Chevrolet S-10s and 5 Chrysler EPIC electric minivans. The expected delivery date of these vehicles is during the first half of 1997. The purchase terms included vehicle and battery warranties, and it is believed to be the first such large fleet purchase of electric vehicles in the United States. The 73 new electric vehicles will be distributed to five organizations in different parts of the United States (Table NAVY-1).

Table NAVY-1. Location of the U.S. Navy's new fleet of electric vehicles. (NFESC - Naval Facilities Engineering Service Center).

Organization	State	Chevrolet S-10	Chrysler Epic
Port Hueneme, PWD	California	21	3
North Island, PWC	California	10	
NFESC	California	1	2
Anacostia	Washington, DC	29	
Norfolk	Virginia	7	

With the addition of the above 73 vehicles, the Navy electric vehicle fleet will once again number over 100. The new vehicles will replace the Navy's "older fleet" of approximately 60 electric vehicles, located at eight sites in the United States (Figure NAVY-1). The Navy has a Memorandum of Understanding (for technical support and data sharing) with the Department of Energy to participate in the Field Operations Program, which succeeded (with different goals) the Site Operator Program. The United States Air Force is also purchasing new electric vehicles; these vehicles will be located at the McClellan Air Force Base and two other Air Force bases.

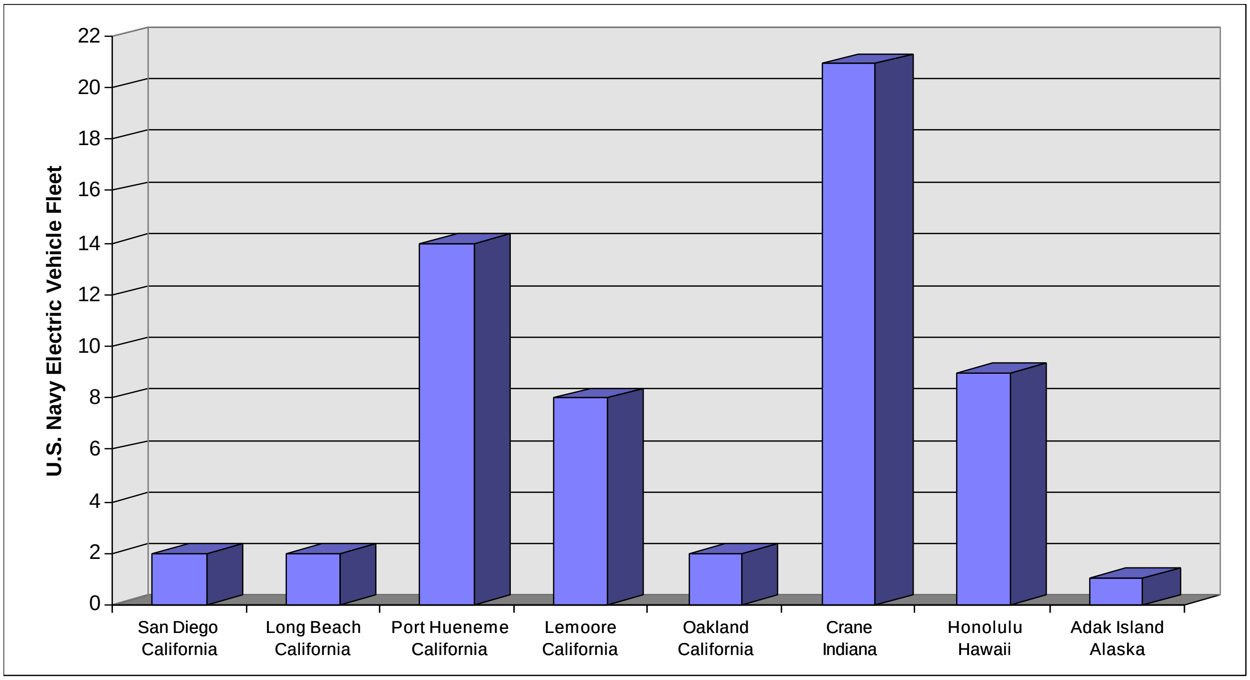


Figure Navy-1. Location of the U.S. Navy's "old fleet" of electric vehicles.

