

Evaluation of Electric Vehicles as an Alternative
For
Work-trip and Limited Business Commutes
Final Report

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16. Abstract This report presents the results of a four-year evaluation of an electric subcompact car. The principal finding was that the 1995-model electric car must be viewed in two contexts, the body/chassis/drive train and the battery/recharge system. Firstly, the vehicle body, chassis and drive train were adequate for the transport of personnel within Connecticut for most routine non-emergency state business. Drivers did notice that the drive train was somewhat underpowered as compared with most other vehicles on the road. The designer of the drive train appears to have placed higher priority on efficiency over acceleration and speed. The car is best suited for use on primary and secondary highways and local roads where speeds are generally below 55 mph. Secondly, you must recognize that several different batteries could power the car. Two different battery types were evaluated in this project. A conventional sealed lead acid battery (CSLAB) powered the first car, and an advanced lead acid battery (ALAB) powered the second. Our finding is that a 50 Ampere-hour CSLAB car configuration was reliable, although cold-weather range was 15-20 miles less than the warm weather range, due to the power-draining effect of the electric heater/windshield defroster. The CSLAB car demonstrated a year-round driving range of 35 miles per charge in Connecticut. The 85- and 95-Ampere-hour ALAB car configurations we tested were uneconomical due to premature ALAB failures in all combinations tested over four years.					
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Executive Summary

This research presents the results of a four-year Evaluation of a battery-electric subcompact car. Two versions of the car were evaluated. A conventional sealed lead acid battery (CSLAB) powered the first vehicle that was evaluated. The second was powered by an advance lead acid battery (ALAB).

A principal finding is that the 1995 model electric car must be viewed in more than one context. Firstly, the vehicle body, chassis and drive train were adequate for the transport of personnel within Connecticut for most routine non-emergency state business. Drivers did notice that the drive train is somewhat underpowered as compared with most other vehicles on the road. The vehicle design places priority on efficiency over power and speed.

We found also that the electric car must be viewed in the context of its battery since several different batteries could power the car. Two different battery types were evaluated in this project.

The first battery we evaluated was a 50 ampere-hour CSLAB. Our finding was that the CSLAB car configuration is reliable. However, in very cold-weather, driving range diminished by as much as 20 miles versus the warm-weather driving range. This is due to the power draining effect of the electric heater and windshield defroster.

The second battery we evaluated in the car was the ALAB. The ALAB car was operated on two different versions of the production ALAB. Our finding after four years of testing was that this car/battery configuration is uneconomical and prone to premature failure.

The principal investigator sits on the board of directors for the Northeast Advanced Vehicle Consortium (NAVC) along with the state fleet manager, who is responsible for implementing alternate fuel technology in Connecticut state government to comply with Federal law. Board membership has provided an opportunity for regular communication between the fleet manager and researcher at board meetings.

The project was successful because it has discouraged expenditures of public funds on ALAB technology that doesn't work well and doesn't last very long.

It is recommended that a nickel cadmium (NiCd) battery be evaluated in this car. The cost of NiCd batteries has fallen sharply in recent years. An evaluation should examine claims that NiCd batteries will both last longer and provide double the range of CSLAB cars. These characteristics would improve the practicality of a battery/electric subcompact car for state fleet needs.

It is further recommended that fuel-fired heaters be evaluated as a means to address heating and windshield defrosting requirements in Connecticut in a manner that does not use much electricity from the battery pack, which supplies motive power.

Disclaimer

The contents of this report reflect the views of the author who is responsible for the facts and accuracy of the data presented herein. The contents do not reflect the official views or policies of the Connecticut Department of Transportation or the Federal Highway Administration. This report does not constitute a standard, specification or regulation.

Acknowledgements

The author wishes to acknowledge the support of both the Federal Highway Administration and The Rideshare Company, which provided the electric vehicles for this project. The author also wishes to acknowledge several individuals.

In the Bureau of Public Transportation the author recognizes the involvement of Bureau Head Harry P. Harris, Manager Michael A. Sanders, James H. Boice and Dennis A. Jolly. Their efforts and continuing support of research in alternative-fuel technologies for transportation deserve recognition.

Mr. Jon Colman, President of The Rideshare Co., and Mr. David Fabricatore, the Rideshare manager responsible for the five electric vehicles (EVs), were excellent partners in this research project. Dave teamed with me each year to participate in the annual weeklong American Tour del Sol (ATdS) road rally for EVs. Without Dave's active involvement and support, this study would simply not have been possible.

Mr. John Hudson of our Research Division (now retired) was the third team member for the 1996 and 1998 ATdS. John handled logistics and drove the support van, which allowed Dave and I to concentrate on the rally.

Ms. Sheilah Pierce of the Northeast Sustainable Energy Association volunteered to drive our support van for the 1997 ATdS when Mr. Hudson was unexpectedly unable to make the trip.

Messrs. Gus Sfakianos and Joe Ambrosio of Neocon Technologies provided technical support and services throughout the study that were indispensable. My understanding of the problems we experienced with the Advanced Lead Acid Battery (ALAB) is largely due to the analysis of our battery-management-system data by Gus and Joe and their expertise in batteries, chargers, battery management systems and electric vehicles.

Mr. Bjorn Mentzer of Mentzer Electronics provided one-on-one training for the author and Mr. Fabricatore in 1996 just before the start of the American Tour del Sol. Mr. Mentzer showed how to utilize data from the Mentzer battery management system as feedback on how efficiently the car is being driven, how much energy is left, and how to draw out the most energy without damaging the battery pack. In our ATdS category - "Production EV with Lead Acid Battery", we set a record for distance driven on a single charge later that week and every year thereafter for four consecutive ATdS events.

Messrs. James Worden and Andrew Heafitz of Solectria Corp., the EV manufacturer, taught efficient driving techniques on three occasions in 1995 (at the Rideshare Co.), 1996 (at ATdS), and 1997 (at ATdS). Their instructions and handouts were invaluable to our good performances at the ATdS. Also, the efficient-driving skills they taught were valuable in daily driving because all four ALAB packs suffered capacity losses (lost driving-range) during their respective evaluation periods, yet we always, with one exception, made it to our destination.

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- Kit Foster, Consulting Engineer, Gales Ferry, Connecticut

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find
LENGTH			
in	inches	25.4	millimetres
ft	foot	0.305	metres
yd	yards	0.914	metres
mi	miles	1.61	kilometres
AREA			
in ²	square inches	645.2	millimetres squared
ft ²	square feet	0.093	metres squared
yd ²	square yards	0.836	metres squared
ac	acres	0.405	hectares
mi ²	square miles	2.59	kilometres squared
VOLUME			
fl oz	fluid ounces	29.57	millilitres
gal	gallons	3.785	litres
ft ³	cubic feet	0.028	metres cubed
yd ³	cubic yards	0.765	metres cubed
MASS			
oz	ounces	28.35	grams
lb	pounds	0.454	kilograms
T	short tons (2000 lb)	0.907	megagrams
TEMPERATURE (exact)			
°F	Fahrenheit temperature	5(F-32)/9	Celcius temperature

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
mm	millimetres	0.039	inches	in
m	metres	3.28	foot	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi
AREA				
mm ²	millimetres squared	0.0016	square inches	in ²
m ²	metres squared	10.764	square feet	ft ²
ha	hectares	2.47	acres	ac
km ²	kilometres squared	0.386	square miles	mi ²
VOLUME				
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m ³	metres cubed	35.315	cubic feet	ft ³
m ³	metres cubed	1.308	cubic yards	yd ³
MASS				
g	grams	0.035	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams	1.102	short tons (2000 lb)	T
TEMPERATURE (exact)				
°C	Celcius temperature	1.8C+32	Fahrenheit temperature	°F

NOTE: Volumes greater than 1000 L shall be shown in m³.

*SI is the symbol for the International System of Measurement

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**Evaluation of Electric Vehicles as an Alternative
For
Work-trip and Limited Business Commutes**

Background

The Department of Administrative Services is responsible for the state central fleet. It is comprised of approximately 4,087 vehicles, which are primarily automobiles and light trucks. Vehicles are assigned to each state agency. This fleet includes 550 emergency vehicles, and most of these are full-size cars assigned to the Department of Public Safety. The Department of Transportation is assigned 265 vehicles, as follows: 133 subcompact cars with air conditioning (w/AC); 84 compact cars and ½ ton pickups w/AC; 12 intermediate cars and compact wagons w/AC; 13 cargo vans, intermediate wagons and full-size cars w/AC; four (4) full-size wagons and crew-cab pickups w/AC; and, 19 carryalls w/AC.

In addition to the 265 lights trucks and cars from the state fleet, the Department of Transportation owns and operates 1,971 additional vehicles, including: 481 buses; 724 dump trucks; 291 pickups; 238 specialty vehicles; 167 vans; 65 sport utility vehicles (SUVs) and Suburbans; and, seven (7) cars (independent of the state fleet).

To comply with the regulations resulting from the Energy Policy and Conservation Act of 1992 (EPACT), the Connecticut State fleet manager has begun purchasing non-emergency automobiles (cars) and light trucks that run on alternate fuels (Alt-Fuel), which are fuels other than gasoline or diesel (See Appendix A). In 1998, to meet the 15% requirement of EPACT, 70 dual-fuel compressed natural gas/gasoline four-door subcompact sedans were purchased. EPACT requires 25% of new vehicles purchased for the State fleet in 1999 to operate on an alternate fuel, 50% in 2000, and 75% in 2001 and thereafter.

One fleet-vehicle option is the electric vehicle (EV). EVs are anticipated to provide three benefits as compared with cars powered by the internal combustion engine: reduced airborne emissions (improved urban air quality); reduced energy consumption per vehicle mile traveled; and, reduced use of petroleum and dependence on foreign oil. The accuracy of marketing claims of EV and battery manufacturers was uncertain. There was a need to obtain and disseminate some first-hand information about the practicality of this Alt-Fuel option.

An indication of fleet range requirements and vehicle use patterns was presented in Transportation Research Record 1049. [1] The 1985 study by Mark R. Berg (Berg) addressed commercial sector fleet vehicles, not government fleets, but the findings are suggestive of the situation in government fleets. Berg stated, "There is no adequate theory to guide the estimation of the extent to which EVs might actually penetrate their potential markets." The publication presents a method for estimation of the substitutability of EV technology in fleets.

Berg wrote that the trip patterns of a fleet could be analyzed to determine where electric vehicles can be substituted, based on typical miles-per-day (mpd) requirements. Fleet vehicles can be segregated into four daily-range groupings: less than (<) 30 mpd, 30 to 59 mpd, 60 to 89 mpd, and greater than 90 mpd. For instance, Berg found that 20 percent of commercial fleet vehicles were driven < 30 mpd (avg. 17 mpd), 26 percent were driven 30-59 mpd (avg. 44 mpd), and 18% were driven 60-89 mpd (avg. 72 mpd.).

In each "mpd" group, a fleet manager can determine the occurrence of occasional higher-mileage trips. For instance, Berg found that in commercial fleets, 56% of the < 30 mpd vehicles were occasionally driven beyond 30 mpd. In fact, 38 percent of the < 30 mpd vehicles were driven

beyond 60 mpd. In the 30-59 mpd group, 59 percent occasionally drove more than 60 mpd, and 41 percent drove beyond 90 mpd. In the 60-89 mpd group, 60 percent of the vehicles were occasionally driven beyond 90 mpd.

In commercial fleets, Berg found that 21 percent of cars and light trucks never had to travel more than 60 mpd. Berg went on to observe that in commercial fleets, although 46% of all fleet vehicles "typically" did not exceed 60 mpd, practical limitations on making other vehicles available for occasional longer trips resulted in his finding that only an additional 9 percent of vehicles could remain within the 60-mpd range limitation. Overall, a combined total 30 percent of the car and light truck fleet was observed to fall within the 60-mpd limitation.

Berg observed that an electric vehicle could be driven most of the time if the driver had ready access to a longer-range vehicle when occasionally needed. That longer-range vehicle could be provided for the occasional higher-mileage day from either the state fleet or through mileage reimbursement to the employee for the use of their private vehicle. If a similar 60-mpd pattern was found in the Connecticut central state fleet, that would equate to about 1,000 non-emergency vehicles.

In state governments, fleet managers could analyze their mpd records to identify where electric vehicles can be substituted, based on the daily single-charge ranges of the electric vehicle models they have available. In the case of the CSLAB and ALAB cars, the longer-range ALAB car, if it were shown to provide a reliable 70 mpd, would have the greater potential as a substitute for gasoline-powered subcompacts in the state fleet. A 70-mpd capability would provide a 10-mpd margin of

range against the maximum required 60 mpd. An approximate number of substitutions could be estimated from an examination of state fleet records following the general approach developed by Berg. However, it was not within the scope of this study to make this analysis.

A public/private partnership was formed in 1994 to demonstrate and evaluate five electric vehicles used primarily in commuter operations on Connecticut highways. The demonstration project was titled, "The Connecticut Commuter Electric Vehicle Demonstration" or CCEVD. The seven (7) partners in the CCEVD were: Connecticut Office of Policy & Management, Connecticut Department of Transportation, The Rideshare Company, Rideworks, MetroPool, Northeast Utilities, and Connecticut Light & Power. The seven partners together pledged \$175,000 in soft and hard matching dollars to secure an equal amount under a federal demonstration project. The demonstration project was administered by the Northeast Alternative Vehicle Consortium (NAVC, which changed its name in 1999 to Northeast *Advanced* Vehicle Consortium) and sponsored by the Department of Defense through its defense diversification program run by its Advanced Research Projects Agency (ARPA). Under the demonstration project, The Rideshare Company purchased, registered, insured, maintained, collected data for, and coordinated the use of the five (5) electric vehicles (EVs). They were identical with respect to their car body, chassis, motor and drive train. Four (4) EVs were identically equipped with conventional sealed lead acid batteries (CSLAB). The fifth EV received a more expensive Advanced Lead Acid Battery (ALAB) to test claims of a 40% longer driving range (70 versus 50 miles) from its premium-priced lead acid battery.

One element of the CCEVD evaluation involved the use of an annual regional road rally for electric vehicles to gather data about the longer-range ALAB electric car. The American Tour de Sol (ATdS) is an

annual weeklong event in the Northeast that was identified as a cost-effective means for the CCEVD partners to gather performance data and information about electric vehicles. The data, gathered at the ATdS under their tightly controlled conditions would serve as benchmarks for data gathered subsequently from commuter driving. In even-numbered years the ATdS is run on relatively flat highway terrain. In the odd-numbered years they hold the week-long event on hilly and mountainous highway terrain. The event is professionally organized, well run and has an excellent safety record. CCEVD obtained data at the 1995 ATdS about their EV's performance; information about nationally recognized data analysis methods (those used by ATdS organizers); and, comparison information and data about other similar and dissimilar vehicles that were entered. However, the CCEVD evaluation of the ALAB car ended shortly after the 1995 ATdS due to battery failure. The vehicle was returned to the EV manufacturer for diagnosis and repair of the ALAB/battery charger/battery management system, under a separate NAVC engineering project.

The Department initiated this research project in early 1996 to partner with the ongoing CCEVD. The Department's participation in the demonstration project was accomplished through the Bureau of Public Transportation and their contractual agreement(s) with The Rideshare Company. The research project was made possible through the loan of two EVs to the Department from the CCEVD.

In addition to annual participation in the ATdS, evaluations of the two EVs included the following: observations and data gathered by driver participants in commuting and work trips; troubleshooting and repair after various breakdowns; data analyses; and, independent tests conducted by the Consumers Union. Eight (8) Department research personnel were approved to participate in the work-trip element of the

evaluation, i.e., approved for driver insurance coverage provided through The Rideshare Co. The combination of driving activities, conducted under a variety of battery levels, weather, traffic and roadway conditions, was anticipated to provide balanced first-hand evaluations of production-EV technology with two different battery systems.

During 1996, the data and information were submitted to Rideshare on a monthly basis for subsequent transmittal to ARPA, where data from this project became part of a national data repository on EVs, which is maintained by ARPA. Department personnel periodically analyzed data obtained from the two assigned EVs, and interim results and preliminary information were posted on an Internet WorldWide Web homepage, maintained by the author (Appendix B). After the two-year CCEVD's NAVC project ended in 1996, the CCEVD continued to make the ALAB car available to the Department for this research project.

During the final year of this project (1998), researchers refocused the project objective on a test of the ALAB manufacturer's claim that their latest battery pack would provide 400 charge/discharge cycles under specific restricted operating parameters, which are delineated in the report section titled, "85 Ah ALAB Car - 1998."

Objective

The objective of the project was to conduct an evaluation of two electric vehicles (EVs) provided by The Connecticut Rideshare Company (Rideshare). Two different EV configurations were to be evaluated, a 30-50 mile range EV (Connecticut Motor Vehicle Registration #EV-2) powered by a conventional sealed lead acid batteries (CSLAB), and a 60-

80 mile range EV (CT Reg. #EV-1) powered by advanced lead acid batteries (ALAB). Both cars were to be driven daily for both the home-to-work commute and for transportation to and from selected work destinations. Only the longer-range ALAB car was to be evaluated through participation in the annual ATdS, because a minimum 50-mile range on a single charge is required.

Parameters of the Study

The table below delineates the primary differences between the subcompact EVs, which were identical in outward appearance.

TABLE 1 Three different lead acid batteries in a subcompact electric car

Vehicle Battery Type	Conventional Sealed Lead Acid (CSLAB)		Advanced Lead Acid Battery (ALAB)			
	CT:EV-2		CT:EV-1		CT:EV-1	
Registration Number	1995, 1996		1995, 1996		1997, 1998	
Evaluation Year(s)	50		95 ¹		85	
Battery Capacity (Ah)	7.8		14.8		13.2	
Battery Capacity (kWh)	Winter Months	Spring, Summer, Fall Months	Winter Months	Spring, Summer, Fall Months	Winter Months	Spring, Summer, Fall Months
Time of Year	<50 ²	50	<70 ²	70	<65 ²	65
Anticipated Driving Range						

¹ 95 Ah ALAB was discontinued in 1996 by manufacturer and replaced with the 85 Ah ALAB.

² Range in winter is anticipated to vary inversely with use of accessories (electric heater/defroster, rear-window defroster, windshield wiper, headlights). Also, at low ambient temperatures battery is anticipated to be less efficient.

The EV powered by a 50 Ampere-Hour conventional sealed lead acid battery (CSLAB) had the lowest first cost of the three alternatives. The two ALABs have higher battery-power capacities of 95 and 85 Ampere-hours and cost five to seven times more than the CSLAB.

The ALAB is a valve-regulated battery. Inside an ALAB are lead-fiberglass wire woven into lightweight mesh. The mesh is coated with an electrochemical paste. The design uses a starved electrolyte system and gas recombination. They are maintenance free, spill-proof, and can be mounted in any position. Claimed battery attributes are: rapid recharge, high peak power (450-500 W/kg, 30 seconds @ 50% Depth of Discharge (DOD), terminal limited), 41 Wh/kg, 90 Wh/l, 12 Volts per battery (nominal), 24.9 kg per battery. [2]

Cabin heating and windshield defrosting in all cars was provided by 1500 Watt electrical resistance units. The energy required from the battery pack for lights, wipers, heating and defrosting when driving in snow/ice storms was anticipated to reduce the driving range by as much as 20 miles (20 ampere-hours) per drive/battery-discharge cycle.

Description of Basic Vehicle

The subcompact EV is a General Motors (GM) Geo Metro 4-door sedan that is retrofitted by the Solectria Corporation to become their "Force" model. The GM model years 1995 through 1999 are essentially identical. The vehicles examined in this study were all from the 1995 model year.



PHOTO 1 1995 Subcompact Electric Vehicle is retrofitted General Motors Geo Metro 4-door sedan

The 1995 EVs in our project all had 1994-production year motors and belt-type drive trains. The motor is the Solectria model AC Gu20, with 42 kW peak power, and is microprocessor controlled. The motor controller is the Solectria model AC32560, which operates at 156-180 Volts and a maximum current of 240 Amps. The five 4-door sedans purchased by Rideshare may have been the last Forces built before the manufacturer changed its standard drive train to a quieter direct-drive design in the spring of 1995.

In 1998, the motor and belt drive system was upgraded on our 1995 ALAB car. This car received a factory upgrade of its motor and drive train, so under the hood it is essentially a 1998 Force. A Solectria motor, model ACgtx20, replaced the original Solectria motor. Manufacturer's specifications for the new AC induction motor state that it will deliver approximately 44 HP and is a brushless sealed design that weighs 78 pounds (lbs.). Company specifications further state that it has extremely low electrical resistance; nominal power is 12 kW and nominal torque is 20 Nm; while maximum power and torque are 37 kW and 70 Nm, respectively. Nominal motor speed is 4,000 rpm, while maximum motor speed is 12,000 rpm. The manufacturer states the motor has an efficiency of 92%. A Solectria model AT1200 gearbox with the standard 12:1 gear ratio replaced the belt drive assembly. The manufacturer describes the gearbox as lightweight, weighing 35 pounds, and supporting a maximum input torque of 10 Newton-meters (Nm). The factory upgrade also included new watertight electrical connectors, an Electromagnetic Interference (EMI) sock around high-voltage wires under the hood to improve radio reception, and a newer fuse box design.

By comparison, the 1995 gasoline-powered version of this car, a General Motors Geo Metro 4-door sedan, was powered by a 1.3-liter four-

cylinder engine, providing 70 horsepower (hp). The electric motors in the CSLAB and ALAB cars provide about 40 hp. [3]

For the four-year project period, we used original-equipment-manufacturer (OEM) Goodyear Invicta GL radial tires, size P155/80R13. This is a 44-psi tire with a tread wear rating of 280, traction rating A and temperature rating B. The Invicta weighs about 14.5 lbs. and has a maximum load rating of 959 lbs. (3,836 lbs. for a set of four).

Each year for the ATdS, Goodyear provided a new set of tires to each entrant. In 1998 they supplied a larger tire, the Integra radial tire, size P165/70R13, which were wider and one pound heavier than the Invicta. In reaction, we changed the wheels on the ALAB car to a lighter, wider (13x5.5 inch) alloy wheel. At the ATdS that year, after consulting with Goodyear representatives it was decided to run the smaller year-old Invicta tires on the new alloy rims. The combination of an Invicta tire and the alloy wheel is 3 lbs. lighter than the same tire mounted on the OEM stock steel wheel with hubcap.

CSLAB Car - Winter of 1995/1996

In November 1995, the first EV was put into service and the evaluation began under this project. This EV was the short-range conventional-sealed-lead-acid-battery car (CSLAB car). It was assigned Connecticut motor vehicle registration number "EV-2." The CSLAB car is not equipped with a battery management system, so data collection consisted of reading and recording data from various gauges that monitor electrical usage in the EV. Evaluation and data-acquisition activities were carried out over a five-month winter period. Data were recorded on ARPA-approved sheets provided by Rideshare in accordance with vehicle

demonstration-project requirements, and the drivers provided written comments about the performance of the EV in daily commuter service.

Arrangements were made with Consumers Union in January 1996 to provide the automobile to the testing facility in Moodus, CT, for their subsequent evaluation. CSLAB car was evaluated during the period February 5-15, 1996. A summary of the results, "Evaluation of an Electric Car by an Independent Auto Testing Facility," was completed in March 1996 (Appendix C). The acceleration data will be of particular importance to fleet managers that need to understand the limitations of the CSLAB car in cold weather. It took 27 seconds to accelerate the quarter mile, reaching a top speed of 52 mph. To reach 60 mph required 0.4 miles. Even with a thermal management system and heating elements in the two battery boxes, extremely cold temperatures degraded CSLAB performance. Drivers need to be made aware of the effect of low temperatures, so they can compensate for safe driving in a car that will be slower than most other vehicles on the road.

At the end of our five (5) month evaluation period, the project coordinator at Rideshare reassigned the CSLAB car to another individual (non-ConnDOT commuter). We prepared to begin our evaluation of the next EV, the ALAB car.

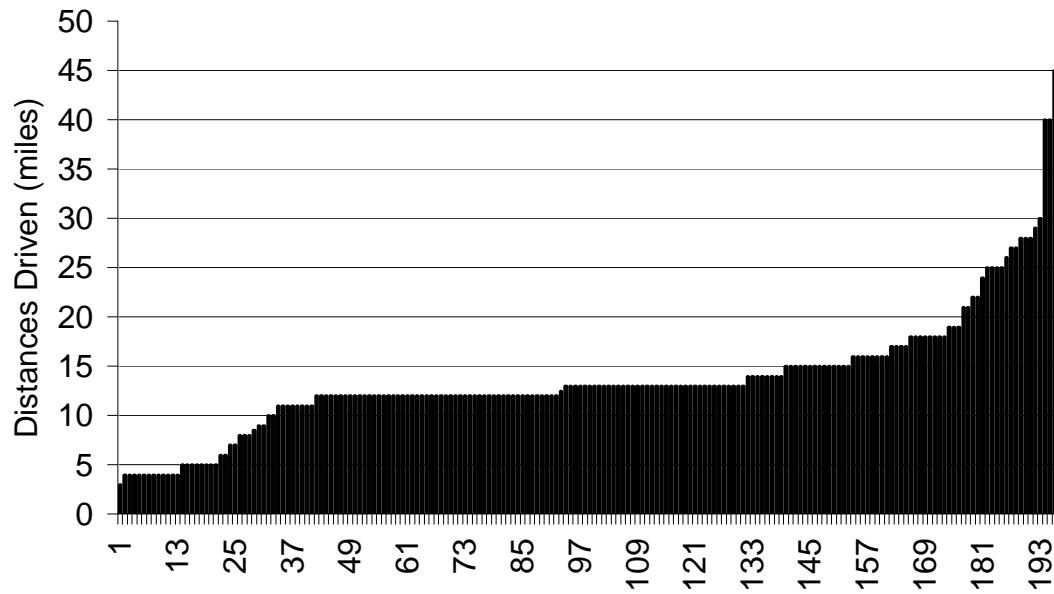


FIGURE 1 Single-charge distances from 196 drives in CSLAB Car during winter of 1995/1996

Figure 1 shows the record of 196 single-charge drives in CSLAB electric subcompact, from November 7, 1995 to March 29, 1996. The average distance driven was 13.6 miles between charges, which was the approximate one-way commuting distance for the two-person car pool. The shortest drive was three miles. The longest drive on a single charge was 45 miles. Researchers followed the manufacturer's recommendation that the CSLAB car be plugged in whenever the car was parked. This procedure is called "opportunity charging."

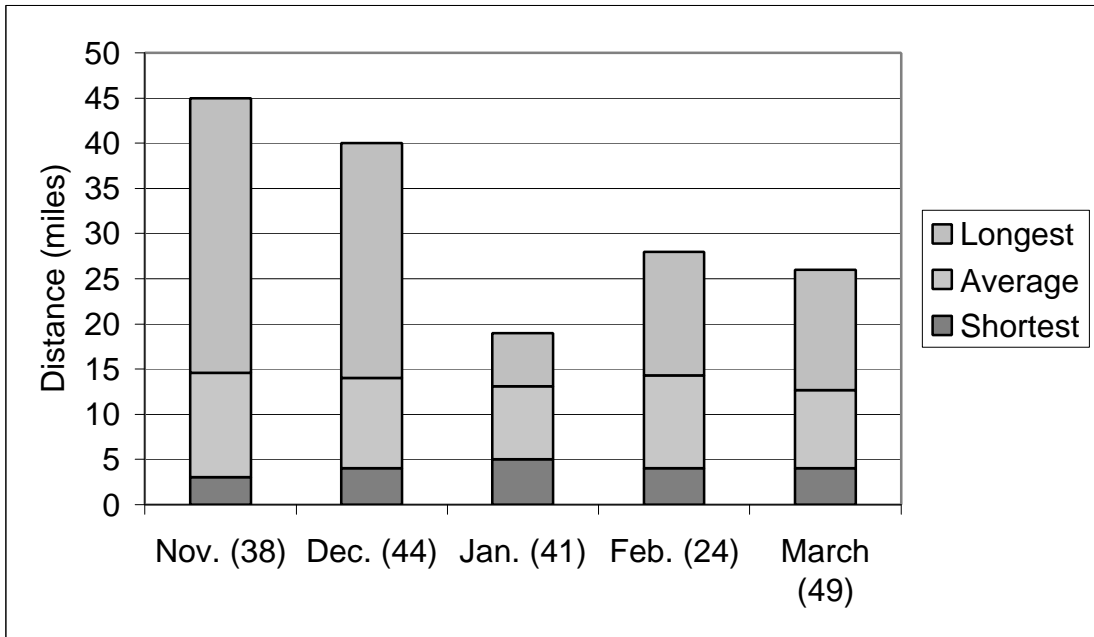


FIGURE 2 Monthly distribution of 196 single-charge drives in CSLAB car during winter of 1995/1996

The number of drives in each month is shown in parentheses (Figure 2). In all, the car was driven 2,828 miles in cold weather. The electric heater was used on 125 of the 196 drives. Electric windshield wipers were used on 28 drives and electric lights were run on 31 drives. Energy was measured with a separate AC kWh meter at the point where electricity entered the car. The energy consumed during this winter period was 1,582 AC kWh, which is the total "wall-plug" energy used for motive power plus all automobile accessories. Based on a \$0.106/kWh utility rate in Connecticut, the retail cost for electricity was approximately \$0.06/mile driven. At the lower national average cost of electricity of \$0.086/kWh, the cost of electricity per mile calculated to \$0.05/mile.

95 Ah ALAB Car - 1996

The second EV was anticipated to provide a reliable driving range between recharges of 70 miles. In winter, due to power consumption for heating and defrosting, we anticipated a 50-mile range.

The Advanced Lead Acid Battery (ALAB) car had experienced battery failure in 1995 under the CCEVD project. Following diagnosis and repair by the EV manufacturer to correct problems experienced in 1995, the car was delivered to New York City on May 10, 1996 and was driven in the 1996 American Tour del Sol (ATdS). A principal from the battery-management company provided training on use of a laptop computer to monitor battery cell parameters as we drove.

At the 1996 ATdS, the ALAB car earned recognition as the "Best Sedan using Lead Acid Batteries" in the production category; "1st Place - Total ATdS Miles for Lead Acid Batteries;" tied for "1st Place - Range on a Single Charge;" "4th Place - Overall Efficiency in Production Category;" and, "4th Place - Total ATdS Miles Overall." Engineers later utilized the data collected that week as a performance benchmark in their analyses of problems that soon occurred with the ALAB.

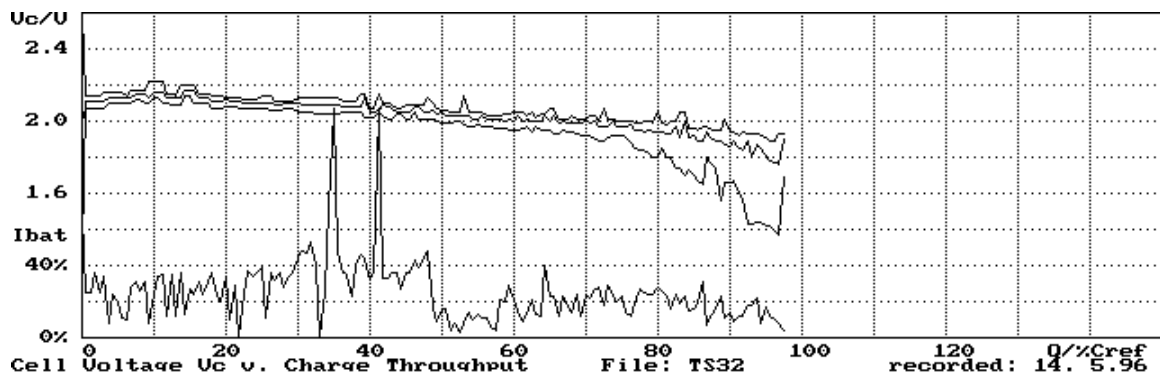


FIGURE 3 Record of voltages over the discharge cycle of ALAB during 141-mile drive at the 1996 ATdS

The graph was produced by the battery management system (Figure 3). It describes the energy-usage by the ALAB car in a single drive. The X-axis represents the depth of discharge (DOD) of the ALAB, where 100% would indicate a completely drained battery.

The upper half of the graph is a record of battery cell voltage over the length of the entire discharge cycle. Voltage values are reported as the average cell voltage in the six-cell ALAB. Each cell has a nominal 2 Volts, so six cells combine to produce the nominal 12-Volt ALAB. Initial cell voltages from the fully charged ALAB are about 2.2 Volts, i.e., the battery voltage is 13.2V when fully charged. The minimum cell voltage the battery can tolerate without damage was thought to be 1.6 Volts per cell, or 9.6 V for the battery.

The lower half of the graph shows the amperage draw throughout the 141-mile drive. Amperage usage is expressed as a percentage of 160 amperes (Amp). The maximum available output is 200 Amp, or 125% of 160 Amp. To illustrate, a 40% value on the graph represents 80-Ampere load on the battery. Note the two amperage spikes at 37 and 42% DOD (X-axis). The two spikes record the vehicle passing slower-moving traffic twice during the timed leg of the rally. The acceleration spikes registered 125% values on the graph, representing the maximum 200 Amp load on the batteries. In all, on that day the ALAB car was driven over the 63.6-mile "leg" plus nine (9) 8.6-mile "laps." The final "ninth" lap was not counted in official rally statistics because the EV did not complete the "lap" within the prescribed time limit. In retrospect, the two acceleration spikes had expended energy that would have been more beneficially used later in the day to drive the car further. That basic trade off between performance and single-charge driving range, i.e.,

efficiency, was clearly illustrated through data collected in the ATdS. More detailed data and information about the daily performance of the ALAB car at the 1996 ATdS is provided in the project's Web site, which is included in this report as Appendix B.

Immediately following the ATdS, on May 20, 1996, the eighteen-month (18) commuter and work-trip element of the evaluation was initiated. Instrument data and narratives of significant events were recorded in accordance with vehicle demonstration project requirements and submitted monthly to Rideshare. Beginning on June 7, 1996, the ALAB car lost about ten percent of its driving range. At roughly two-week intervals, the battery capacity dropped in successive 10% increments until on July 29 the daily commuter/work-trip evaluation was suspended. At that point the range of the car had diminished to 10 miles (16 Km) (see Figure 5).

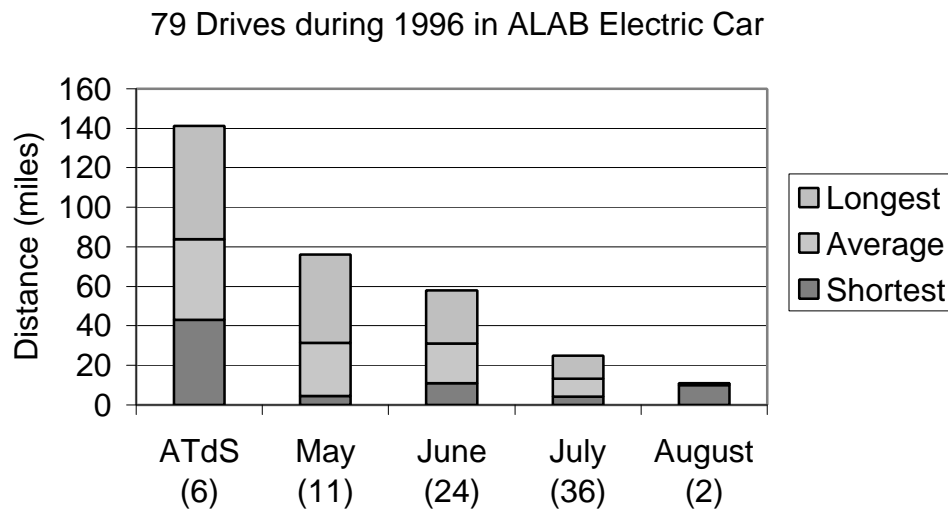


FIGURE 4 Monthly distribution of 79 single-charge drives in ALAB car during ATdS and during four months of daily use in Connecticut during 1996

In Figure 4, the number of drives represented by each bar appears in parentheses. The graph displays statistics about the shortest, longest and average distances driven on each fully-recharged ALAB. The

95 Ah ALAB delivered 79 cycles during its lifespan, but only sixteen full-capacity cycles were experienced before the first 10% loss in battery-capacity occurred.

As a result of the progressive battery failures that occurred during the spring and summer of 1996, which resulted in diminishing range, the car was removed from commuter service for repairs. Because the car was not working properly during the commuter evaluation, it was not provided to the Consumers Union automobile testing facility in Moodus for their evaluation in 1996. The evaluation of the ALAB car was suspended on July 29, 1996. The vehicle was towed to an EV specialist on October 3, 1996. Data from all battery cycles had been recorded and was provided to the EV specialist, EV manufacturer, Rideshare, and the battery company for their analyses. July 1996 was also the last month data was transmitted by Rideshare to DARPA under the CCEVD project, as this project was now completed.

Six problem areas were identified that contributed to failure in the ALAB car. Problems were identified with wiring and electrical components that required repair. Three of the thirteen batteries were found to be mounted incorrectly, which was thought to have lead to internal damage from road shocks. The battery manufacturer identified errors in pre- and post-delivery battery cycling procedures, principally associated with battery overcharging. The car manufacturer and researchers had followed the manufacturer's recommendation that the ALAB car be plugged in whenever the car was parked, i.e., at every opportunity. What was not known was that recharging after short drives was resulting in overcharging, which damaged the cells due to battery gassing. Pre-delivery test-drives by the car manufacturer may have been too short between recharges. New procedures were recommended by the battery manufacturer that established a minimal battery depth-of-

discharge (DOD) percentage of 10% that must be reached before recharging, representing a minimum drive of 8-9 miles. Another problem was overcharging and gassing that occurred when the fully charged ALAB car was initially unplugged and driven with the regenerative-brake circuit turned on. Regeneration is a beneficial concept that extends the range of the vehicle, however the system has no safeguards against overcharging the batteries. A manual procedure was established to drive a minimal distance (about 7 miles or until 7-8 Amp-hours was drawn off the ALAB) with the regeneration circuit turned off, after which the circuit could be turned on. The fifth problem area occurred in normal commuting situations. Occasionally, the ALAB was inadvertently overdrawn when attempting to accumulate data on performance for routine 70-mile single-charge drives. While driving in commuting situations, it is not practical to keep the laptop computer running and connected to the battery management system, which is necessary to monitor battery-cell voltages. Therefore, a daily-commuting procedure was recommended to limit the DOD to 80%, so that battery voltages would always remain at or near nominal 12 volts/battery throughout the drive. This change shifted the driver's priority away from testing manufacturer's claims about the number of miles that could be driven per charge. The new driver emphasis was to control the electrical-use-per-charge parameter and simply document whatever number of miles were driven. Another problem was identified in the thermal management system. The capabilities for regulation of temperatures in the two battery boxes was identified as too limited for our operating environment in terms of high-temperature control. The EV Specialist advised that overheating in the battery box would cause battery damage, while too-cold temperatures would only reduce single-charge driving range without harm to the ALAB.

The breakdown of the ALAB car in 1996 delayed the Department's evaluation schedule, but much was learned about current problems with

the state-of-art ALAB car. All of the problems in the ALAB car were believed to be repairable.

It was necessary to replace the 95 Ah ALAB battery pack with new 85 Ah ALABs. The manufacturer had discontinued production of the 95 Ah batteries sometime in 1996 and began producing a slightly smaller ALAB with 85 Ah capacity. The manufacturer stated that the 85 Ah ALAB had been developed for one of the big three automakers that intended to use the ALAB in their battery-electric minivan. It was believed also that the ALAB would remain "healthier" if charged at a quicker rate. A dual-amperage charger was installed for 1997, which operated at either 30 or 50 Amps. Finally, a new low-voltage cut-off guideline of 1.8 V/cell (10.8 V/battery) was established.

The revised project work plan called for resuming the ALAB-car evaluation. Once all the repairs were completed, the Department's evaluation resumed in May 1997.

85 Ah ALAB Car - May 1997 to March 1998

The repaired 85Ah ALAB car was delivered in time for participation in the 1997 American Tour De Sol (ATdS), again with the support of Rideshare. Results from the 1997 ATdS were again positive; details are reported in Appendix B. On odd-numbered years, the ATdS featured hilly and mountainous highway terrain. The ALAB car had no problem driving the Kancamagus Highway. The drives on this highway reached an elevation of 2,800 ft above mean sea level and involved climbing grades of up to 12.7 percent at 35-40 mph.

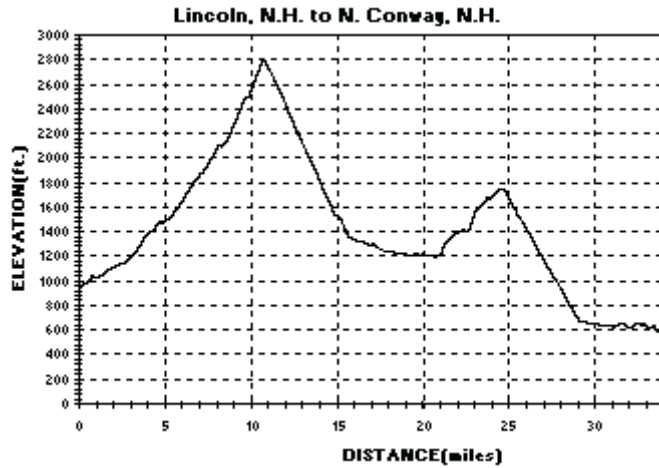


FIGURE 5 Elevation data for a hill-climbing element of ALAB car evaluation at the 1997 ATdS

On May 24, 1997, after a 41-mile drive over the Kancamagus Highway and without recharging (Figure 5), the car was driven another 10 miles on local roads to the top of Cathedral Cliffs in North Conway, New Hampshire. This drive involved short steep grades of up to 19% that required the maximum amperage draw of approximately 144 Amps. Pack voltage remained at the nominal 156 volts (12 V/battery) throughout the hill climb. In one section of road with the 19% grade, the ALAB car slowed to a halt and it was necessary for the two passengers to get out of the car before it could climb the 19% grade. That appeared to define the grade-climbing limits of the ALAB car. To summarize, grades encountered in the 1997 ATdS were higher than those generally found in Connecticut. The ALAB car demonstrated that although it is underpowered it could climb all but the most severe grades (19%) with three adults (combined weight of 600 lbs). More details are presented in Appendix B.

Following the 1997 ATdS, the ALAB car continued to function normally and data gathering resumed from daily commuting and work trips in the ALAB car. Data were recorded from instrument and battery-management system output daily in accordance with the Department's research project work plan requirements.

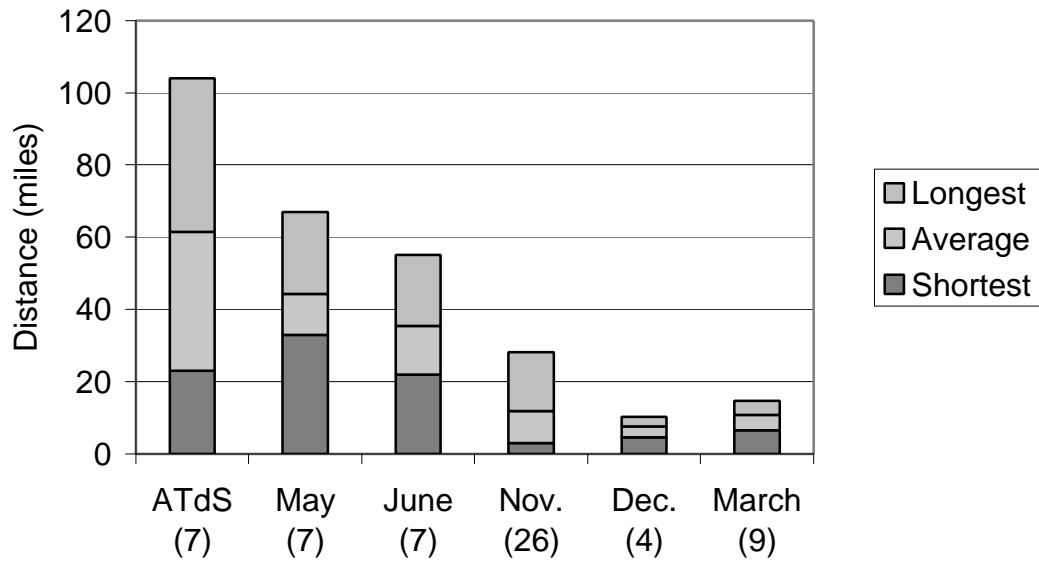


FIGURE 6 Monthly distribution of 60 single-charge drives in ALAB car during ATdS and five months of daily use in Connecticut during four months in 1997 and March 1998

Data from the ALAB car with the 1997 ALAB battery pack was collected in May, June, November and December in 1997 and March 1998. The graph displays statistics about the shortest, longest and average distances driven on each fully-recharged ALAB (Figure 6). Battery capacity loss first occurred on June 5, 1997 after just seventeen (17) drives. A total of 1,423 miles were driven in 60 drives with the 85 Ah battery pack. Half of that mileage was accumulated in May 1997. The car was idle for repairs during the months of July, August, and September 1997 due to failures of the 30/50-Amp charger on June 15. The 12-Amp charger was reinstalled and the car returned to commuter service, but the battery pack developed an open circuit (shook apart on rough roads in construction zone), which idled the car in October. The car was operated again in November and December. During this period the ALAB continued to lose capacity. The car was again idle in January and February in 1998 for troubleshooting. In March 1998, the ALAB car was again used for limited commuting. The 85 Ah ALAB continued to experience progressive battery capacity losses. During March 1998, the

single-charge driving range of the car diminished to about 11 miles, marking the end of the 1997/1998 evaluation period.

Because the car was not working properly during the commuter evaluation period in 1997, it was not provided to the Consumers Union automobile testing facility in Moodus for their evaluation.

85 Ah ALAB Car - 1998

The five 4-door sedans purchased by The Connecticut Rideshare Co. have 1994-production-year motors and belt-type drive trains. In fact, these cars may have been the last units built before the manufacturer changed its standard drive train to the quieter direct-drive design. In 1998, to gather data and information about the newer motor and drive train, we upgraded the motor and belt-drive system on our 1995 ALAB car. The car received a factory upgrade of its motor and drive train, making it essentially a 1998-model EV under the hood. The upgrade was described earlier in the section, "Description of Basic Vehicle."

Also upgraded were the laptop computer and battery-monitoring software. The on-board, 12 Amp, 220-Volt battery charger was replaced with an on-board 22 Amp, 220 Volt Charger. The new charger supplied 20.5 Amp +/- 0.5 Amp, for 3.2 kW at 156 Volts DC output. The charger was still controlled by the original 1995 computerized battery management system, but our system did receive a software and EPROM upgrade. The EPROM profile supplies 19.8 to 20.8 Amp, and it was anticipated that the actual amperage range would be even narrower, from 19.5 to 20.4 Amp. For an 80% DOD, the new 20.5-Amp charging system was designed to recharge the ALAB pack in two charging-cycle phases, as follows: 3.5 to 4 hours under the first phase at the 20-Amp rate to basically recharge

the pack; followed by 4-4.5 hours under a second phase at low amperage to equalize voltage levels in individual batteries, resulting in uniform cell voltages across all thirteen batteries.

A new objective was established in 1998 to test the ALAB manufacturer's new claim that if certain limitations were observed, the battery would provide 400 cycles, or as much as 18,000 miles (45 miles/charge x 400 cycles) over the life of the ALAB pack. The principal change involved limiting the demands on the new ALAB. With input from the EV consultant and an article about ALAB technology published in the Battery Digest Newsletter, we established a new limitation guideline of 70 percent DOD based on the one-hour discharge rate of the battery or approximately 72 Ah, instead of the advertised three-hour discharge rate (85 Ah). [4]

As in 1997, the car battery was not recharged until more than 10 percent discharge had occurred. Additionally, the car would be driven observing a limitation on the peak amperage draw from the ALAB of about 100 Amps. Travel on expressways was avoided in view of the peak load limitation, although on the highways in the Connecticut river valley the car would accelerate to 55 mph under the 100 Amp current draw, albeit at a slower rate than would have occurred at a higher amperage. Under these operational limitations, the car was being driven a lot like a neighborhood electric vehicle.