YORK TECHNICAL COLLEGE

Introduction

York Technical College is a two-year public institution, located in Rock Hill, South Carolina. York Technical College initially became involved with electric vehicles during the late 1980s. Their original fleet included Griffon vans, Ford Escorts, and Unique Mobility sedans, all with lead-acid batteries; as well as Volkswagen pickups and sedans with nickel-iron batteries. Newer vehicles were added, including Geo Metro and Chevrolet S-10 conversions. The major objectives of the York Technical College electric vehicle program included

- Public awareness
- Public education
- Curriculum development and training
- Field data collection
- Vehicle modification and upgrades.

Public Awareness and Education

During York Technical College's involvement with the Site Operator Program, York Technical College participated in and supported over 500 public awareness activities. These activities included

- Programs at area elementary and secondary schools
- Participation in area events such as parades, civic events, fairs, and orientation programs
- Displays at museums and shopping malls
- Tours of York Technical College's electric vehicle laboratory for students
- Elementary and secondary school teacher workshops on the electric vehicle technology and the impact on the environment.

York Technical College participated by displaying electric vehicles, providing electric vehicles for people to drive, and making presentations on electric vehicle technology advancements, electric vehicle impacts on the environment and energy consumption, electric vehicle availability, and the future of electric vehicles. York Technical College developed a network of public and private partners to support the introduction of and education about electric vehicles in North and South Carolinas. York Technical College also supported their partners' efforts to evaluate the suitability of using electric vehicles in their respective fleets. These partners included:

- Duke Power
- South Carolina State Energy Office
- South Carolina Central Electric Power Coop
- City of Charlotte

- City of Rock Hill
- Discovery Place Science Museum
- North Carolina Alternative Energy Center
- Palmetto Electric Coop
- Santee Cooper Electric Coop
- South Carolina Coastal Center
- York Electric Coop.

York Technical College also developed and published a series of educational brochures on electric vehicles (available at http://ev.inel.gov/sop); the subjects included:

- History of Electric Vehicles
- The Effect of Electric Vehicles on the Environment
- Electric Vehicle Systems, including Charging, Motors and Controllers, Batteries, and Auxiliary Equipment.

Curriculum Development and Training

The main thrust of the Site Operator Program at York Technical College was training and public education. During York Technical College's tenure as a member of the Site Operator Program, York Technical College developed training programs on electric vehicle maintenance, technology, safety, and operations. York Technical College conducted a *Develop a Curriculum* program for electric vehicle technicians, which resulted in the definition of the tasks and the level of competency required for an electric vehicle technician. From this competency profile, York Technical College developed a two-year associate degree program for the electric vehicle technician. York Technical College also developed and conducted a number of continuing education courses to train individuals interested in, and working in, the electric vehicle field. These courses include the following:

Basic Electric Vehicle Operator Training

This course was designed to familiarize the electric vehicle operator with the fundamentals of driving an electric vehicle safely and efficiently. The course covered the factors that affect range, as well as driving techniques to obtain maximum performance and range. The course also covered identifying and using the electric vehicle specific instruments and controls, as well as proper techniques to safely and properly charge electric vehicles. This course was designed to be a half-day long.

Introduction to Electric Vehicle Technologies

This course was designed to provide the individual uneducated about electric vehicles with the fundamentals of electric vehicle technology. The purpose is to better prepare individuals who are considering the use of electric vehicles with information on the pros and cons of electric vehicles and their impact on the environment and the economy. This course can be 2 or 3 days long, and it covers

- History of electric vehicles
- Environmental issues

- Legislation, mandates, and incentives
- Technology of electric vehicle components
- Availability of electric vehicles
- Maintenance issues.

Introduction to Electric Vehicle Maintenance and Repair

This introductory course is designed to prepare the maintenance technician with the minimum skills to conduct simple testing and repair of the most common problems encountered with electric vehicles. This course is two and one-half days in duration and it covers:

- Electric vehicle familiarization
- Test equipment familiarization
- Component test procedures
- Troubleshooting electric vehicle faults
- Component removal and replacement procedures
- Electric vehicle safety.