At the 1998 ATdS, as in 1997, the Connecticut team observed the conservative battery voltage cutoff of 1.8 V/cell (10.8 V/battery). The ALAB-car team won various trophies and received special recognition from several government officials and the press at the conclusion of the event. Although it was not an objective of the study to "win" at the ATdS, the ALAB car did run well, we obtained good data and did

contribute to a favorable reputation for the partnering organizations that made this project possible. The five (5) longest drives in 1998 occurred during the ATdS and were accomplished within the voltage-cutoff guideline. The good showing was indicative that this year the ALAB car would run better than in previous years.

Following the 1998 ATdS, the ALAB car was running well and data gathering resumed from daily commuting and work trips in the ALAB car. Data were recorded from instrument and battery-management system output daily in accordance with our research work plan requirements. Periodically, information was posted to the project Web Site (see Appendix B).

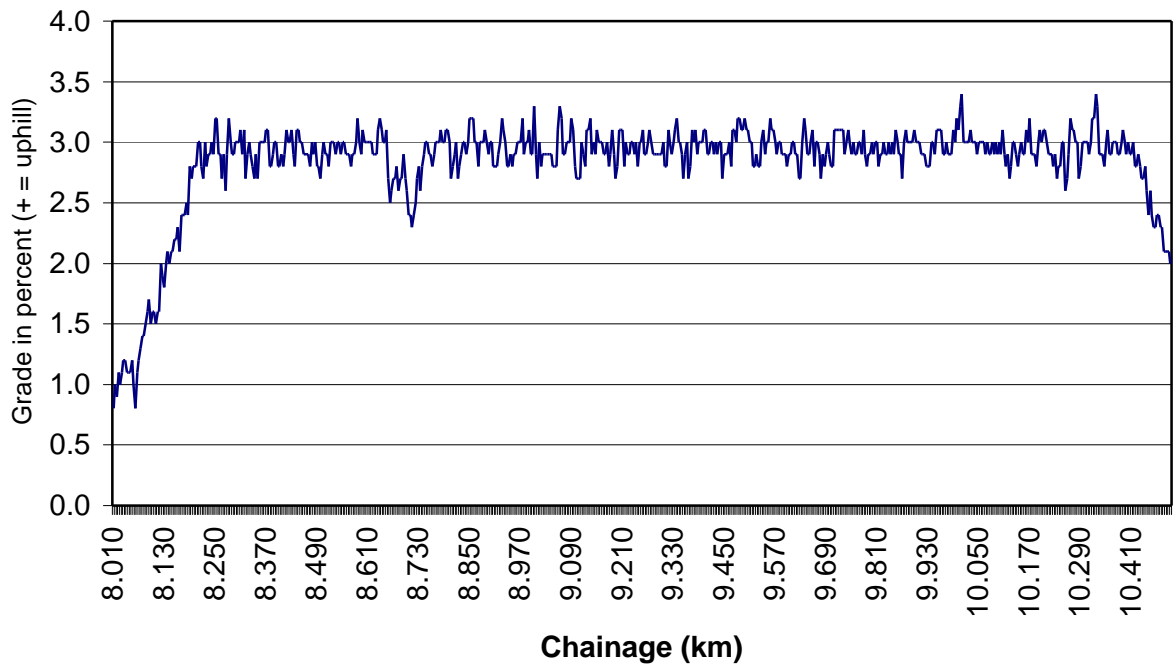


FIGURE 7 Constant three percent grade on 1.4-mile (2.2-km) section of I-384 slowed the ALAB car from 65 mph to 57 mph at full power

During this period the vehicle was used for commuting and work trips. One routine work trip is from the Hartford area to the University of Connecticut (UConn). A common route for a portion of this trip is Interstate I-384. The speed limit in this 8.5-mile Interstate

is 65 mph. One 1.4-mile stretch has a constant 3 percent grade (see Figure 7). In six drives to UConn during June and July in 1998, the ALAB car could not maintain the 65 mph speed on the 1.4 km section with the 3 percent grade. At full power, speed gradually dropped from 65 mph to about 57 mph and held steady thereafter to the crest of the hill.

The ALAB car ran well in May and June, and 48 single-charge drives were completed. However, just seven weeks after the car entered service with the new ALAB, problems developed with battery #4 after a 56-mile drive on July 5, 1998.

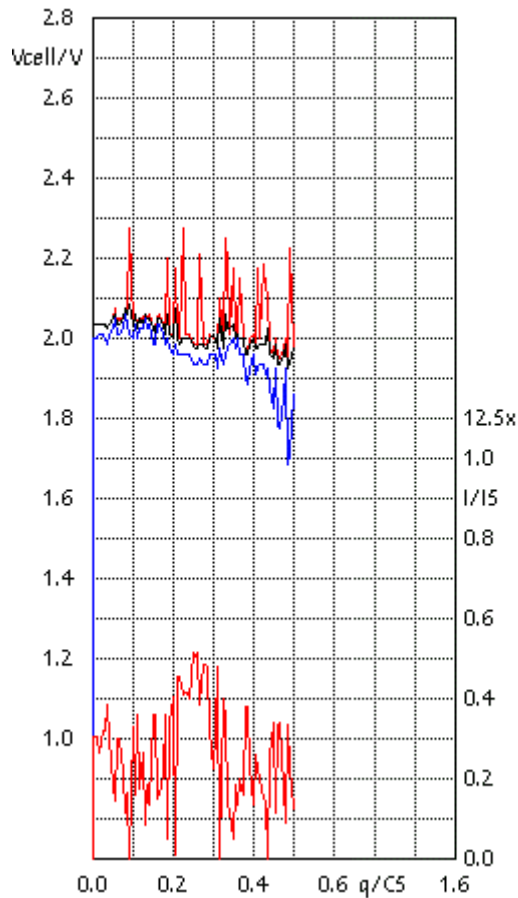


FIGURE 8 Voltage pattern in 1998 ALAB reveals that battery #4 is very weak by discharge cycle #50, July 5, 1998

The graph produced by the battery management system describes the energy usage on that drive (Figure 8). The x-axis represents the depth

of discharge (DOD) of the ALAB. The drive utilized only fifty percent of the battery capacity (50% DOD).

The upper half of the graph records battery cell voltage during the entire discharge. The voltage values are reported as a cell voltage in a six-cell battery. Each cell has a nominal two volts, so six cells combine to produced the nominal 12-Volt battery. Cell voltages are reported in three lines for the highest, lowest and average batteries in a 13-battery pack. The two lines representing batteries with highest and average voltage are very close to each other on the graph. At fifty percent DOD, average voltage is approximately 1.95 V., very close to the nominal value. Only battery #4 had low voltage. It is represented as the lowest-voltage line on the graph. From 44 percent to 49 percent DOD, voltage of battery #4 plunges from 1.9 V to 1.7 V, below the 1.8-V. limit, indicating permanent capacity loss has occurred in that battery (#4). The ALAB car was taken out of service in August for replacement of battery #4. Data from the 68 single-charge drives with the original 13-battery pack is presented in Figure 9.

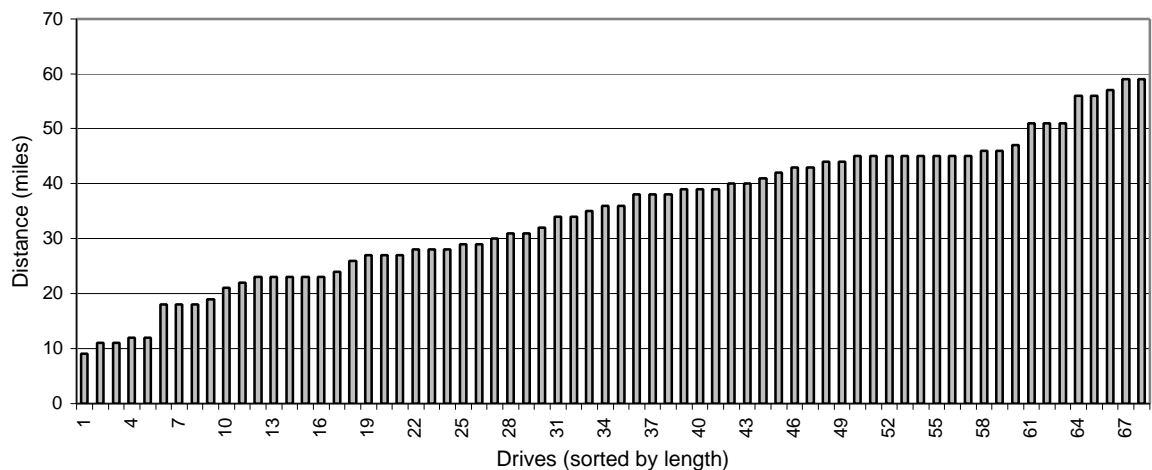


FIGURE 9 Single-charge distances from 68 commuting and work-trip drives in ALAB Car during 1998 before Battery #4 failed and was replaced

The distribution of single-charge distances driven in commuting and work trips shows that the majority of drives were accomplished

within the 70 percent DOD limit. We avoided small short cycling battery discharges (short drives) and deep discharges (long drives).

The replacement battery was a spare ALAB, taken from storage. Two spare ALAB units had been purchased in 1997 and stored at room temperature with periodic trickle charging. Following that repair, the ALAB car was returned to commuter service in the last week of October. During October and November, the spare battery experienced progressive capacity losses and the single-charge driving range was reduced. However, another 35 drives were completed before another problem arose: the 20.5-Amp battery charger failed at the end of November. At that time the ALAB car was taken out of service and the evaluation of the ALAB car was concluded.

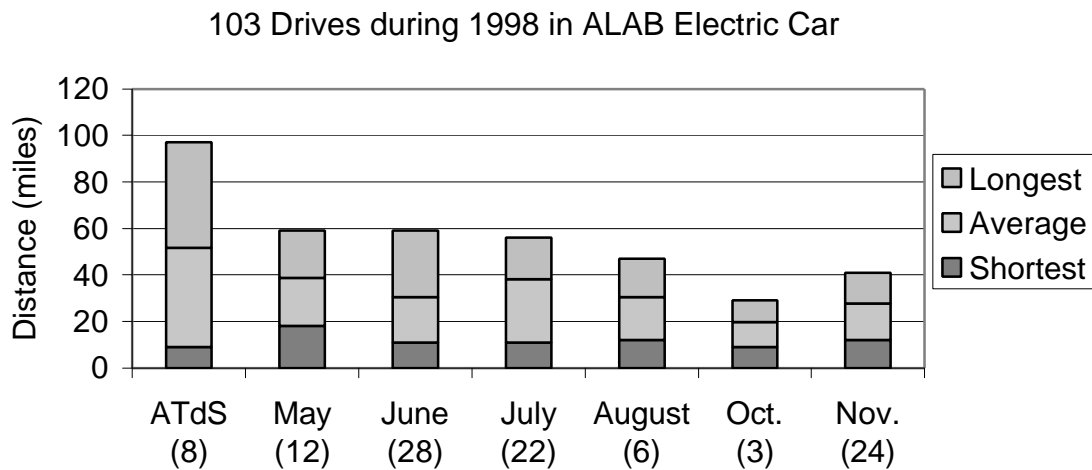


FIGURE 10 Monthly distribution of 103 single-charge drives in ALAB car during ATdS and six months of daily use in Connecticut during 1998

The graph in Figure 10 displays statistics about the shortest, longest and average distances driven on each fully-recharged ALAB. There were a total of 103 drives on the 1998 ALAB pack, including drives in October and November, which occurred after battery #4 was replaced with a spare ALAB.

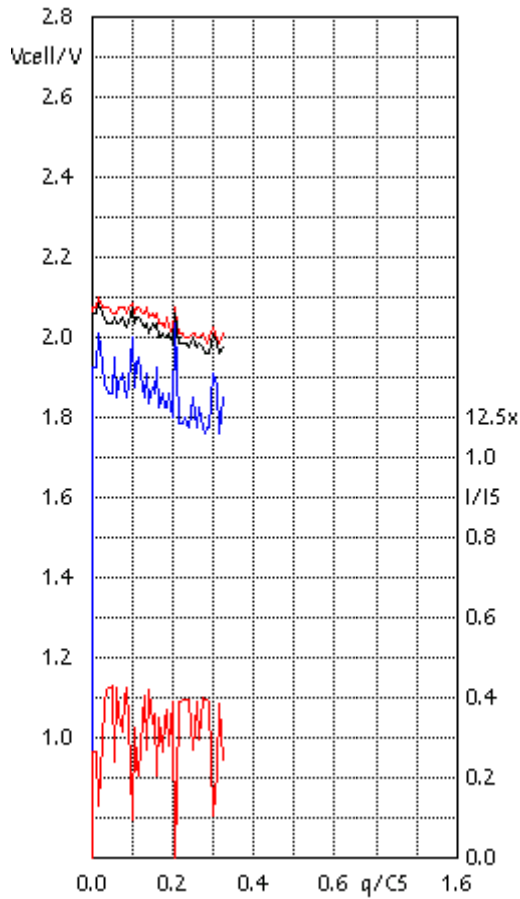


FIGURE 11 Voltage pattern this 24-mile drive on November 3, 1998 shows that replacement battery #4 is very weak by comparison to the other twelve ALAB units

The graph from the battery management system on November 3, 1998 records the voltages for the second cycle after battery #4 was replaced with a spare (Figure 11). The spare was the better of two ALAB units held in storage for 18 months with occasional trickle charges to maintain the battery. The top of the graph shows batteries with highest, average and lowest voltages. The lowest voltage line represents the replacement battery, starting at 1.93 V (11.58 V/when fully charged, while the other twelve ALAB units start at 2.06 V/cell (12.36 V/battery). Amperage draw for driving was very modest, with peak draw below 70 A (refer to lower half of graph and y-axis on the right, where 0.4 refers to $0.4 \times 160\text{A} = 64\text{ A}$). After a 20 percent discharge (0.2 on x-axis), average cell voltage is 2.0 (12.0 V/battery), but the

replacement battery registers 1.8 V/cell (10.8 V/battery), the low-voltage cutoff for driving the ALAB car.

Overall, the 1998 ALAB car was driven 3,815 miles on the battery pack in mostly warm weather and consumed 961 AC kWh. The energy consumed during this spring, summer and fall period was 961 AC kWh, with a retail cost of approximately \$0.027/mile driven, based on a \$0.106/kWh utility rate in Connecticut. At the lower national average cost of electricity of \$0.086/kWh, the cost of electricity per mile calculates to \$0.022/mile driven.

Average commuting distance driven during May through August was 35 miles per charge. The effect of the drives that occurred after battery #4 was replaced with a spare was 33.1 miles/charge, a slight reduction in the overall average distance driven per charge in the ALAB car over a total of 103 drives. The standard deviation was 13.1 miles per drive, meaning that two thirds (68 drives) were from 20 to 46.2 miles between battery recharging.

Findings

The principal finding is that the 1995-model electric car must be viewed in more than one context. Firstly, the vehicle body, chassis and drive train are adequate for the transport of personnel within Connecticut for most routine non-emergency state business. Drivers do notice that the drivetrain is somewhat underpowered as compared with most other vehicles on the road, but that was also true for the gasoline-powered Geo Metro. The EV manufacturer that converted the Geo Metro to an electric vehicle has placed a higher priority on efficiency versus power, and both acceleration and top speed reflect that priority.

Secondly, the electric car must be viewed in the context of its battery since many different batteries could power the car. Two different battery types were evaluated in this project.

The first type was a 50 Ampere-hour conventional sealed lead acid battery (CSLAB). The finding is that this car/battery configuration is reliable, although actual cold-weather range was almost half the manufacturer's claimed warm-weather range, because of the power-draining effect of the electric heater/defroster, rear-window defroster, windshield wipers, and headlights. Fuel-fired heater/defroster units are now options on this electric subcompact car and are anticipated to provide more consistent year-round single-charge driving range.

The second type was an advanced lead acid battery (ALAB). The car was operated on two (2) different versions of the production ALAB. The first was a 95 Ampere-hour ALAB. The second was an 85 Ampere-hour battery. Several combinations of battery chargers, charging profiles and driving/operating parameters were utilized during the four years in attempts to eliminate premature battery failure. The finding is that

this car/battery configuration with the ALAB is uneconomical due to premature battery failure.

A 1985 Transportation Research Board publication about daily driving-distance needs in the U.S. commercial-vehicle market provides a method to determine how many and where short-range electric subcompacts could be utilized in fleets. The method could be applied to state government fleets.

The regulations associated with the Energy Policy Act of 1992 and the Clean Air Act were not prescriptive as to which alternative fuel vehicles must be purchased for state fleets. Fleet managers can exercise considerable judgment in their purchasing decisions. Although there are obvious fuel conservation, energy independence and air quality benefits to electric vehicles, there are very few electric vehicle models that can actually be purchased and are supported in Connecticut by their manufacturers. The lack of available vehicle makes and models continues to limit a fleet manager's options for incorporation of EVs into the state fleet.

It will be important to base state purchasing and leasing decisions on the most reliable information available about the practicality, performance and reliability of available electric vehicles.

The practicality of electric vehicles for work trips is determined largely by their driving range and cruising speed capabilities as compared with fleet-usage needs.

In this project, we found marketing claims of both the electric car and battery manufacturers were inaccurate as applied to Connecticut

(Table 2). It is unlikely that a fleet manager will make decisions about the acquisition of EVs for the fleet based solely on manufacturers' claimed performance and warranties. Prudent decision-making will likely involve careful assignment of EVs to daily driving missions that are well within the vehicles' capabilities and close monitoring thereafter to build experience.

TABLE 2 Findings for three different lead acid batteries in a subcompact electric car

Vehicle Battery Type	Conventional Sealed Lead Acid (CSLAB)		Advanced Lead Acid Battery (ALAB)			
	CT:EV-2		CT:EV-1		CT:EV-1	
Registration Number	CT:EV-2		CT:EV-1		CT:EV-1	
Evaluation Year(s)	1995, 1996		1995, 1996		1997,1998	
Battery Capacity (Ah)	50		95 ¹		85	
Battery Capacity (kWh)	7.8		14.8		13.2	
Time of Year	Winter Months	Spring, Summer, Fall Months	Winter Months	Spring, Summer, Fall Months	Winter Months	Spring, Summer, Fall Months
Anticipated Driving Range	<50 ²	50	<70 ²	70	<65 ²	65
Observed Driving Range	~30	~40	ND ³	ND ⁴	ND ³	~45
Cost/mile for electricity at \$0.106/kWh (CT rate)	\$0.06 ²	\$0.03 ⁵	ND ³	ND ⁴	ND ³	\$0.027
Cost/mile for electricity at \$0.086/kWh (Nat'l rate)	\$0.05 ²	\$0.025 ⁵	ND ³	ND ⁴	ND ³	\$0.022
Battery Cost per mile (between 'pack' replacements)	\$0.11 to \$0.19 ⁵		ND ⁴		\$1.66 ⁶	

NOTES:

- ¹ 95 Ah ALAB was discontinued in 1996 by manufacturer and replaced with the 85 Ah ALAB.
- ² Range in winter varied inversely with use of accessories (electric heater/defroster, rear-window defroster, windshield wiper, headlights). Also, at low ambient temperatures battery is anticipated to be less efficient. Cost/mile is higher in winter than summer due to use of these electric accessories.
- ³ Not determined because ALAB car was not operated in winters of 1995/1996 (by Rideshare), 1996/1997, 1997/1998 or 1998/1999 primarily due to battery failures.
- ⁴ Not determined because ALAB car was not operated long enough before batteries began to lose capacity.
- ⁵ Data provided by Rideshare from CCEVD project. Average 0.287 AC kWh/mile in spring, summer and fall months. Capital cost/mile based on experience with four CSLAB cars and CSLAB replacement cost per pack. Distances driven in the four CSLAB cars on their battery packs were from 11,300 to 22,100 miles over 24 to 32 months.
- ⁶ Cost/mile based on 103 drives before 1998 ALAB pack failed in final year of evaluation.

In table 2 we are reporting the single-charge range of the ALAB car as 45 miles because that was sustainable for 50 drives before one of the thirteen batteries began to lose capacity. It is important to note a noticeable difference between 40-mile drives in the CSLAB and ALAB cars. By design, the ALAB car has full power throughout the drive because the DOD is constrained to 70 percent in order to avoid damaging the battery. This constraint causes the battery voltage to remain at its nominal 12 volts throughout the drive. Thus, driver has consistent power for acceleration and hill climbing in the ALAB car. The CSLAB car, in contrast, is driven to a deeper discharge level, and as voltage declines so does power for acceleration and hill climbing.

An evaluation involving a single ALAB car and a single CSLAB car cannot provide statistically definitive predictive statements about a large fleet of electric cars (population), but good quality control in the manufacture of the electric vehicles makes it likely that in-service tests of only a small sample of EVs will provide sound first-hand data and experience useful in evidence about the accuracy of marketing claims of EV and EV-battery manufacturers, and much useful firsthand information about both capabilities and limitations of the subcompact battery/electric car.

Summary of Costs

The capital cost of the CSLAB car with options was \$34,776 in 1995, which included a \$500 multiple-car-purchase discount. The options included in the CSLAB car were: battery thermal management, electric heating and air conditioning, cabin preheat, trip odometer, emergency shutoff button, 2 kW charger, analog volt meter, digital amp-hour meter, and installation charge for AC-Watt meter (for project data collection).

Present-day pricing of CSLAB cars in a fleet procurement would be determined through competitive bidding and could be lower or higher depending on quantity, options and competitive market factors. For use in Connecticut fleets, a fuel-fired heater should be included in the car specification. This option was not available in 1995.

The capital cost of the base ALAB car, including the same options as on the CSLAB car (electric heater and air conditioning, etc.) was \$43,546 in 1995, which included the \$500 multiple-car-purchase discount. The ALAB model is no longer available from the EV manufacturer.

The 'fuel' cost for the CSLAB car is based on a combination of ConnDOT and Rideshare records (see Table 2). Rideshare observed average electricity consumption of 0.287 kWh/mile in spring, summer and fall months. The cost per mile calculates to \$0.03/mile for electricity in winter driving, based on a \$0.106/kWh utility rate in Connecticut. At the lower national average cost of electricity of \$0.086/kWh, the cost of electricity per mile calculated to \$0.025/mile.

ConnDOT's observed average electricity consumption for winter months was 0.559 AC kWh/mile. Energy usage is higher in cold weather due to the use of the electric heater, used on 125 of 196 drives. Electric windshield wipers were used on 28 drives and electric lights were run on 31 drives. The cost per mile calculates to \$0.06/mile for electricity in winter driving, based on a \$0.106/kWh utility rate in Connecticut. At the lower national average cost of electricity of \$0.086/kWh, the cost of electricity per mile calculated to \$0.05/mile.

The replacement cost of the CSLAB is reported in Table 2 as a per-mile cost based the 1998 replacement cost of \$2,145/pack (13 batteries) plus \$275 for shipping and labor to install and cycle the battery.

Rideshare provided data from both the CCEVD project and their maintenance records in subsequent years. Distances driven in the four CSLAB cars on their battery packs ranged from 11,300 to 22,000 miles over 24 to 32 months. The resultant cost-per-mile range is \$0.11 to \$0.19.

In the final year of the ALAB-car evaluation, the car was driven 3,815 miles on the ALAB pack in mostly warm weather. The energy consumed during this spring, summer and fall period was 961 AC kWh, with a cost-per-mile of approximately \$0.027/mile driven, based on a \$0.106/kWh utility rate in Connecticut. At the lower national average cost of electricity of \$0.086/kWh, the cost of electricity per mile calculates to \$0.022/mile driven.

The price of ALAB packs varied each year during this evaluation. Prices for 13-battery packs were: \$5,720 in 1995; \$7,345 in 1996; \$7,020 in 1997; and, \$6,045 in 1998. These prices do not include shipping and labor to install and cycle the batteries.