Field Data Collection

The majority of field testing activities were performed on older technology vehicles. While the test results were not always applicable to the newest generation of vehicles, the student's exposure to testing methods was of value and the testing of these older vehicles played a key role in establishing the maintenance database that was used to develop the maintenance training programs. These older vehicles also provided ideal platforms to incorporate new technology components.

Three vehicles with new technology components were tested and these vehicles were a Ford Escort with an advanced DC motor and Genesis lead-acid batteries, a Solectria Geo Metro with an AC motor and Sonnenshein lead-acid batteries, and a US Electricar S-10 pickup with an AC motor and Genesis lead-acid batteries.

The vehicles using the Genesis lead-acid batteries experienced rapid battery degradation due to inadequate and improper battery charging profiles. The Genesis battery pack in the Ford Escort deteriorated within 1,800 miles. All efforts to rejuvenate the batteries failed. The batteries in the S-10 lasted about 5,000 miles before they failed. The range of the S-10 was about 70 miles when the batteries started to fail.

Vehicle Modification and Upgrades

York Technical College actively modified and upgraded its own fleet of electric vehicles as well as the vehicles of several of its education partners. This involvement allowed the faculty, staff, and students to maintain their familiarity with the operation, function, and interaction of the electric vehicle components and systems. Vehicle modifications included changing onboard chargers, controllers, other vehicle subsystems, as well as battery modules and packs. Most notable of these modifications was the conversion of a Ford Escort from a lead-acid battery pack to a nickel-cadmium battery pack. The Escort's lead-acid batteries were replaced with nickel cadmium batteries donated by the SAFT Battery Company. However, from the start, a suitable charger that could provide the required charging algorithm for the nickel-cadmium batteries was not available. However, the nickel-cadmium batteries did exhibit an initial 20–30% improvement in range.

The Ford Escort that received the advanced brush DC motor operated at 120 volts and it was powered by two Genesis parallel battery packs. The two packs contained 8.4 kWh of energy; with an energy efficiency of 3.57 mi/kWh, the vehicle had a range of 25–30 miles. At approximately 1,500 miles, the range began to decrease and by approximately 1,800 miles, the vehicle would no longer operate as the batteries would no longer hold a charge.

The VW pickups were upgraded with new DC motors and controllers, and the nickel-iron batteries were replaced with flooded lead-acid batteries. These pickups continue to be used by the Palmetto Electric Co-ops and they continue to provide good service with ranges of 40–50 miles.

Lessons Learned

The most significant lesson learned during York Technical College's participation in the Site Operator Program is that in an area such as the electric vehicle field, where technology is changing and improving rapidly, training, testing, and public education materials must be reviewed and updated regularly.

Field testing of vehicles must be accelerated to collect high mileage and data in a short period of time so that the data can identify any problems and corrective action taken before the next generation electric vehicle is introduced. Field test data collected on old vehicles is not useful and not only takes up valuable time and resources, but it also clouds the issue on the performance of the current generation electric vehicles.

The lack of service manuals and manufacturer-supplied, vehicle-specific training meant that each operator had to invent the maintenance procedures to keep his electric vehicle in operation. For future purchases, a service manual and schematics, even if they are basic, must be provided with each vehicle. Failure to do this severely limits the operator's ability to maintain his or her fleet of electric vehicles.

With the current generation of lead-acid batteries, better coordination between the electric vehicle manufacturer and the battery manufacturer is needed. Most of the battery degradation experienced at York Technical College can be attributed to improper charging algorithms. Proper charging will not only extend the life of the battery pack, but it will also provide for the maximum range on each charge cycle.

As a result of all of the public appearances and presentations, York Technical College found that the public has a great interest in electric vehicles. Many people said that they would like to own an electric vehicle some day. However, all said that before they would seriously consider purchasing an electric vehicle, the purchase price would have to be competitive with the price of conventional gasoline-powered vehicles. Range was another issue of concern, but it did not seem to be as important an issue as the purchase price. Many people felt that they could use a vehicle with a 50- to 60-mile range. However, this must be the true useable range under actual driving conditions. The number of interested people would increase if a public charging infrastructure was available so that they could charge vehicles while at work or shopping. Increased emphasis should be placed on developing a public charging infrastructure and an integrated training program to support the operation and maintenance of electric vehicles.

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