The replacement cost of the ALAB is reported in Table 2 as a per-mile cost based the 1998 replacement cost of \$6,045/pack (13 batteries) plus \$275 for shipping and to install and cycle the battery. The distances driven in the ALAB car in 1998 before battery failure on this pack was 3,815 miles over 7 months. During that period the car was idle for over three months due repairs to correct for the failure of one of the thirteen batteries and two failure occurrences of the battery charger. Based on the 1998 price of the ALAB and its service life of 3,815 miles, the capital cost per mile for the battery was \$1.66/mile.

Basic Subcompact Car, Electric Drivetrain

A major U.S. automobile manufacturer manufactures the subcompact car body and chassis. The body and chassis are designed as an inexpensive lightweight steel car model. A fleet manager cannot escape the fact that this subcompact car is one of the least expensive, no-frills economy cars on the market. [4] It has adequate seating for four adults, but limited interior room. Trunk space is less than the General Motors internal combustion engine (ICE) version of this subcompact car due to the space required for the battery box. All these EV characteristics must be taken into consideration and will determine where the battery/electric subcompact can and cannot be assigned in state agencies.

The electric motors, gearboxes, motor controllers, regenerative brakes, and other components unique to the battery/electric cars were very reliable in the cars we drove during the four-year project.

Reliability shortcomings we observed were almost exclusively in the area of the batteries themselves and battery recharging equipment. In 1997, one charger breakdown disrupted data collection for a month. In 1998, two charger breakdowns disrupted data collection, and over 100 days elapsed awaiting charger repairs/replacement.

On-board chargers are beneficial because they provide the driver with greater versatility when the battery must be recharged. Opportunity charging can occur at a variety of unplanned locations if the electric car is equipped with common extension cords and electrical adapters.

50 Ah CSLAB-powered Electric Subcompact Car

It is recommended that electric subcompacts in the fleet utilize the CSLAB when the fleet vehicle will have short routine driving missions and do not require significant expressway driving.

The needs of the state fleet are year round and the seasonally lower range of the CSLAB car in winter cannot be ignored. The driving range on a single charge with conventional sealed lead acid batteries (CSLAB) is sufficient for a winter driving mission of about 30 miles round-trip, and a three-seasons driving mission of about 45 miles. The addition of a fuel-fired heater/defroster is anticipated to increase the winter driving range and improve driver/passenger comfort.

The CSLAB responds well to opportunity charging. Recharging facilities should be prearranged for those locations where the CSLAB car will be parked during the day, in addition to overnight charging. Where day-time opportunity charging is available, year-round daily driving requirements can be accommodated by the CSLAB car that exceed 30 miles. The daily range of those CSLAB cars will depend on the time available for opportunity charging during the workday, i.e., how long the car is parked and plugged in for opportunity charging.

During longer drives and at higher speeds, the CSLAB voltage decreases to and below nominal voltage levels. The driver will then notice that available power has diminished somewhat and remains this way through the remainder of the drive. At lower voltage levels, the driver will notice that the CSLAB car is less able to accelerate and climb grades, at rates and speeds compatible with faster highway traffic. This predictable and repeatable performance characteristic of the conventional lead acid battery needs to be considered when assigning the

CSLAB car. Drivers should receive training on what to expect and how to operate the vehicle safely, given its limitations.

The fleet manager will need to plan for disruptions to fleet-car availability to facilitate changing out the battery packs every eighteen to twenty-four months, the anticipated life of a CSLAB.

85 and 95 Ah ALAB-powered Electric Subcompact Car

It is recommended that electric subcompacts in the fleet not utilize the ALAB. The ALAB is prone to early failure, making it very unreliable and uneconomical in a fleet. The CCEVD and this project evaluated ALAB batteries produced in 1995, 1996, 1997, and 1998. The 1995 and 1996 production batteries were identical, rated at 95-ampere hours. The 1997 and 1998 ALAB production batteries also identical, rated at 85-ampere hours.

Each year when the ALAB was new, the driving range of the electric vehicle was sufficient for a daily-driving mission of forty-five miles round-trip, and that lasted for up to 50 drives. Progressive capacity losses in the ALAB reduced the single-charge driving range over time throughout the battery pack's cycle life and made it difficult for drivers to know how far they could drive the ALAB car.

Protracted project delays occurred due to battery failures each year. Charger failures were also a delaying factor in 1997 and 1998. The project evolved into a four-year effort to both investigate and troubleshoot the Advanced Lead Acid Battery (ALAB) in a subcompact electric car.

The project successfully assembled various battery charging, monitoring and control equipment components in an effort to overcome failures of the ALAB. Through trial and error, we ultimately demonstrated that an electric vehicle equipped with the ALAB could be made to run relatively well for a short time if restricted to neighborhood electric operating parameters that avoid high-ampere loads on the ALAB, if not recharged prior to a minimal 5 percent DOD, and if not driven distances that result in over 70 percent DOD (about 45 miles or 70 Ah). However, even under these restricted conditions, the ALAB did not demonstrate sufficient cycle life for fleet use.

In the final year, the project observed a useful life of ALAB to be about 50 cycles before one of the thirteen batteries failed, which limited driving range thereafter. Unfortunately the replacement battery, the better of two spare ALABs in storage for eighteen months, had lost capacity while in storage. It was one volt lower than the rest of the batteries in the pack. Overall, the largest number of cycles on an ALAB pack occurred in the fourth and final year of the project, and was 103 cycles. This was very uneconomical for a \$6,500 battery pack, and represents a capital cost of \$1.66/mile for the battery.

Cycle life of the ALAB appears to be shortened as a result many factors: the design of the battery, re-charge parameters, opportunity charging, regenerative braking to a nearly-full ALAB, imprecise re-charging (amperage fluctuations from the charger), high peak discharge loads such as for hard acceleration, and deep discharges of the battery associated with long drives that require more than 70 percent DOD.

Developments after Conclusion of Project

In late 1998, members of the CCEVDP suggested the ALAB car be used to test another type of battery and a wintertime fuel-fired heater. Also, there were discussions with a fuel cell manufacturer about a possible evaluation of a preproduction prototype hydrogen fuel cell functioning as a range extender for the EV. A private EV Specialist analyzed several possible fuel-cell/EV combinations in November 1997. In our simplified analysis, the EV operated as a conventional battery/electric car. A small on-board fuel cell was started after sufficient DOD occurred during the drive. Thereafter, the fuel cell was assumed to run continuously, delivering energy to the battery. The results suggested that even a very small fuel cell could supplement battery capacity and double or even quadruple the driving range of the subcompact EV.

The Department converted the ALAB car to nickel cadmium batteries (NiCd) in 1999, which were anticipated to provide four years or more of service. The NiCd pack consists of 26 six-volt batteries (156 V) and cost approximately 34% more than the 1998 cost for the ALAB. A favorable battery-replacement cost-per-mile parameter is anticipated, which would be lower than for the CSLAB car if the NiCd battery were as long-lived as is claimed. The claimed range of the car is 70 miles per charge. That evaluation is anticipated to be completed in four years.

New Jersey DOT initiated a research project with the EV specialist, a New Jersey fuel cell manufacturer and others to investigate the concept of a fuel-cell range extender. New Jersey installed NiCd batteries in their fuel-cell hybrid EV. Their car was unveiled at the 1999 ATdS.

References

1. Berg, Mark R., "The Potential Market for Electric Vehicles: Results from a National Survey of Commercial Fleet Operators," Transportation Research Record 1049, 1985.
2. Reisner, D. E., "Commercial Off-the-Shelf (COTS) Batteries for Motive Power," US NANOCORP, Inc., North Haven, CT, 1996.
3. Consumer Reports, "Small, Cheap Cars," Consumer Reports, September 1995, PP 614-619.
4. Mosely, Patrick T., "The ALAB - Yesterday, Today and Tomorrow," Battery Digest Newsletter, Issue No. 25, April 1998, PP 1-6.

Appendix A. Information about the Energy Policy Act of 1992

Energy Policy Act of 1992 (EPACT) -- The primary objective of the 1992 Act is to strengthen national energy security by reducing dependence on imported oil. Final rulemaking by the Federal Department of Energy under 10 CFR Part 490, "Alternative Fuel Transportation Program," was mandated by the Energy Policy Act of 1992. The DOE program applies nationwide and DOE will directly administer the program. The new regulation, issued around 3/19/96, calls for certain percentages of new fleet vehicles to be powered by alternative fuels.

For example, alternative fuels must power 10 percent of new light duty motor vehicles acquired in 1997 through purchase or lease by state government fleets. Percentages rise each year for both public and private sector fleet operators: 15% in 1998, 25% in 1999, 50% in 2000, and 75% in 2001. Exemptions remain in force for emergency motor vehicle, law enforcement and vehicles used for national security, non-road vehicles, and "motor vehicles that are normally parked at the personal residence of the individuals that usually operate them."

Internet Site for Electric Commuter Vehicle Evaluation in Connecticut

Advanced Lead Acid Battery (ALAB) Electric Car

1996

[1996 American Tour de Sol -- Daily records of the sedan's performance](#)

[1996 American Tour de Sol -- Results, including a 141-mile drive on a single charge](#)

[1996 performance of the electric car following the 1996 Tour de Sol](#)

1997

[Pictures of 1997 Advanced Lead Acid Battery \(ALAB\) Electric Car](#)

[American Tour de Sol Results in 1997 - Hilly & Mountainous Highway Terrain](#)

[1997 performance of the electric car following the 1997 Tour de Sol](#)

1998

[American Tour de Sol Results in 1998 - Level Highway Terrain](#)

[1998 performance of the electric car following the 1998 Tour de Sol](#)

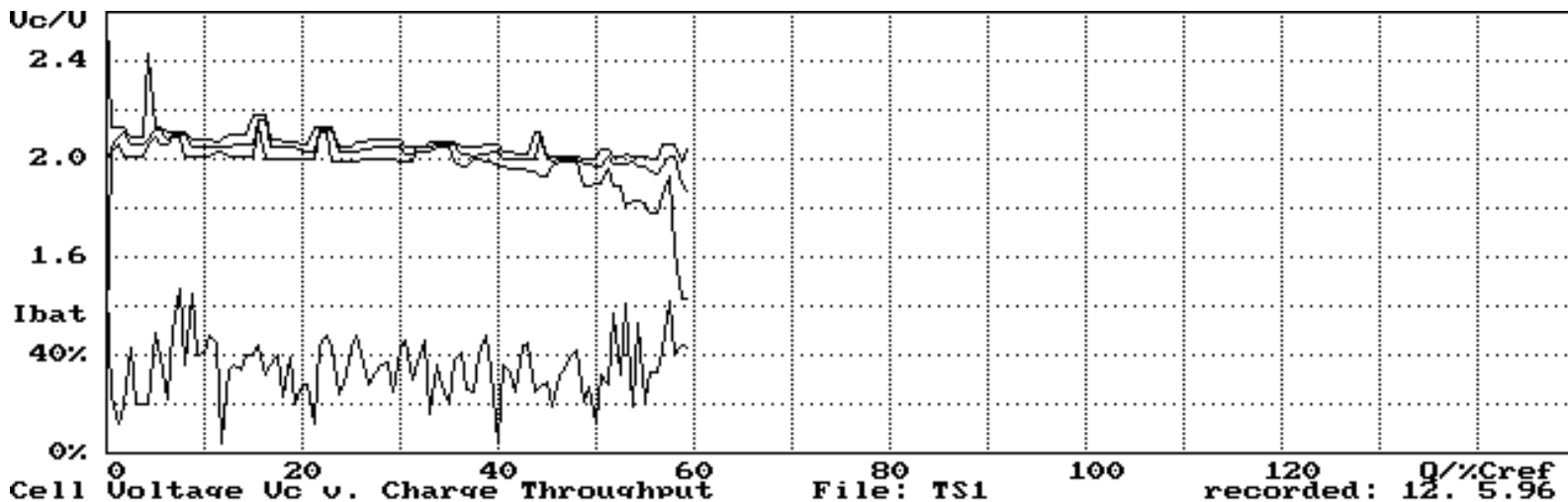
[Future of the electric car following the 1998 Tour de Sol](#)

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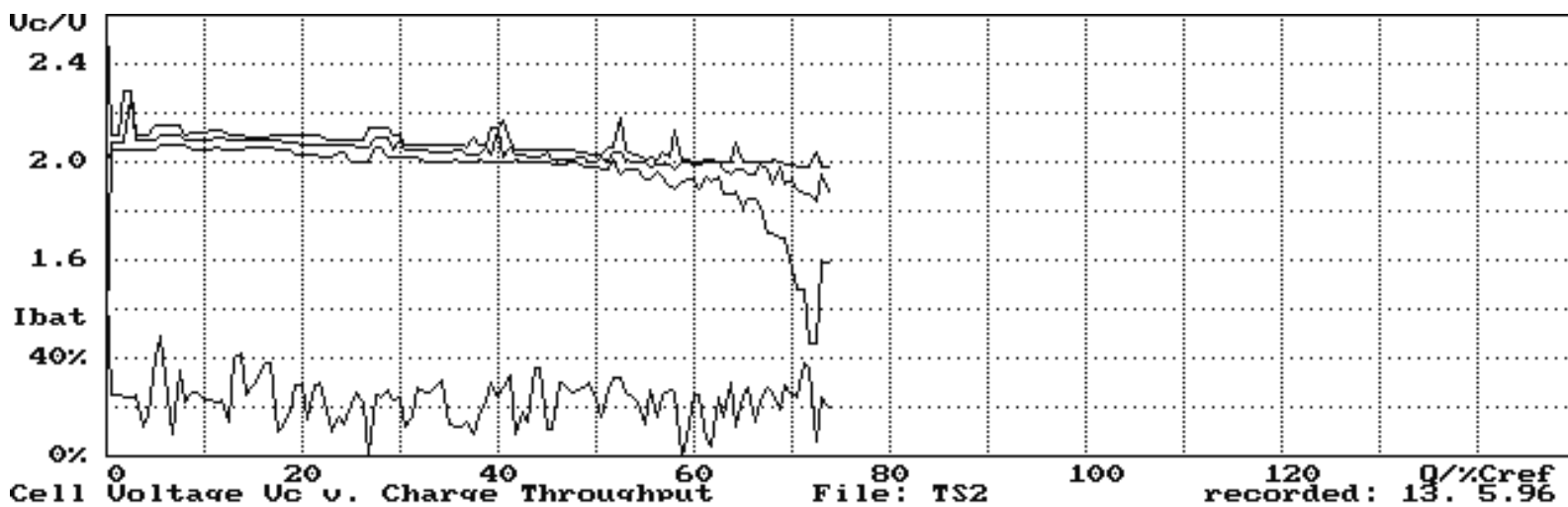
Electric Commuter Vehicle Evaluation in Connecticut

Daily records from the Connecticut team's production electric car at the 1996 Tour de Sol

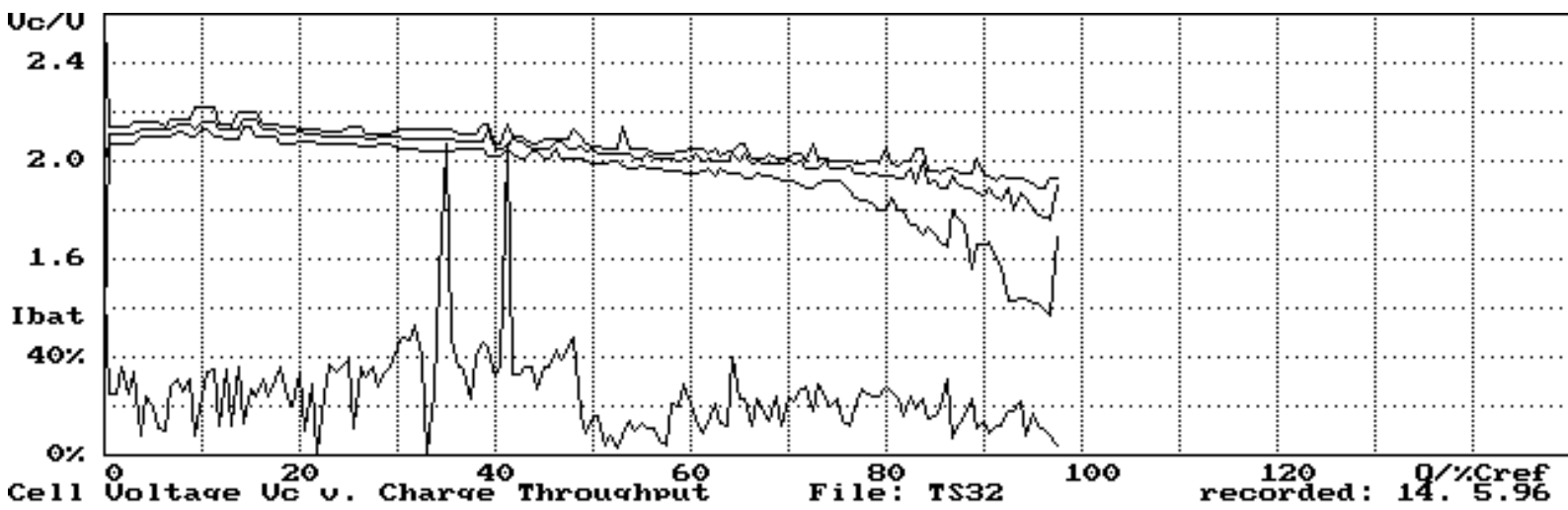
Firstly, data from the "leg" driven on Sunday at Tour de Sol is shown below. Top lines graph the voltage history (high-, average-, and low-voltage batteries) during the entire battery discharge cycle. Bottom lines graph the record of amperage draw throughout the 65.4-mile drive on Sunday.



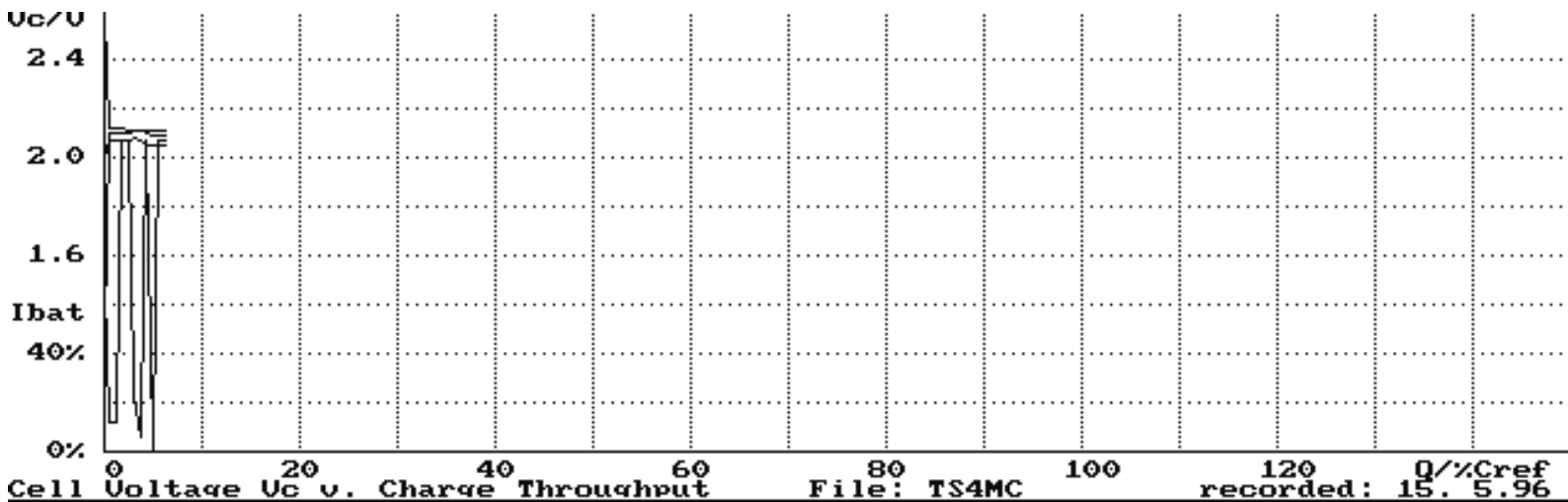
Next, data from Monday at Tour de Sol is shown below. The data represent the energy consumption record for a 97.5-mile drive on a single charge.



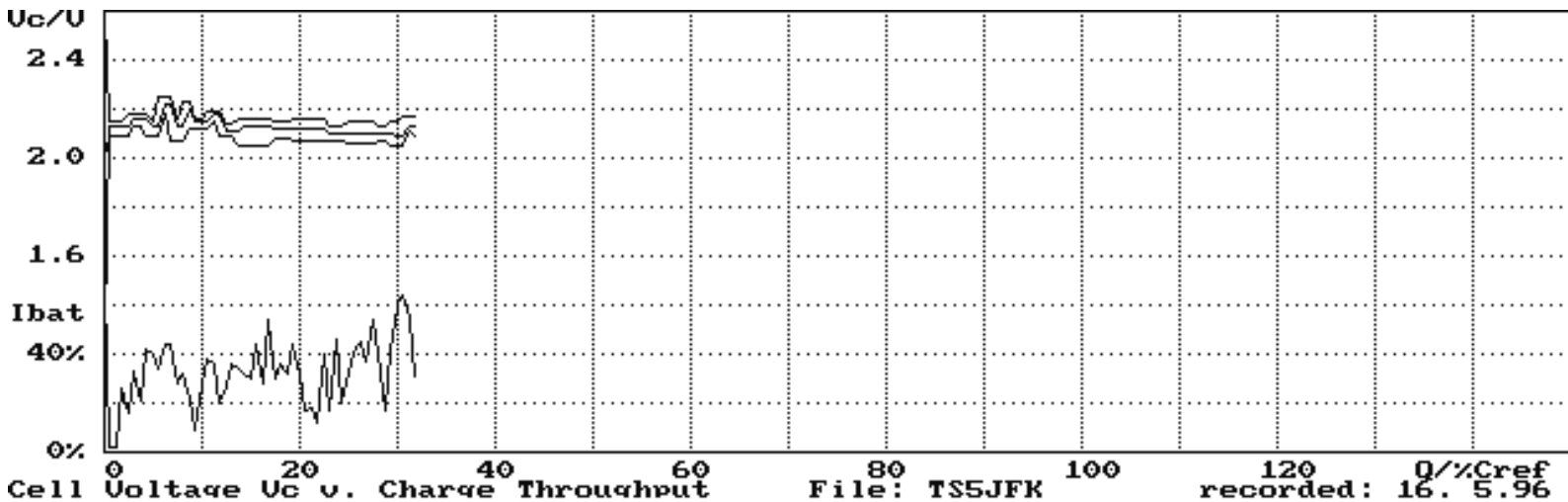
Data from Tuesday at Tour de Sol is shown below. The production electric sedan was driven 141 miles. When the trip odometer reached 139, the battery monitoring system showed the batteries were near exhaustion, and we stopped the car to rest the batteries. The voltage rebounded and we continued the lap. Officially, we didn't finish the last "lap" within the allotted road-rally time frame (we were a minute over).



Data from the motor cross and acceleration-test events on Wednesday at Tour de Sol are shown below. Data from the 71.4-mile "Leg" on this day are not available.



Data from Thursday at Tour de Sol record the energy-use pattern for the 43-mile drive into Washington, DC, and are shown below.



Below is the battery-cycle data screen. Cycle 138 records the 43-mile Thursday into Washington, DC Whereas cycle 132 records the earlier 141-mile drive on Tuesday.

V O L T A G E H I S T O R Y File: D138											recorded: 16. 6.96		
Cyc!	Ba	W0 Ba	W1 Ba	W2 Ba	W3 Ba	W4 Ba	W5	Ba	Best	Avg	QM	T	
138!	7:2050	13:2060	3:2067	4:2073	1:2080	2:2093	11:2148	2099	31	0			
137!	1:2395	9:2389	7:2386	13:2379	8:2376	2:2376	10:2333	2366	43	1			
136!	3:2141	4:2148	2:2151	1:2151	10:2164	11:2167	13:2177	2164	6	0			
135!	12:2200	13:2190	6:2190	9:2184	7:2184	8:2180	3:2148	2174	27	0			
134!	3:1992	1:2001	4:2008	2:2008	13:2021	9:2027	12:2044	2021	63	0			
133!	5:2395	13:2369	9:2369	1:2369	7:2363	8:2360	10:2311	2350	99	0			
132!	2:1689	13:1770	3:1858	4:1897	6:1904	1:1907	12:1959	1891	98	0			
131!	9:2399	13:2395	7:2395	1:2392	8:2389	5:2389	10:2353	2379	75	0			
130!	2:1676	13:1757	1:1878	3:1897	7:1904	5:1907	12:1979	1901	78	1			
129!	1:2395	13:2392	9:2392	7:2389	5:2389	8:2382	10:2366	2382	61	1			
128!	13:1624	2:1624	1:1875	5:1901	7:1907	4:1940	12:1985	1894	73	1			
127!	10:2529	4:2460	1:2415	9:2408	8:2402	7:2402	3:2373	2412	0	1			
126!	4:2350	2:2350	3:2353	10:2360	1:2366	12:2369	9:2379	2366	3	0			
125!	11:2395	9:2347	7:2343	5:2343	13:2340	12:2340	3:2320	2340	33	1			
124!	3:2011	4:2018	2:2018	1:2018	13:2027	11:2034	12:2041	2027	32	0			
123!	4:2529	3:2496	2:2496	1:2480	13:2473	9:2470	11:2288	2405	0	1			
122!	10:2285	11:2288	6:2291	12:2298	5:2369	8:2395	4:2526	2408	0	0			
121!	12:2623	1:2607	8:2591	5:2591	10:2587	6:2581	3:2441	2561	0	1			
120!	10:2353	11:2356	3:2356	4:2360	6:2366	2:2366	9:2382	2369	3	0			
119!	9:2386	13:2382	7:2382	5:2382	1:2382	8:2379	10:2356	2369	16	0			

end.

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[Send E-Mail to James Sime, participant/driver in 1996 Tour de Sol.](#)

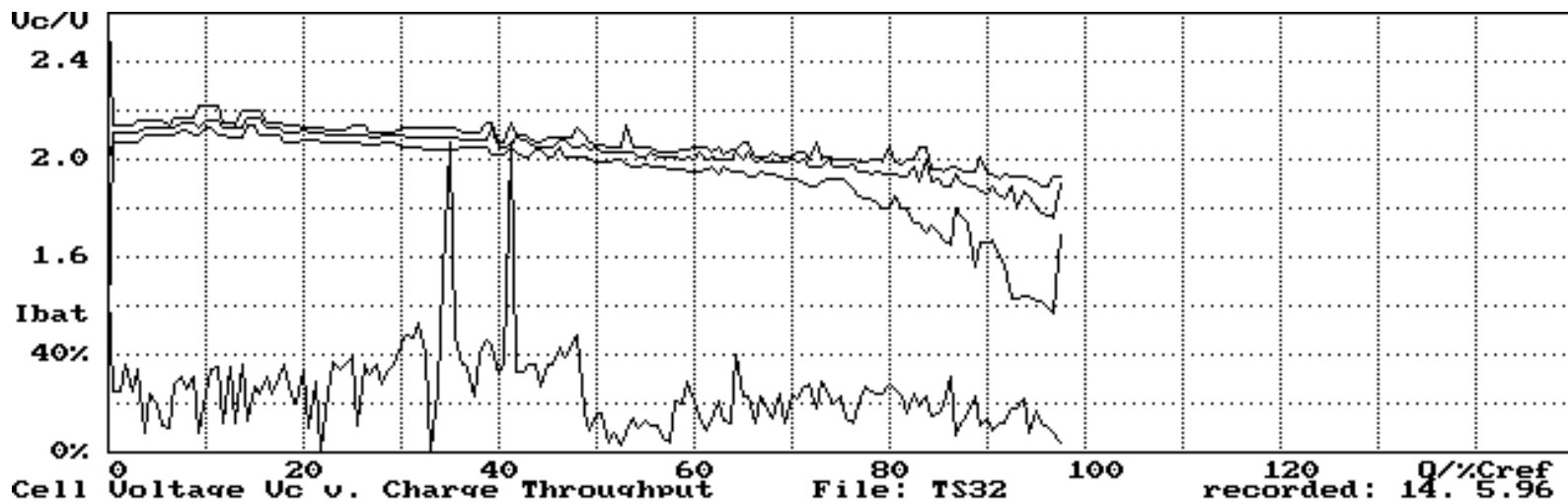
Connecticut Department of Transportation, Bureau of Engineering and Highway Operations, Division of Research

Electric Commuter Vehicle Evaluation in Connecticut

Last updated 8/04/97

The 1996 ATdS began in Manhattan, NYC on Sunday, May 11, 1996. Five days later, it ended on the Washington Mall before the Capitol in Washington, DC.

A three-person team was responsible for this Connecticut entry. Two persons (driver & navigator) drove a CT Rideshare-owned 1995-model production electric car, which was manufactured by the Solectria Corporation. The car was equipped with Horizon advanced lead-acid batteries from Electrosource Inc., Mentzer 220 volt charging system and the Badicheq computerized battery management system.



The above graph was produced by the BADICHEQ battery management system. It describes the energy-usage by the ALAB Car (#50), a Solectria Force four-door sedan with Electrosource Horizon advanced lead-acid batteries. The upper half of the graph is a record of battery cell voltage over the length of the entire discharge cycle. The lower half of the graph shows the amperage draw throughout the 141-mile drive. Amperage usage is expressed as a percentage of available amp-hours. The maximum available is 200 amp-hours. Note the two amperage spikes about 40+/- miles into the first leg. They record the team passing slow-moving traffic twice in attempts to increase their average speed, which was required to reach the finish line within the time frame for this leg of the rally. The two attempts to increase average speed expended energy that could have been used later in the day to establish a longer distance record. In all, the car was driven over the 63.6-mile "leg" and nine(9) 8.6-mile "laps." The ninth lap was not counted in official rally statistics because the car did not complete the "Lap" within the prescribed time limit.

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Battery capacity diminished during the daily commuting, which resumed in May 1996 following the ATdS. The vehicle received a normal charge, but achieved only a 44% capacity level at full recharge, as measured by the battery management system.

A complete data set was recorded for CT:EV-1 that covered all post-delivery battery recharge and discharge cycles. These data were analyzed by engineers to determine the cause(s) of the repeated losses in battery capacity. A [summary of the engineering analysis](#) was prepared for The Rideshare Company. Repairs were completed and the car was returned to service in May, 1997.

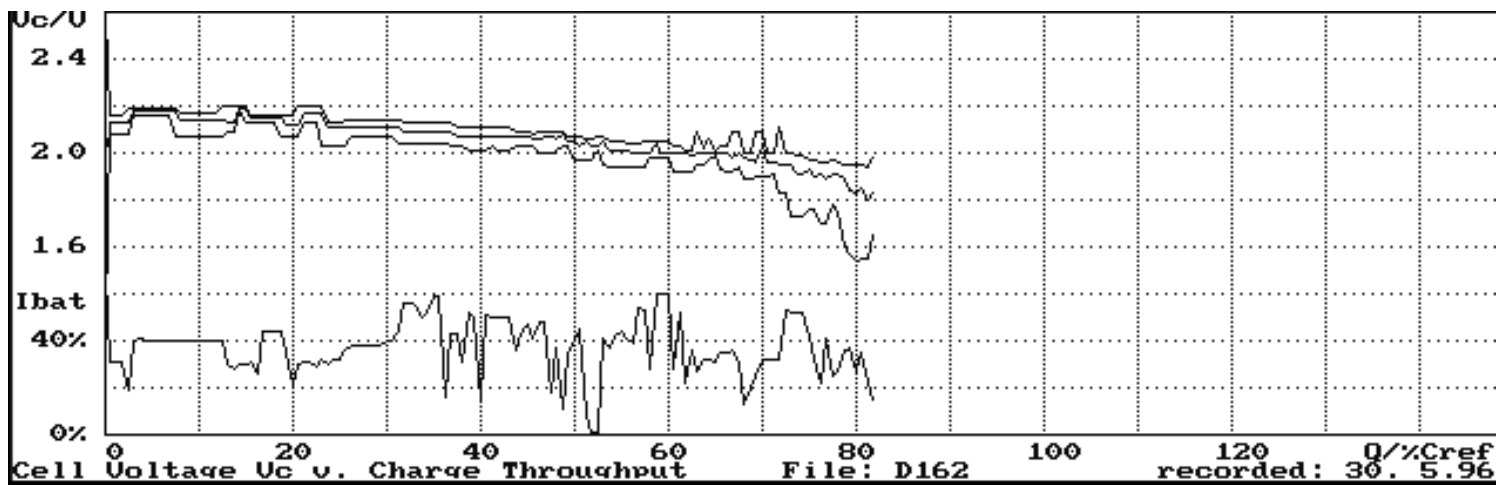
Data from the Battery Management System

[Battery Recharge Bar Chart](#)

Chronology Highlights

May 1996

A typical commute and work-trip is represented by the discharge cycle recorded on May 30, 1996, shown below. CT:EV-1 was first driven 12 miles in a morning commute to the office in Rocky Hill. Without recharging, it was next driven to the University of Connecticut to transport personnel to and from a meeting; finally returning to the Rocky Hill office. In all, 70 miles were driven before recharging at the Rocky Hill facility. Before the return commute, CT:EV-1 received a partial recharge.

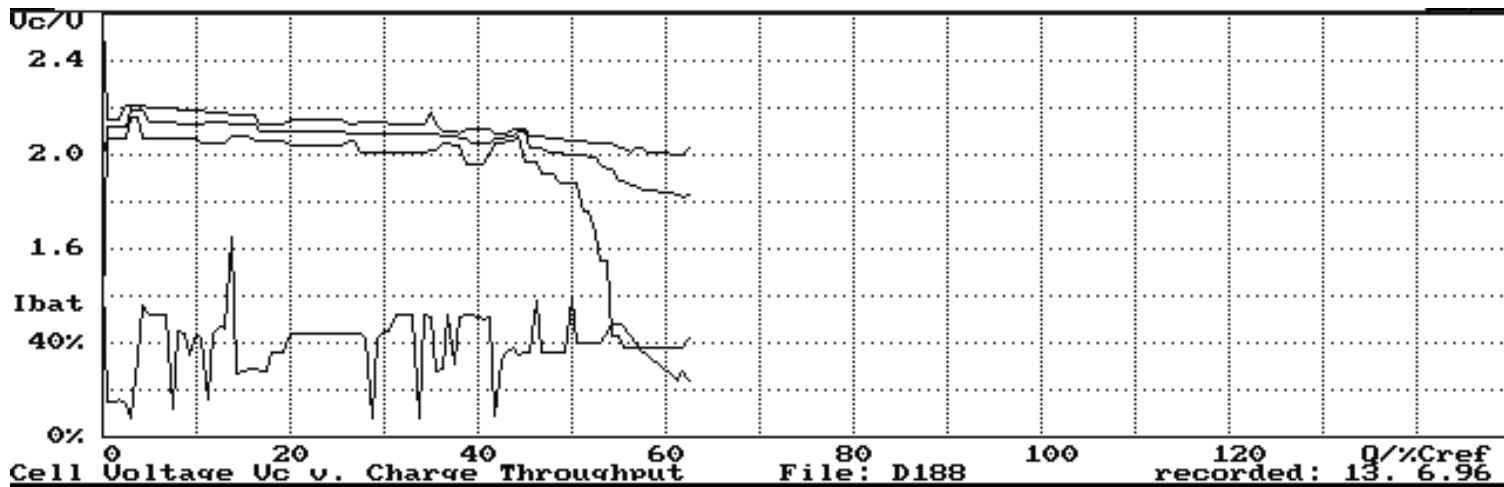


Discharge cycle for typical 70-mile drive in Connecticut

Following the drive, the electrical system recharged to the prior level, designated by the battery management system as the 62% level. This was the same battery recharge level experienced throughout the 1996 Tour del Sol.

June 1996

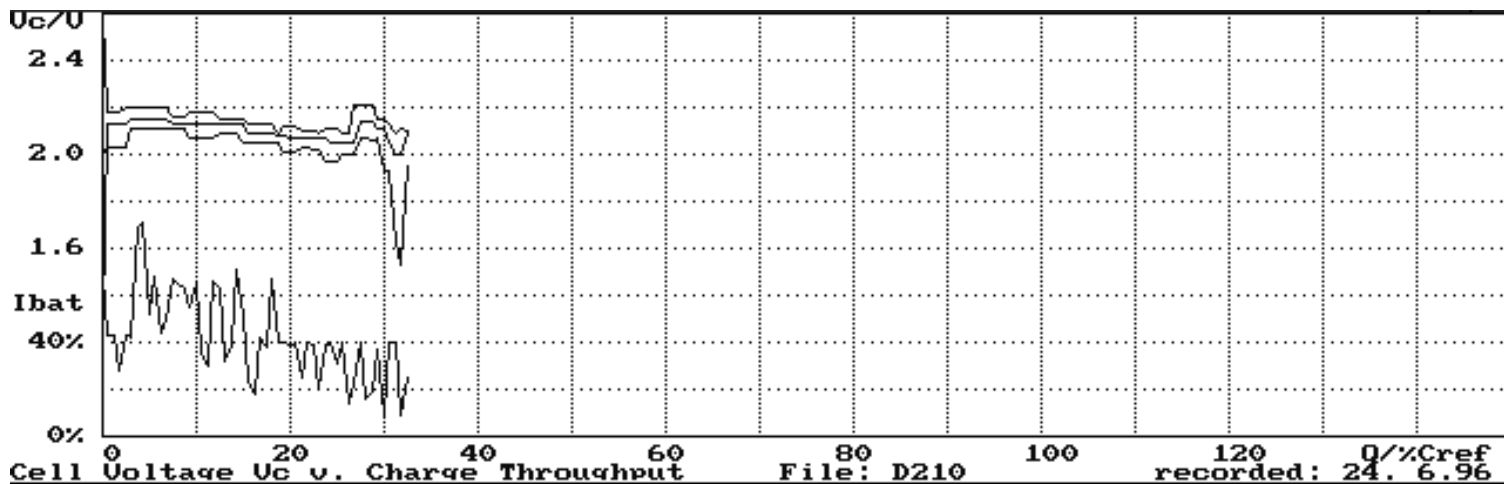
On June 12, 1996, CT:EV-1 was driven 58 miles before it displayed the "E-6" error message on the dash instrumentation of its battery management system. This message notifies the driver that at least one of the 13 batteries has discharged to the minimum allowable voltage level.



Battery discharge cycle for a 58-mile drive including Interstate driving.

Following this 58-mile drive, the electrical system never again recharged the battery pack to the 62% level. Thereafter, a full charge registered at the 54% level on the battery management system instrumentation. Diminished battery capacity reduced the driving range for CT:EV-1 to approximately 40 miles, although it was not driven this far on a single charge. On two occasions CT:EV-1 was driven 35 miles on individual charges with sufficient remaining battery capacity to have driven further, according to its battery management system data.

On June 24, 1996, CT:EV-1 was driven 32 miles on a round-trip commute, which followed the typical route. There was nothing unusual about the daily commute or the short errand following the commute. The initial battery management level at full charge was 54%. At thirty-one and a half miles into the drive, CT:EV-1 registered the "HALT" warning and shortly thereafter the "E-6" error condition. The vehicle was stopped at the side of the road to rest the batteries. After two minutes, the battery voltage levels had rebounded sufficiently to drive the last 600 meters (2,000 feet) to reach the commuter's home where recharging began immediately.



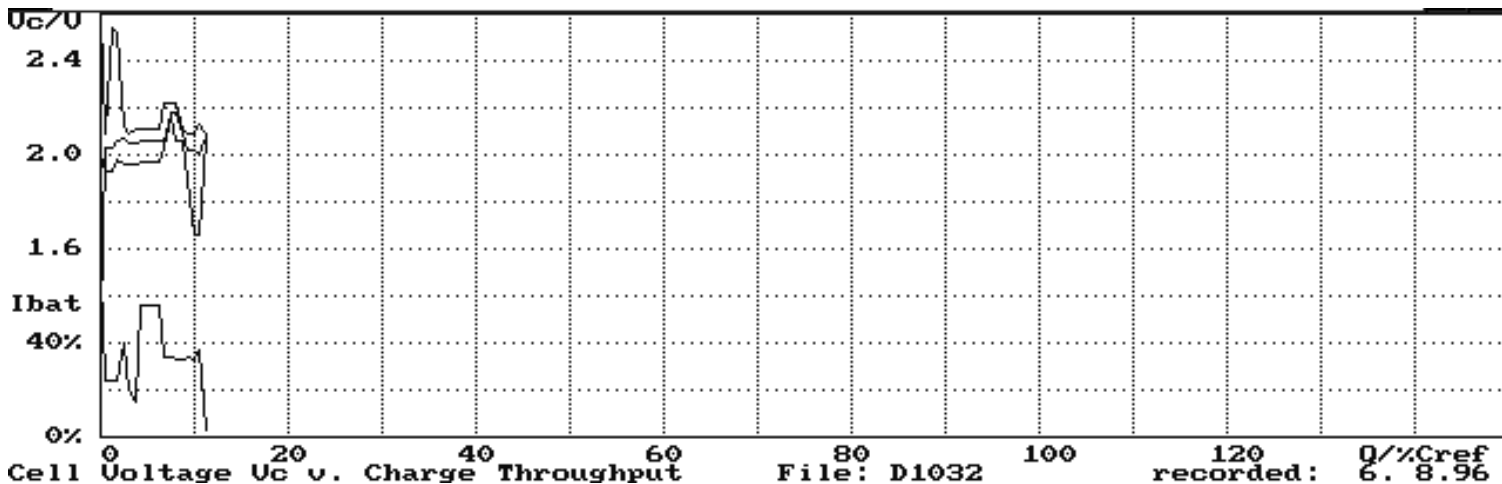
Discharge cycle for 32-mile commute and short errand on local roads

Following this 32-mile drive, the electrical system never again recharged the battery pack to the 54% level. Thereafter, a full recharge registered at the 31% level on the battery management system. The maximum distance CT:EV-1 was driven on a full charge after this event was 25 miles.

July 1996

On July 12, 1996, CT:EV-1 lost additional battery capacity and recharged thereafter to the 23% level. Range was reduced to about 15 miles under local driving conditions that included a short distance of 55-mph driving on the Charter Oak Bridge (Route 3) over the Connecticut River.

On July 23, 1996 the battery capacity diminished again following a 13-mile commute. During this period, CT:EV-1 had sufficient range for only a one-way commute before requiring a recharge. During the morning commute, an "E-6" error condition occurred one-half mile from the office. The vehicle received a normal charge at work, but achieved only a 16% capacity level at full recharge, as measured by the battery management system.



Last commute in CT:EV-1 was a low-speed 11-mile back-road route.

The complete data set for CT:EV-1 covered all post-delivery battery recharge and discharge cycles. These data were analyzed by engineers at Electrosorce Corp. to determine the cause(s) of the repeated losses in battery capacity. A [summary of the engineering analysis](#) was prepared for The Rideshare Company. Repairs are anticipated to be completed and the car returned to service in May, 1997.

Once repairs were completed and following the 1997 American Tour de Sol, a 24-month, 4-seasons evaluation would resume.

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Electric Commuter Vehicle Evaluation in Connecticut

Loss of Driving Range over Time -- Summary of Engineering Analysis

During initial vehicle tests, the battery pack (pack) was repeatedly discharged less than five percent (5%) depth of discharge (DOD). Following any discharge cycle, the battery management system carries out a full charging routine. In the case of the recharging that followed the minor DODs, the pack was overcharged. Overcharging, in turn, resulted in a "gassing" reaction within the battery. The gassing reaction causes a loss of some acid and permanent damage to the batteries.

Data from the battery management system showed six discharges to or below 100% depth of discharge (DOD) prior to cycle 188. In cycle 188, the battery pack (pack) was discharged past 100% and then parked in the discharged state for about 18 hours until arrangements were made to recharge the pack. The pack was definitely damaged at this point, however a loss of capacity was evident before this discharge cycle.

Recommendations:

- Discharge the pack more than five percent depth of discharge (5% DOD) prior to recharging.
 - Limit the DOD to 80%.
 - Recalibrate the battery management system periodically. A recalibration every three months will verify the capacity readout from the system is accurate.
-

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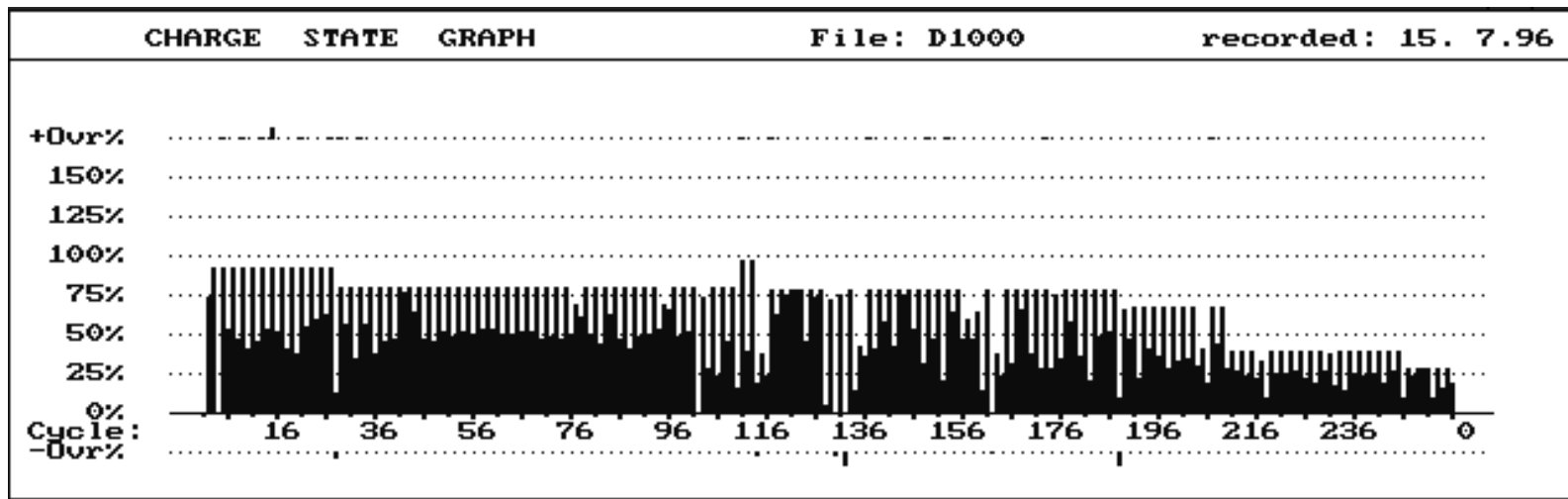
[Go to Recharge Bar Chart.](#)

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Electric Commuter Vehicle Evaluation in Connecticut

1996 Bar Chart of Battery Discharge & Recharge Cycles



Bar chart shows battery-pack recharge and discharge levels diminishing over time.

This bar chart covers the period from before delivery of the vehicle for use in the 1996 Tour del Sol to July 15, 1996. Battery cycle numbers are represented on the X-axis. Odd numbers represent battery discharges (driving the car), and are followed by the even numbered cycles of recharges. The technician loaded the battery management system with 110 cycles of battery history from another system. Actual data from CT:EV1 starts at cycle 111. A battery recharge level of 82% was achieved for most cycles from number 111 through 187.

Partial charging took place occasionally. Interestingly, a nearly complete recharge occurred twice, in cycles 111 and 113, which was during the manufacturer's vehicle-test period (before delivery). It is not known why the maximum recharge level dropped to 82% in cycle 115.

The battery management system reportedly subtracts about 20 points from the recharge-level statistic and displays the remainder on the dashboard instrumentation. Therefore, a 62% level that the driver sees is actually an 82% recharge level. Using this approach, the driver of CT:EV-1 receives the "HALT" warning (level=0%) from the dashboard instrument readout when approximately 20% of capacity remains. This is sufficient power to drive approximately 20 miles at moderate-to-low speeds before the battery is considered completely discharged.

The diminished battery capacity occurred in distinct steps, always downward as though it were a ratchet. Drops occurred after discharge cycles 188, 210, and 246. More detailed information on these events is presented on the previous page.

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Connecticut Department of Transportation, Bureau of Engineering and Highway Operations, Division of Research

Electric Commuter Vehicle Evaluation in Connecticut



The 1994 1/2 Production Electric Vehicle has been driven in three (3) American Tour de Sol events.



On display at the 1997 American Tour de Sol in Waterbury, Connecticut.

The car is equipped with Electrosorce Horizon advanced lead-acid batteries, Mentzer 220 volt charging system and the Badicheq computerized battery management system. A pack of thirteen batteries powers the car. The Horizon is a valve-regulated advanced lead acid battery. Inside are lead-fiberglass wire woven into lightweight mesh. The mesh is coated with an electrochemical paste. The design uses a starved electrolyte system and gas recombination. They are maintenance free, spill-proof, and can be mounted in any position. Battery attributes are: rapid recharge, long cycle life, high peak power (450-500 W/kg, 30 seconds @ 50% Depth of Discharge (DOD), terminal limited), 85 Ah capacity, 41 Wh/kg,

90 Wh/l, 12 V, 24.9 kg per battery, and 400-cycle life at 70% DOD. [1]

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[1] Reisner, D. E., "Commercial Off-the-Shelf (COTS) Batteries for Motive Power," US NANOCORP, Inc., North Haven, CT, 1996.

Connecticut Department of Transportation, Bureau of Engineering and Highway Operations, Division of Research

Electric Commuter Vehicle Evaluation in Connecticut

1997 American Tour de Sol

Results and Preparation Notes

The 1997 ATdS began on May 19 in Waterbury, CT and finished in Portland, ME. The electric production vehicle won several competitive categories. The route traveled north to White River Junction, Vermont; then east through the Kancamagus Highway in the White Mountains of New Hampshire; and, on to Portland. The vehicle was driven 490.4 miles, and the five-day course included hilly and mountainous terrain with grades as steep as 19%.

Awards from 1997 Tour de Sol

"Best Lead Acid Battery Sedan, Production Category"

"Best Range for a Lead Acid Battery Vehicle, Production Category"

On a single charge with the 85 Amp-Hour batteries, the car was driven 104.1 miles in hilly and mountainous terrain, with course elevations ranged from 400 ft to 1,900 ft above mean sea level.

ATdS Day 1 - Daily Efficiency Award, "Most Efficient Production Vehicle"

ATdS Day 5 - Daily Efficiency Award, "Most Efficient Production Vehicle"

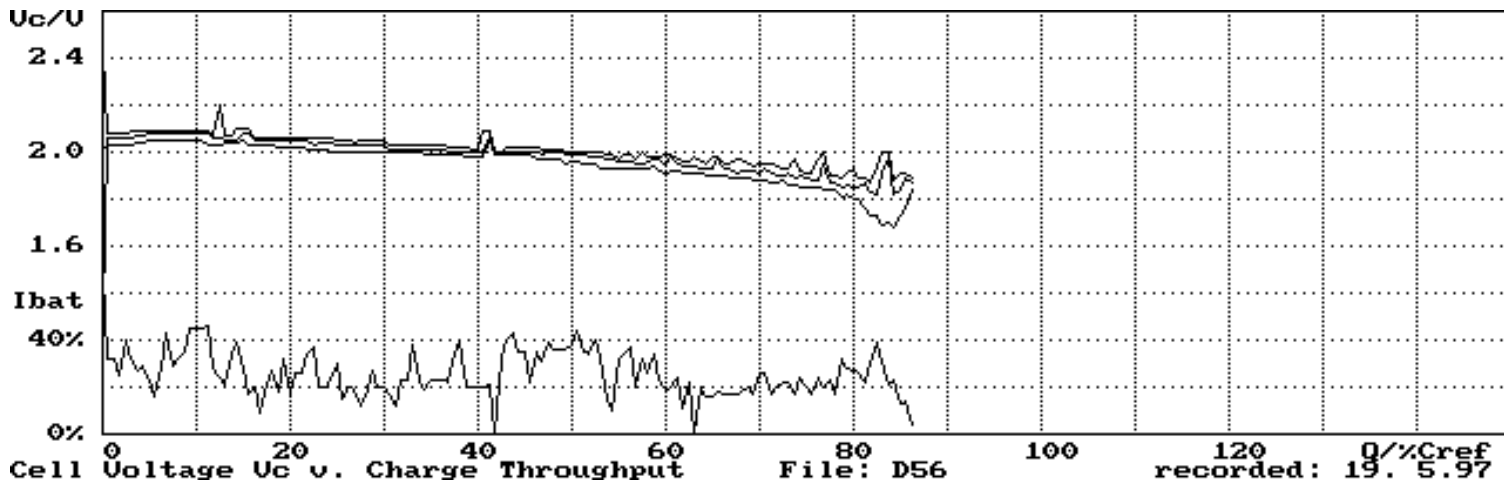
Preparations for the 1997 American Tour de Sol: the 1994 1/2 Solectria "Force" received new Electrosource, Inc. Horizon 85 Amp-hr. advanced lead acid batteries.

Daily Data from the Battery Management System

Monday

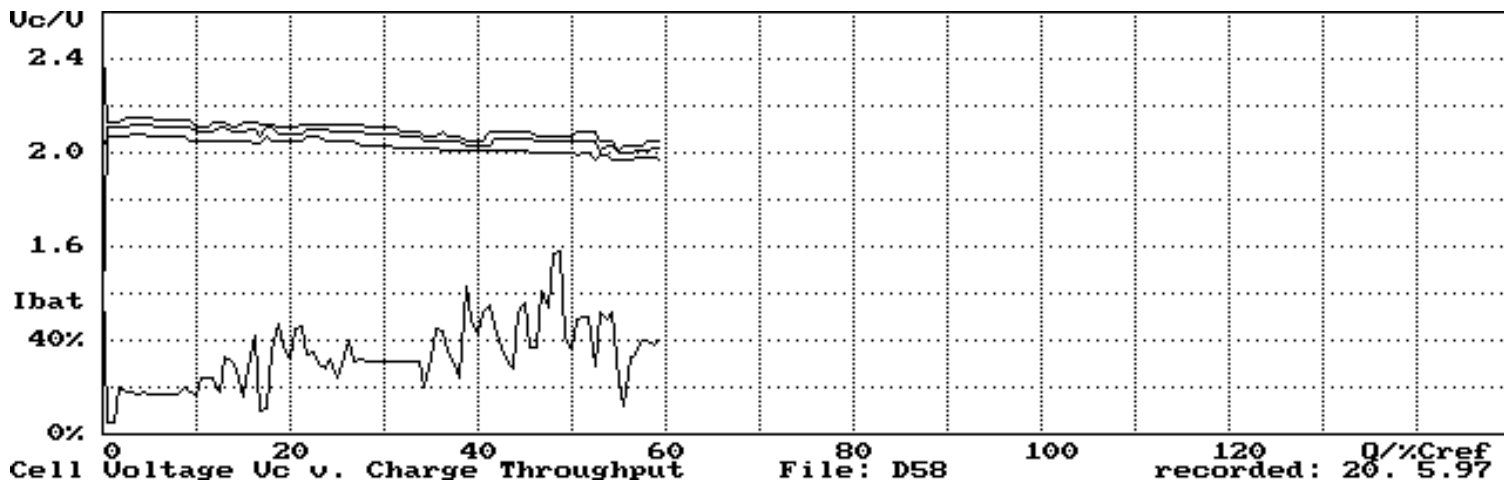


Car 50 on display in Waterbury, prior to start of first leg.

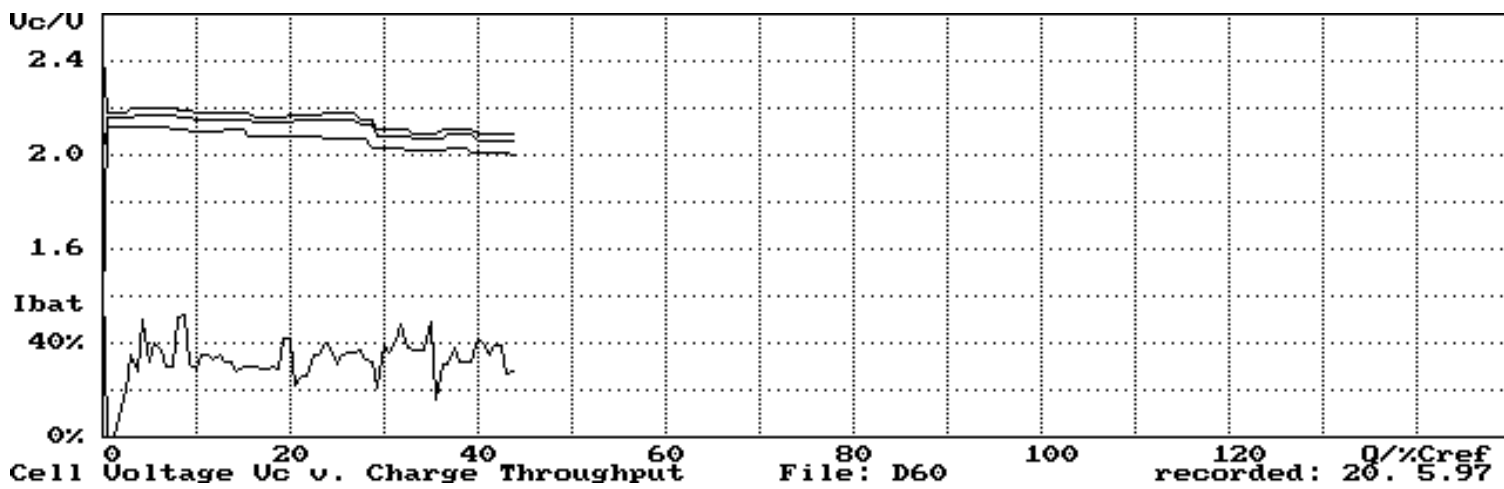


Discharge cycle No. 56 is a record of Leg 1 plus Extra Laps on Monday, 5-19-97. Data were recorded at 5:47 p.m. following the end of the last extra Lap. In total, 102 miles were driven over 262 minutes. The Leg began in Waterbury, Connecticut and ended in Northampton, Massachusetts. Elevations along the route began at 280 ft above sea level, rose to 975 ft and ended at 230 ft in the Connecticut river valley. Badicheq battery management system displayed a beginning value of 67 at full charge in the morning, and ended with 0 [E-6 error condition], indicating a full discharge. The kilowatt-hour meter began with 0 and ended with 13.38.

Tuesday

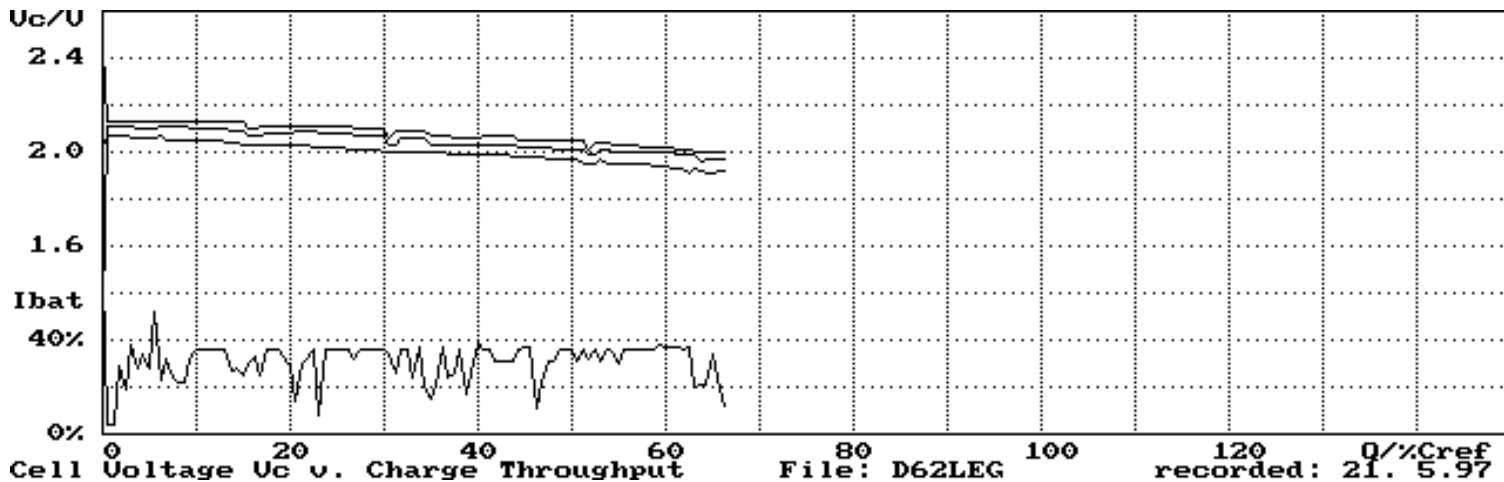


Discharge cycle 58 is a record of Leg 2 on Tuesday, 5-20-97, which ended at 2:44 p.m., Tuesday at ATdS, Leg 2 in the morning, where 62.6 miles were driven in this leg over 125 minutes prior to midday charging in Bellows Falls, Vermont. Elevations along the route began at 230 ft above sea level in Northampton, rose to 750 ft and ended at 390 ft in the Connecticut river valley. Badicheq began with 77 [ten percentage points higher than on Monday] and ended with 6; The kilowatt-hour meter began with 0.11 and ended with 9.22. Amp-Hour meter began with 0 and ended with 62.29.

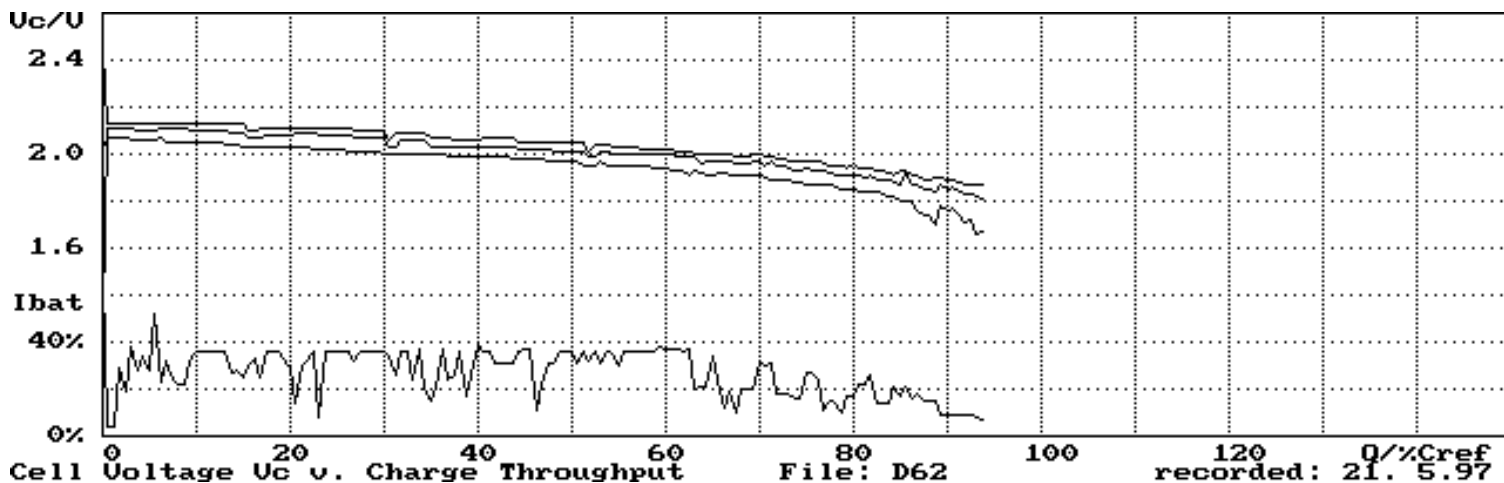


Discharge cycle 60 is a record of the late afternoon Leg on Tuesday, 5-20-97, which began at 5:45 and ended just before 7 p.m. in White River Junction, Vermont. This Leg followed midday recharging, and 45 miles were driven over 74 minutes. Badicheq began with 76 and ended with 23; kilowatt-hour meter began with 0 and ended with 6.97; and, Amp-Hour meter began with 0 and ended with 46.57.

Wednesday

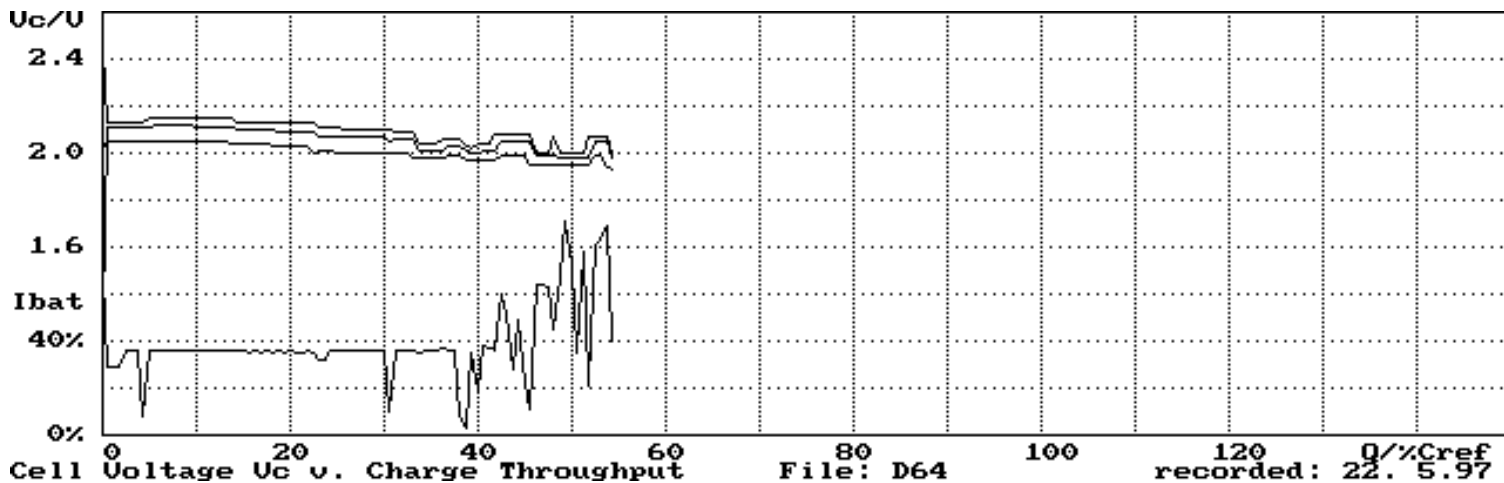


Discharge cycle 62 Leg is a record of Leg 3 on Wednesday, 5-21-97 and was recorded at 1:34 p.m., before beginning Extra Laps. The Leg was 68.4 miles long and was driven in 125 minutes. Elevations began in Vermont at 380 ft above sea level, rose to 1,880 along the route and ended in Lincoln at 980 ft. Without recharging, Car 50 initiated the Extra Laps at 2:10 p.m. in Lincoln, New Hampshire.



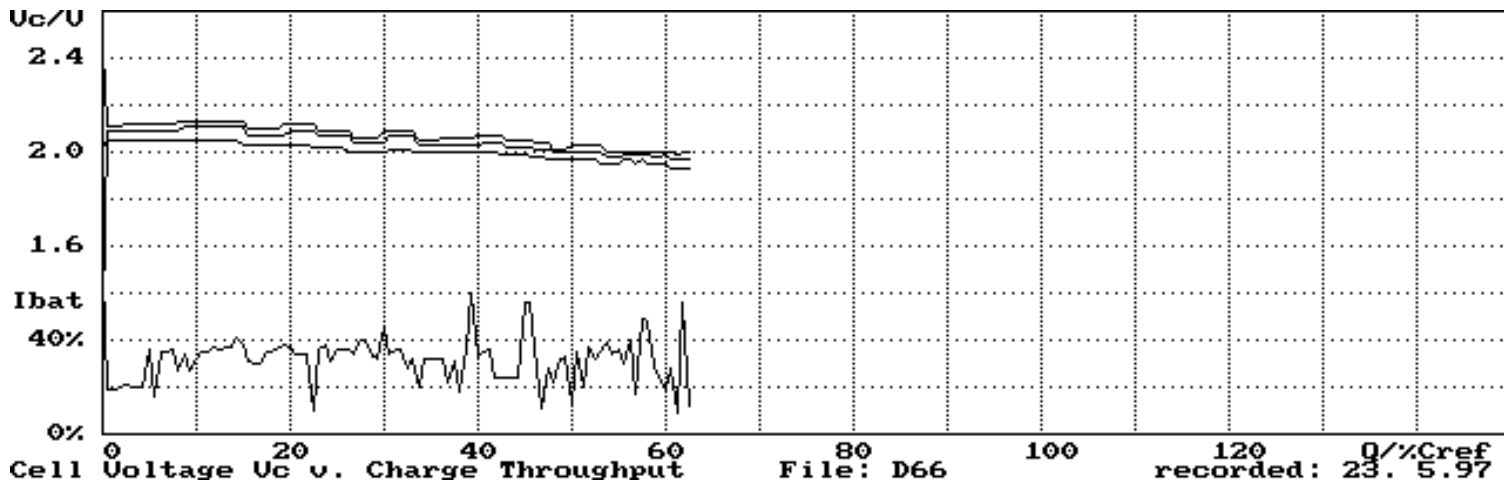
The final cycle 62 record was recorded on 5-21-97 at 5:58 p.m., Wednesday at ATdS, and comprises both Leg 3 and the Extra Laps, where total miles for the day was 104.4 over 198 minutes for an average speed of 31.6 mph. Badicheq began with 77 and ended with 0 [E-6 error message]; DC kilowatt-hour meter began the Leg with 0.11 and ended the extra laps with 14.40; and, Amp-Hour meter began with 0.70 and ended with 97.68, which exceeded the 85 Amp-Hour capacity rating of the battery pack.

Thursday



Discharge cycle 64 is a record of Leg 4 on Thursday, 5-22-97, which ended at 7:20 p.m. following public displays in North Conway, New Hampshire. Total driven this day was 51 miles and included an afternoon drive up to Cathedral Cliffs, which involved a drive up 19% grades to a fine view of North Conway and the surrounding mountains. The drive began at Lincoln, New Hampshire at 980 ft above sea level, rose to 2,800 ft along the route, and ended on North Conway, New Hampshire at 550 ft. The Leg alone was 41.2 miles and was driven in 75 minutes and required 5.99 kW-hours. The initial Badicheq reading was 88 and the end-of-day reading was 16; kilowatt-hour meter began the Leg with 0.08 and ended with 8.64; and, Amp-Hour meter began with 0.55 and ended with 57.36.

Friday



Discharge cycle 66 is a record of Leg 5 of ATdS on Friday, 5-23-97, recorded 5:56 p.m., following a drive to Portland and public display of the cars in a downtown area. Leg 5 was a 61.8 miles in length and driven in 101 minutes. Elevations began in North Conway, New Hampshire at 550 ft above sea level and ended in Portland, Maine at 110 ft. In late afternoon, all cars were driven a short distance from downtown Portland to South Portland. Badicheq began the day at 86 and ended with 18; kilowatt-hour meter began the Leg with 0.0 and ended with 8.87; and, Amp-Hour meter began with 0.57 and ended with 59.45.

For further information, contact James Sime by E-Mail.

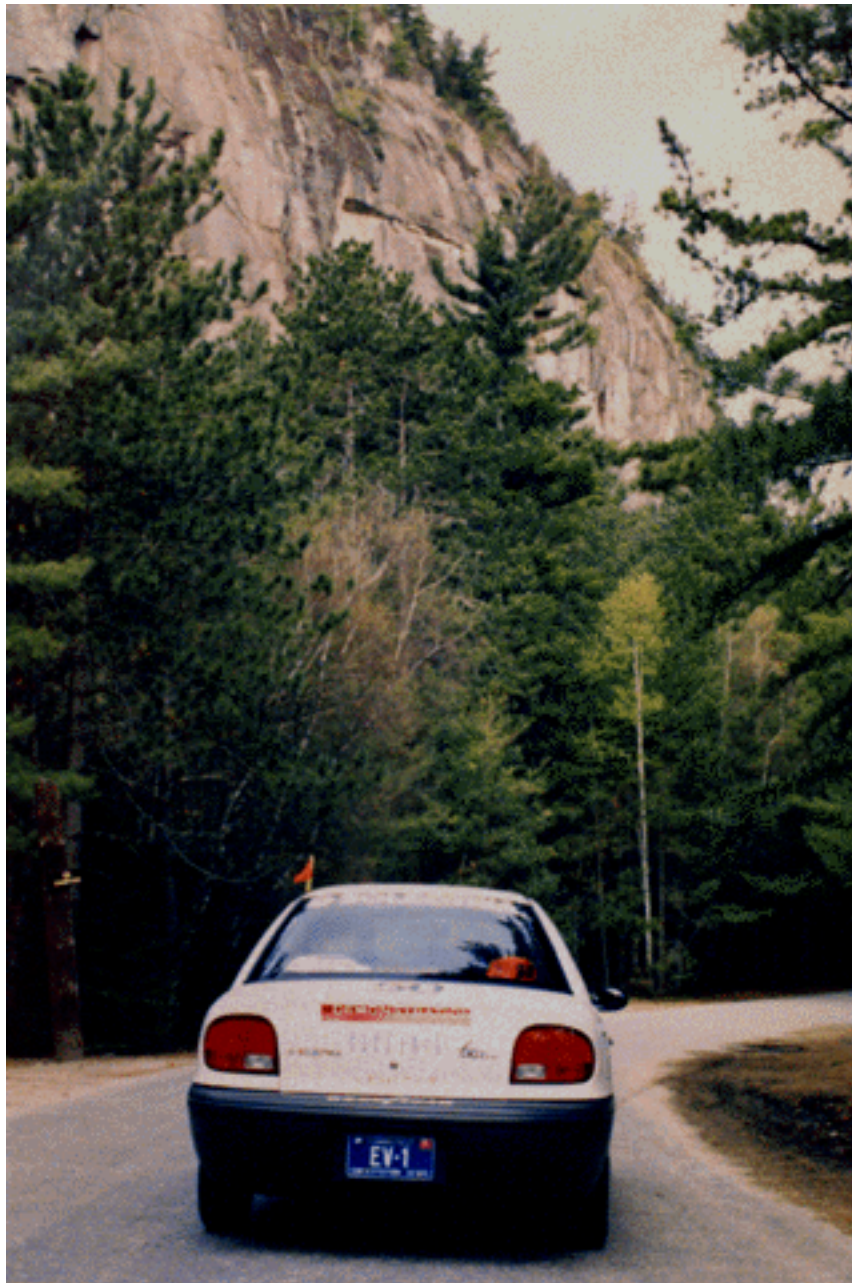
Connecticut Department of Transportation, Bureau of Engineering and Highway Operations, Division of Research

Electric Commuter Vehicle Evaluation in Connecticut

1997 American Tour de Sol



The drive up Mount Washington was canceled due to snowfall and an unplowed mountain road that day. As a consolation, rally organizers offered an optional drive to the top of Cathedral Cliffs outside North Conway, New Hampshire.



Car 50 (CT:EV-1) drives to base of Cathedral Cliffs outside North Conway, New Hampshire. The drive to the top followed, which included steep grades of nearly 20 percent.



View from the top of Cathedral Cliffs, North Conway, New Hampshire.

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Connecticut Department of Transportation, Bureau of Engineering and Highway Operations, Division of Research

Electric Commuter Vehicle Evaluation in Connecticut

Record of Preparations for Resumption of Commuter Evaluation and 1997 ATdS

March 19, 1997: Consultation with an engineering consultant included their modeling of energy use for the electric vehicle with a variety of possible batteries. It was determined that the Horizon battery pack could not be replaced with GNB batteries. GNB is a valve-regulated lead-acid battery with the following attributes: 170 W/kg, 85 Ah capacity, 35 Wh/kg, 85 Wh/l, 12 V, 29.1 kg per battery, and >400-cycle life at 70% DOD.[1] The low peak power of GNB was not projected to be able to provide the power necessary to climb hilly terrain during the second half of the discharge cycle. Also, the battery company could not provide a warrantee that met the needs of the Rideshare Co. Another battery, produced by Exide, was considered and rejected because its 80 Ah and power discharge characteristics were found to be unsuitable for hilly terrain in the consultant's vehicle-model projections.

Nominally, the attributes of the Horizon batteries appeared essential to the success of the electric vehicle. The vehicle was designed to utilize Horizon batteries with 95 Ah. The battery manufacturer is not currently producing this battery model and it was necessary to obtain thirteen 85 Ah Horizon batteries from the company. The 85 Ah Horizon battery is a smaller battery, but has improved chemistry. They are anticipated to provide the capability to expend bursts of energy late in its discharge cycle (near the vehicle's maximum range), as for passing and hill climbing. This capability is anticipated to be essential for the terrain of the route through the White Mountains of New Hampshire.

Arrangements were made to utilize and evaluate a higher-output battery charger, also. The vehicle comes equipped with a 3 kw 'smart' charger that draws a nominal 20 Amps on a 220 Volt circuit. A higher-output charger "10 kw charger" will provide a 5-9 kw charging rate, drawing either 30 or 50 Amps at 220 Volts. The 10 kw charger is compatible with the vehicle's computerized battery management system and according to our EV consultant, recent experience suggests that a higher charging rate is related to longer lived, 'healthier' batteries. It is anticipated the higher-rate charger will be advantageous because it provides quicker 'fill-ups.' The charger evaluation was anticipated to last several months.

The vehicle manufacturer recently agreed to loan the Rideshare Co. a NESEA-compliant Watt Meter for the 1997 Tour de Sol, as was provided in 1996. Goodyear Tire and Rubber supplied new high pressure, low rolling-resistance tires. Wheel alignment and the brakes were inspected and adjusted to ensure optimal safety and efficiency.

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[1] Reisner, D. E., "Commercial Off-the-Shelf (COTS) Batteries for Motive Power," US NANOCORP, Inc., North Haven, CT, 1996.

Electric Commuter Vehicle Evaluation in Connecticut

Developments following the 1997 ATdS

- At the final day at 1997 ATdS in Portland, ME, the battery level, as measured by BADICHEQ, was initially 88%. The car was driven in the Saturday motocross competition, followed by a drive downtown to a parking garage. Overall, 33 miles were driven on Saturday and 46.61 Ah were drawn from the battery. The car was parked until it was transported back to Connecticut on Monday, 5/29/97.
- Following participation in the 1997 American Tour de Sol (ATdS), Car 50 was returned to daily commuter service in Connecticut on Tuesday, 5/30/97.
- Daily data acquisition resumed in accordance with project requirements.
- At the 1997 ATdS, current draw had been limited to 30 Amps due to limitations on electrical amperage available from the charging trailer. Back in Connecticut after the ATdS, the battery charger Amperage circuit was switched to the 50 Amperage level. Plans were made to replace this off-board Lockheed-Martin charger with the more convenient on-board 12 Amp 220 Volt Mentzer battery charger. The Mentzer charger had been removed earlier in preparation for the ATdS.
- During March and April of 1998, the motor and belt drive system on the 1995 Force was upgraded. The car received a factory upgrade motor and beltless drive train, so under the hood it's now a 1998 Solectria Force. The original Solectria motor, model AC GV20 was replaced by a model AC GTX20. This new AC induction motor is a brushless sealed design and weighs 78 pounds (lbs.). It is compact and has extremely low electrical resistance. Nominal power of the GTX20 is 12 kW and nominal torque is 20 Nm, while maximum torque is 46 Nm. Nominal motor speed is 4,000 rpm, while maximum motor speed is 12,000 rpm. The belt drive assembly was replaced with the Solectria model AT1200 gearbox with the standard 12:1 gear ratio. The gearbox is lightweight, weighing 35 pounds. All thirteen Electrosource horizon batteries were replaced with a new set of 85 Amp Hour horizon batteries. Neocon Technologies Inc. replaced the on-board 12 Amp 220 Volt Mentzer battery charger with a 22 Amp 220 Volt K&W Charger, which has smaller variability in charging amperage levels than the Mentzer. This was thought to be beneficial for the ALAB. A longer cycle life was anticipated with the K&W charger. The charger is controlled by the Badicheq battery management system, which received a software upgrade. Also, the laptop computer and Badicheq laptop software were upgraded to the new Windows 95 version. For the past three years we have run Goodyear Invicta GL radial tires, size P155/80R13. This is a 44 psi tire with a tread wear rating of 280, traction rating A and temperature rating B. The Invicta weighs about 15 lbs. and has a maximum load rating of 959 lbs. (3,836 lbs. for a set of four). For the 1998 ATdS, Goodyear sent the Connecticut team Intrepid radial tires, size 175/70R13. This 44 psi tire has a rated load capacity of 1,047 lbs. (4,188 lbs. for four) and a tread wear rating of 380; traction rating A; and, temperature rating B. The Intrepid weighs about 16 lbs., 1 lb. more than the Invicta. The Intrepid has a 5.25 inch tire width, about 7/8 inch wider than the Invicta. However, the width of tire-to-pavement contact appears to be only 0.125 inch wider due to a rain channel running down the center of the tread (like

the Goodyear Aqua tread). We decided to pursue a comparison of EV efficiency with these two tires after the ATdS. The wider Goodyear Intrepid tire led us to purchase a wider wheel as well. We selected a 10 lb. Panasport 13x5.5 inch alloy wheel. The Intrepid/Panasport tire and wheel combination is approximately 2 lbs. lighter than the Invicta mounted on a steel wheel with hub cap.



Connecticut Department of Transportation, Bureau of Engineering and Highway Operations, Division of Research

Electric Commuter Vehicle Evaluation in Connecticut

1998 American Tour de Sol Results for Team 50

Overview

The 1998 ATdS began on May 8 in New York City, NY and finished in Washington, DC. The Connecticut entry, an electric production vehicle, won several competitive categories. The route traveled west from the Big Apple to Morristown, New Jersey; then south to Princeton, New Jersey (NJ); south to the Burlington County Institute of Technology, NJ; southwest to New Castle, Delaware (DE); south to Dover, DE; west to Sandy Point, Maryland (MD), near Annapolis; and, then westward into Washington, DC. The vehicle was driven 380.7 miles.

Team 50 Awards from 1998 Tour de Sol

"First Place in Production Category (PbA, Lead Acid Battery)"

"Best Sedan: Production Category (PbA)"

"Best Range: Production Category (PbA)"

"Certificate of Accomplishment: Production/PbA Category"

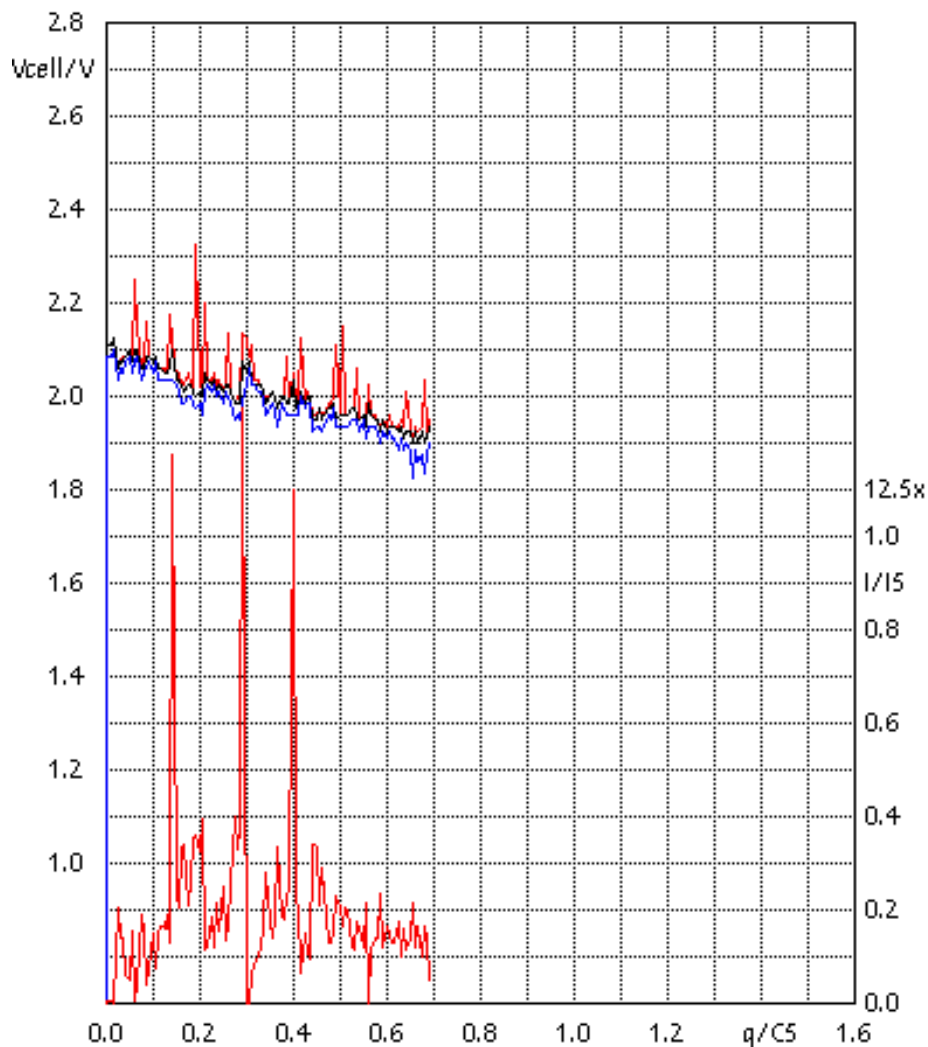
On a single charge with the 85 Amp-Hour batteries, the car was driven 97 miles on 12.77 DC kWh in Dover, DE.

[There were no ATdS Daily Efficiency Award at the 1998 ATdS.]

[Preparations for the 1998 American Tour de Sol](#) included: replacing the motor and drivetrain, battery pack, battery charger, tires, and wheels; and, updating the battery management system.

Daily ATdS Data from the Battery Management System

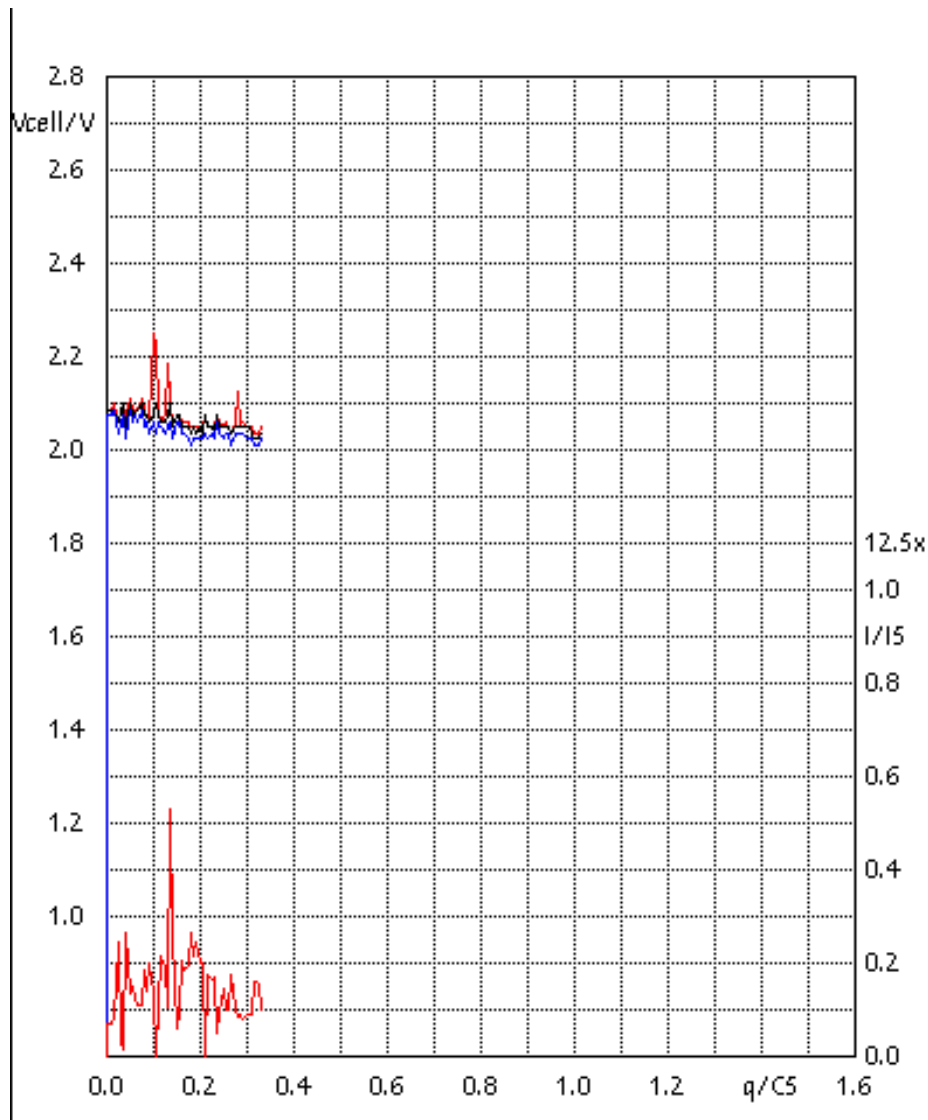
Sunday, May 10, 1998



Discharge cycle No. 006 is a record of Leg 1 plus Extra Laps on Sunday, May 10, 1998. In total, 71.3 miles were driven over 3:26:47 hours:minutes:seconds, which was 3:47 minutes:seconds to spare and utilized 9.98 DC kWh. The Leg began in Manhattan, New York City and ended the day in Princeton, New Jersey. There was no mid-day recharge at the stop and display in Morristown, NJ. Elevations along the route began at 10 ft above sea level, rose to 240 ft and ended at 35 ft in Princeton.

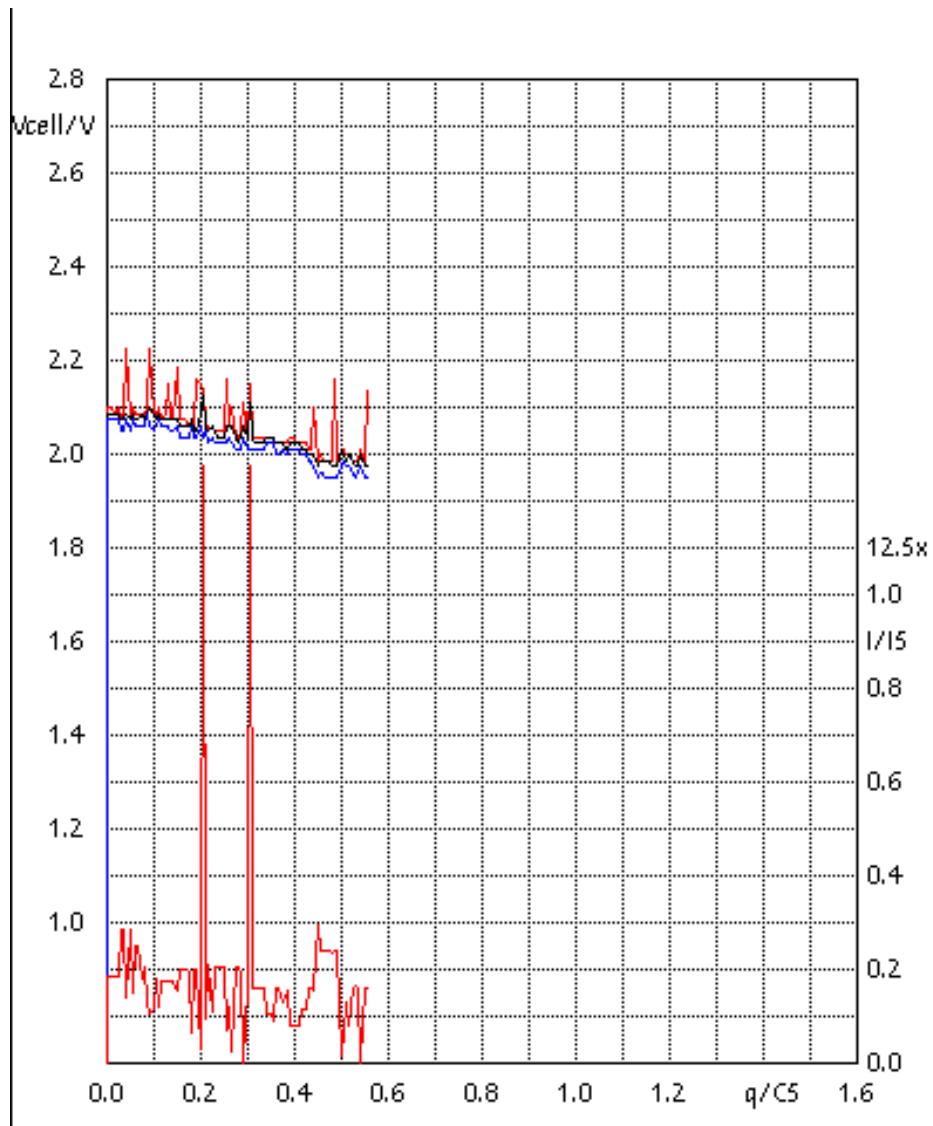
The Badicheq battery management system displayed a beginning value of 80 at full charge in the morning, and ended with 0 ["HALT" system warning], indicating an approximate 73% depth of discharge. Battery voltages at the end of the drive were on average 11.4 Volts. Battery #4 registered 10.9 Volts.

Monday, May 11, 1998



Discharge cycle No. 008 is a record of Leg 2 on Monday, May 11, 1998. The morning drive was the first of two Legs planned for Monday. It started in Princeton, NJ, and proceeding 37 miles south to the Burlington County Institute of Technology, NJ. The maximum time allowed for this leg was 1:40, so the minimum average speed needed to be 22.15 miles per hour (mph). Team 50 drove the Leg in 1:34:17, which is 5:43 early. Actual average speed was 23.55 mph. The elevation at the start was 35 ft above sea level in Princeton; it rose no higher than 200 ft along the route, and ended near sea level at the BCIT in NJ.

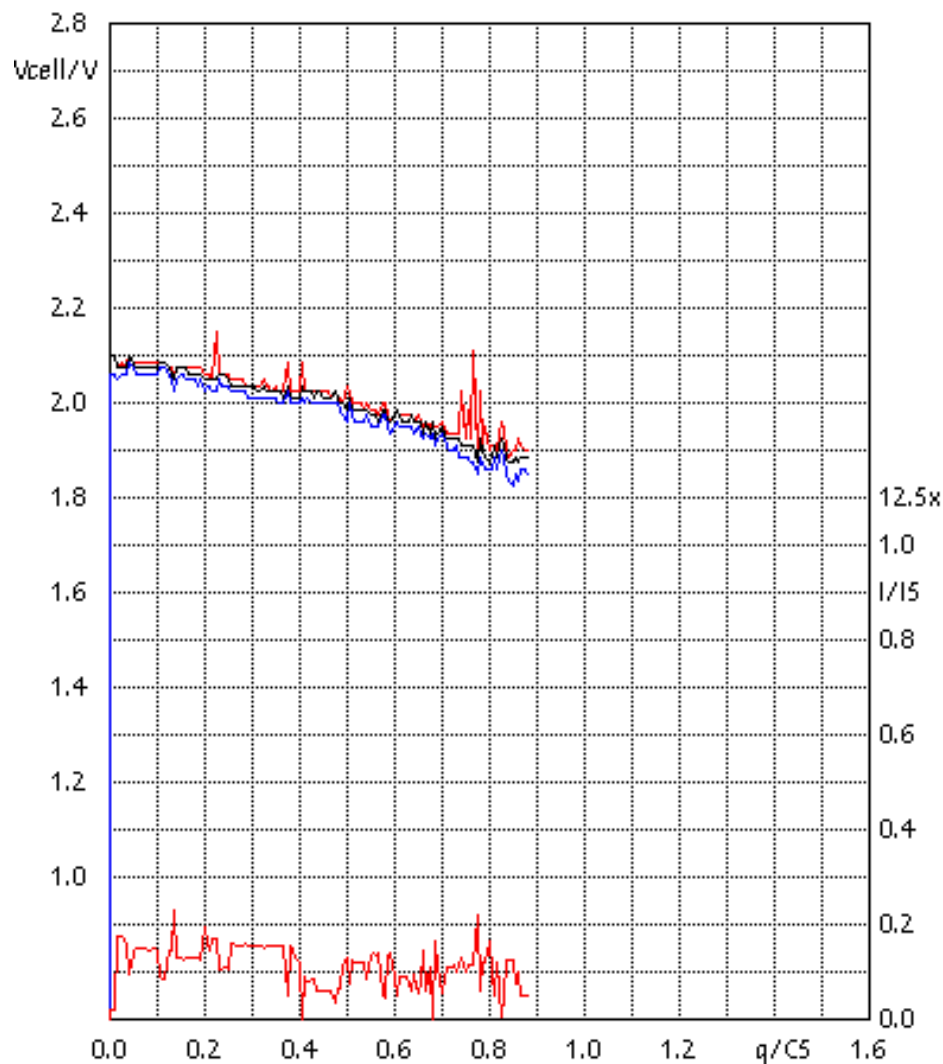
The Badicheq displayed a beginning value of 80 at full charge and ended Leg 1 with 41 remaining. Power use during the 37 mile drive was 4.87 DC kWh. The recharge required 6 AC kWh to recharge 4.81 DC kWh for a charging efficiency of 81%.



Discharge cycle 10 is a record of the late afternoon Leg on Tuesday, May 11, 1998, which began at 4:20 pm and was completed in 2:34:14, which was 5:46 (min./sec.) early. The actual average speed was 24.8 mph. Elevations began near zero in New Jersey, rose to between 150 and 200 ft above sea level in four locations and ended in New Castle, Delaware at about 20 ft above sea level.

The Badicheq began with 80 and ended with 13. The DC kilowatt-hour meter recorded 8.00 kWh consumed over the 63.66 mile Leg. The recharge required 12 AC kWh to recharge 8.41 DC kWh for a charging efficiency of 70%.

Tuesday, May 12, 1998



Discharge cycle 12 Leg begins as a record of Leg 1 on Wednesday, May 12, 1998, driven before beginning Extra Laps south of the Delaware Capital. The Leg was 55.0 miles long and was driven in 116 minutes.

Elevations began in New Castle, DE at about 30 ft above sea level, rose to about 140 ft at two locations along the Leg, and ended in Dover, DE at about 15 ft above sea level. Without recharging, Car 50 initiated the Extra Laps at 1:40 p.m. in Dover, Delaware.

BATTERY STATUS REPORT Date: 07.06.98 21:56:39

DATA SOURCE: D:\MENTZER\ver40\cod13.BAQ Ident: 1507491 RECORDED: 13.05.98 08:44:40

WORST BLOCKS: 1: 96% 2: 96% 3: 96% 4: 96% 5: 96% 6: 96%

CHARGE AND ENERGY:

CYCLES: 6 CHARGE/Ah OVERCH/Ah >80% ENERGY/kWh

TOTAL INPUT 247.9 0.6 332.0

TOTAL OUTPUT 314.9 0.0 20.0 366.0

DOD FREQUENCIES:

DOD/%: <5 <10 <20 <40 <60 <80 <90 <95

FREQUENCY 0 0 0 2 3 1 1 0

CYCLE DATA HISTORY:

CYC BA1-VOLT BA2-VOLT BA3-VOLT BA -BEST VTOT QST QDY QOV Q20 TEMPS TCY TAC STA

13 13 15.0 12 15.0 8 15.0 1 14.5 15.0 95 0 0 0 15 25 11 99F...

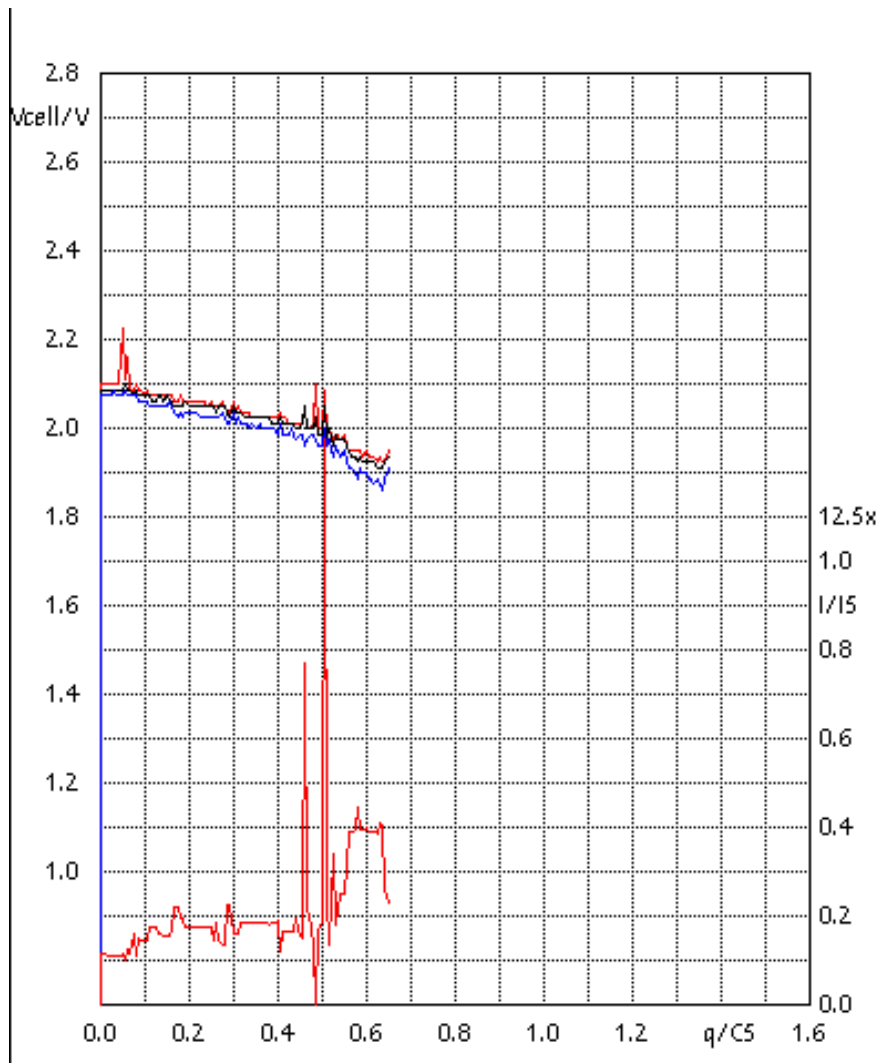
12 4 10.9 7 11.0 3 11.1 2 11.2 11.2 89 6 0 16 15 20 11 44

Data for cycle #12 was recorded on May 12, 1998 at 6:00 p.m., Tuesday at ATdS, and comprises the combination of the 55-mile Leg, nine (9) Extra Laps, the drives to the lap area, the return to the Capital area, as well as the early evening drive to the charging area. Team 50 drove their EV a total of 97 miles that day on 12.77 DC kWh. The recharge required 19 AC kWh to recharge 13.29 DC kWh for a charging efficiency of again 70%.

Badicheq reached the "HALT" when the reading declined to zero during the ninth Lap. Team 50 drove the final 7-8 miles back to the Capital and on to the charging area by driving slowly and constantly viewing the Badicheq voltage readings by way of the laptop computer.

To avoid damaging the battery, the Team cut off driving Laps when the Badicheq dash instrument readout declined to a reading of 2-3. The day ended with a reading of 12.88 DC kWh usage for 97 miles, as compared with last year's 14.4 DC kWh for a 104.4-mile drive. That equates to 7.53 miles per DC kWh in 1998 on flat terrain, and 7.25 miles per DC kWh in 1997 over mountainous terrain. Both the 1997 ATdS drive and this drive in 1998 exceeded the 85 Amp-Hour capacity rating (3-hour rate) of the battery pack.

Wednesday, May 13, 1998



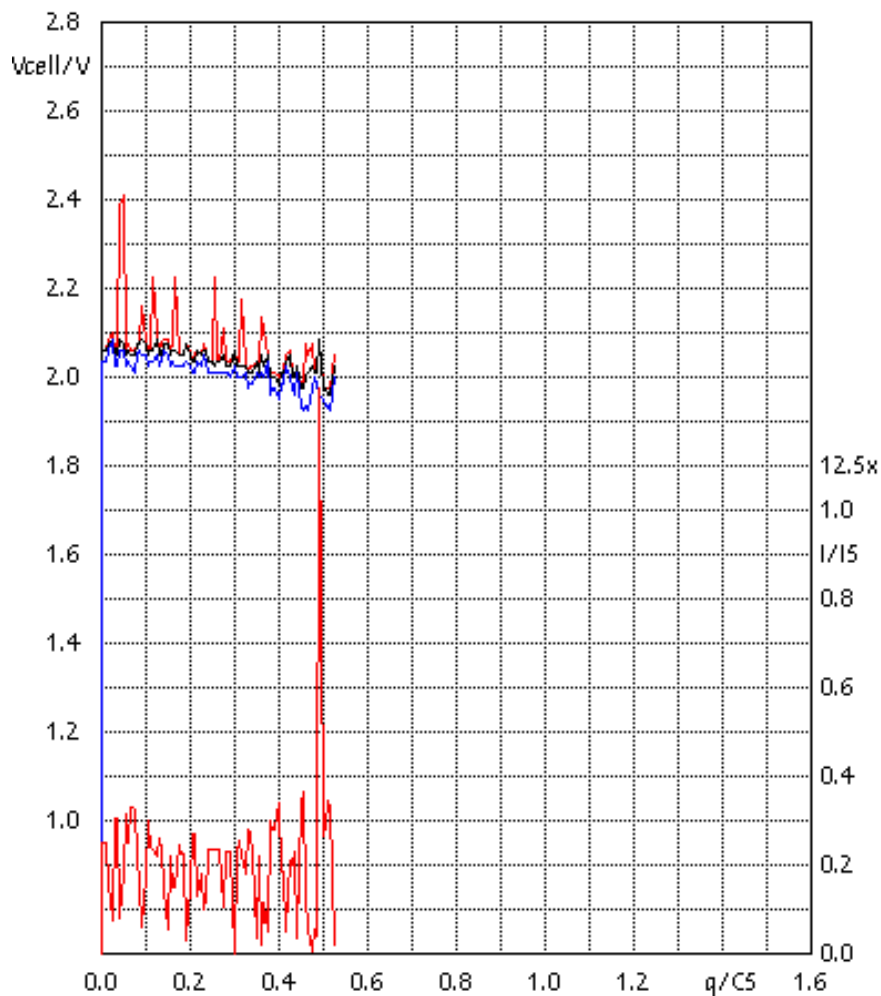
Discharge cycle 14 is a record of Leg 4 on Wednesday, 5-13-98, which began in Dover, Delaware at the Polytech School. The drive on the morning leg was 68.7 miles long, concluding at the Sandy Point State Park in Maryland. Team 50 drove the Leg in one hour and 58 minutes for an average speed of just under 35 miles per hour (mph). Elevations began at the start of the leg at 18 feet above sea level, rose to nearly 150 ft about twenty miles into the leg, and ended in Sandy Point, MD back down at about 10 ft above sea level.

The 68.7-mile Leg required 9.35 DC kWh or about 62.38 Amp-hours from the ALAB, which has a 72 Amp one-hour rating.

The initial Badicheq reading was 80 and the end-of-Leg reading was 1. Mid-day charging for one hour was allowed before the Autocross and 1/8th mile acceleration tests were run in the afternoon. After one hour of charging, 2.77 DC kWh in additional energy (18.58 Amps) was stored in the battery pack, raising the Badicheq reading from 1 to 33.

Top speed in the single 1/8th mile acceleration test was 54 mph. The two completed autocross circuit times were 30.581 and 30.135 seconds.

Thursday, May 14, 1998



Discharge cycle #18 is a record of the final Leg of ATdS on Thursday, 5-14-98, recorded following a drive to the Arlington, Virginia staging area. This final Leg was 44.9 miles in length and driven in 1 hour and 46 minutes, for an average speed of 25.4 mph. Elevations began in Sandy Point, Maryland at 10 ft above sea level, rose to about 100 ft along the route, and ended in Arlington, Virginia at 20 ft above sea level. Badicheq began the day at 80 and ended in Virginia with 21; 6.01 DC kilowatt-hours were consumed (40.1 Amp-hours).

Shortly after completion of the Leg, all cars were driven about 5 miles in parade fashion with police motorcycle escort into downtown Washington, D.C. for a public display of the cars in an area adjacent to the Capital building.

[For further information, contact James Sime by E-Mail.](#)

Connecticut Department of Transportation, Bureau of Engineering and Highway Operations, Division of Research

Electric Commuter Vehicle Evaluation in Connecticut

Last updated March 11, 1999

- Following the 1998 American Tour de Sol (ATdS), CT:EV-1 resumed service in daily commuting and for work trips.

- Daily data acquisition resumed in accordance with project requirements.

- Fifty cycles were completed by the first week of July, 1998. A pattern was developing in the battery management system data that indicated the voltage in battery #4 was consistently low. On July 5, 1998 data from cycles #45-50 were sent via Email to Neocon Technologies for their analysis.

- On July 20, 1998 the two spare Electrosorce 85 Amp-Hr batteries were delivered to Neocon Technologies for testing. Testing will determine which of the 15-month-old spare batteries is the better one to replace battery #4 in CT:EV-1.

- Cycle #74 was reached on August 18, 1998. The car was operated daily during this period. However, that evening the charger malfunctioned and the battery pack was not recharged. Plans were made to install a new K&W charger and replace battery #4 at the same time.

- By August 25, 1998 the K&W charger had been removed from the car and shipped to Neocon Technologies for troubleshooting. Neocon Technologies shipped a temporary replacement Solectria 3 kW charger.

- On August 29, 1998 CT:EV-1 was driven 23 miles after charging on the Solectria 3 kW charger. The voltage level in battery #4 collapsed to 9.8 Volts at about ten (10) miles into the drive, while the rest of the battery pack (12 other batteries) operated normally throughout the drive at between 12 and 11.6 Volts. An "E-6" error message registered on the driver display due to the low voltage level of battery #4.

- On August 29, 1998, daily driving was suspended until all repairs (install a new K&W charger and replace battery #4) are completed.

- On October 29, 1998, a new K&W charger was installed. On October 30, 1998 a replacement for battery #4 was installed. The replacement battery is one of two spare batteries purchased eighteen months earlier and held in storage.

- Daily service and data collection resumed on November 1, 1998 with five short (12- to 24-mile) drives between recharges intended to bring the battery back up gently to higher capacity usage levels.

- From November 1 to 27, 1998 the car was driven on 25 days for a total of 685 miles. Distances driven between recharges ranged from 12 to 41 miles. Two-thirds of the drives (18) ranged between 20 and 35 miles between recharges. The four highest distances driven were 35, 38, 40, and 41 miles. The three shortest drives were 12, 16,

18, and 19 miles. The median and mode were both 28 miles (on six occasions the car was driven 28 miles); while the mean distance was 27.4 miles.

- Battery #4 had been taken from storage and installed. This replacement battery was a concern throughout November due to its lower voltage levels, observed during each and every drive cycle.
-
- On the evening of November 27, 1998 the K&W charger failed to complete the charge cycle. The charger was removed the following week and shipped to NEOCON for diagnostics. Without the charger, daily driving was suspended. Data collection was ended at ALAB cycle #106.
-
- In January 1999, the focus of the project shifted to data analysis. Once completed, a draft final report will be prepared to present project findings. The K&W charger was replaced by the manufacturer with a new model in late February. The ALAB batteries are being removed in March and the car will be retrofitted with 15 kWh Nickel-cadmium batteries.
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Connecticut Department of Transportation, Bureau of Engineering and Highway Operations, Division of Research

Electric Commuter Vehicle Evaluation in Connecticut

1998 - Final Year of ALAB Evaluation

- Discussions took place about the future of the electric vehicle in this project. An energy budget model for a fuel-cell hybrid was prepared by engineers at Neocon Technologies in December, 1997. The model addressed the effect on driving-range extension of a small power generator. A small fuel cell outputting a constant 1.2 kW showed a potential to extend the range between 70 and 150 miles above it's demonstrated 60-70 miles between charges, assuming the vehicle was driven on flat terrain at 30-35 mph.
- There was interest in the concept of extending the range of the vehicle to a more practical 150-200 miles between recharging while maintaining zero emissions. A small fuel cell would be more affordable than a large unit and may have practical application as an EV range extender. The computerized battery management system can be configured to turn the fuel cell on and off in relation to the battery charge/recharge state.
- Another possibility was to use a larger 5 kWh fuel cell combined with a smaller battery or a capacitor.
- A third possibility was to utilize the vehicle as a test bed for a different battery with the potential to provide not less than a 100-mile range, as it appears this will be required for small EVs to be viable state fleet cars in Connecticut.

OUTCOME --

- One battery with excellent characteristics is the Lithium-ion battery. The battery, still in prototype at battery manufacturers, has a specific energy that is 120 Watt-hours per kilogram, 140% higher than the specific energy of a Nickel-cadmium battery. The implication is that range of our typical subcompact EV could increase from 70 miles to over 210 miles for the same weight of batteries carried in the car. This would almost certainly provide for most in-state daily driving-range needs of state employees. Unfortunately, the Li-ion battery is not anticipated to be in production until 2005 and pricing is undefined.
- Another battery with very good characteristics is the Nickel-metal Hydride (NiMH) battery. The battery, which went into production in November 1998 at the Ovonic company, provides 70 Watt-hours per kilogram, 40% greater power storage capacity than the NiCd battery. Unfortunately the 40% increase in specific energy cost 392% more than the NiCd battery. The range of the Solectria Force subcompact has been established by others (Boston Edison for example) and is about 90 miles in daily driving for a 16 kWh battery pack (253 kg), which is 61 kg lighter than the 15 kWh NiCd (314 kg). Others have installed more of the lighter weight NiMH batteries in the Solectria Force to achieve longer driving range. If the car carried 23,300 Wh (314 kg) of NiMH batteries, the range of the car would be approximately 130 miles.
- In November 1998 we learned that the New Jersey DOT had contracted with a fuel

cell manufacturer in their state to procure a 3 kW fuel cell for installation in their Solectria Force. The car will use 100 Ah water-cooled SAFT Nickel-cadmium batteries (NiCd). Neocon Technologies will integrate the fuel cell into the Solectria Force. Neocon engineers project the range will be extended to 400 miles in the American Tour de Sol (ATdS).

- In January 1999 we decided to remove the failed ALAB battery pack and retrofit the car with 100 Ah water-cooled SAFT Nickel-cadmium batteries (NiCd) batteries. The anticipated range is 70 miles at 80% DOD in day-to-day driving. The range attainable under ATdS conditions for Connecticut's EV is anticipated to be 120 miles.
- The Connecticut and New Jersey DOT electric cars are the same make and model. They will have the same battery type. Both cars have the newer direct drive transmissions.
- From an experimental-design vantage, the Connecticut car can act as the "control" vehicle for the New Jersey car with experimental range-extending fuel cell. For this reason, Connecticut and New Jersey DOT researchers have agreed to share data gathered from their respective vehicles.

Connecticut Department of Transportation, Bureau of Engineering and Highway Operations, Division of Research

Evaluation of a CSLAB Electric Car
by an
Independent Auto Testing Facility

March 1996

An evaluation plan was established on January 25, 1996 for an electric vehicle (CT motor vehicle registration #EV-2) with conventional sealed lead acid battery (CSLAB), a retrofitted 1995 Geo Metro four-door sedan. The Connecticut Commuter Electric Vehicle Demonstration Project (CCEVD) panel endorsed the plan and James M. Sime (JMS) of the Connecticut Department of Transportation, Division of Research, made final arrangements with an independent auto testing facility (IATF). The plan calls for the CSLAB car to be evaluated twice this year. The first evaluation will be described in this report. The second will be scheduled for warmer weather later this year when temperatures are above 15.6'C (60'F). Based on experience IATF personnel gain from their initial evaluation, it is anticipated they may modify subsequent evaluations.

The car was driven to the testing facility on February 5, 1996 in temperatures between -18'C (0'F) and -10'C (14'F). The cold-weather evaluation concluded on February 13, 1996 and the car was driven back to the Hartford area on February 15, 1996. During this week-long evaluation, various IATF staff members drove the CSLAB car. The EV evaluation included: acceleration tests; range tests; weighing the car; and, driver evaluations of vehicle performance under normal driving conditions, the IATF's standard 48.3 km (30 mile) trip circuit, a 1.6 km (1 mile) urban-trip circuit, and for commuter trips.

IATF personnel had just completed an evaluation of a 1996 four-door Geo Metro and did not repeat evaluation elements common to both cars. The IATF provided this Geo to Mr. Sime for his daily driving needs during the period IATF evaluated the CSLAB car. The driving experience provided useful first-hand information to Mr. Sime about the characteristics of an unmodified Geo.

VEHICLE WEIGHT

IATF personnel weighed the CSLAB car and calculated the payload capacity. Comparative information about the 1996 Geo Metro Sedan demonstrates the negative effect on the load-carrying capacity of a retrofitted Geo Metro chassis.

Car	Std. 1996 Geo Metro	1995 Electric Geo (EV-2)
Weight (Wt.)	936.7 kg (2065 lb)	1182.1kg (2606 lb)
Rated Maximum. Wt.	1248.3 kg (2752 lb)	1248.3kg (2752 lb)
Net Payload Capacity	311.6 kg (687 lb)	66.2kg (146 lb)
Front/Rear Weight Ratio (%)	61/39	48/52

RIDE, COMFORT & TIRES

The CSLAB car comes equipped with high-pressure (high capacity) tires rated at 303.4 kPa (44 psi) for a combined total capacity of 1740 kg (3836 lb). The CSLAB car was delivered to IATF with tires inflated to 303.4 kPa (44 psi). All IATF testing was performed with all four tires inflated to 303.4 kPa (44 psi). IATF personnel noted that handling and ride were not as good as a conventional Geo, and observed that the combination of the different weight distribution of the CSLAB car and its high-pressure tires were the principle factors. Transient handling and ride were slightly improved by lowering the front tire pressure to 234.4 kPa (34 psi).

IATF personnel took note of the considerable noise made by the car at normal driving speeds. IATF personnel observed that the manufacturer had since changed to a direct drive versus the belt drive on the CSLAB car. Direct drive is reported to be quieter than a belt-drive system. No measurements were made of the noise level in the CSLAB car at various operating speeds.

PERFORMANCE

Acceleration tests were performed with a full battery-charge level and at the maximum power-saver setting. Temperatures during acceleration tests were -5.5'C (22'F).

Kilometers per Hour (Miles per Hour)	Elapsed Time in Seconds	
	Std. 1996 Geo Metro	1995 Electric Geo (EV-2)
0-48.3 (0-30)	5 sec.	10 sec.
0-80.5 (0-50)	NA	25 sec.
0-96.6 (0-60)	15.3 sec.	35 sec.
72.4-104.6 (45-65)	NA	not tested
0.4 km (quarter mile)	20.4 sec.	27 sec.

The 0-96.6 (0-60) test required 0.64 km (0.4 miles) to reach its speed. The top speed reached in 0.4 km (quarter mile) was 83.7 km/hr (52 mph). The test was run only in the downwind direction. It is anticipated the CSLAB car's acceleration will be documented at 16.1 km/hr (10 mph) intervals [0-16.1, 0-32.2, 0-48.3, etc.(0-10, 0-20, 0-30, etc.)] in the next (Spring 1996) evaluation. The IATF director noted that the U.S. Advanced Battery Consortium (USABC) has a short-term goal for electric cars of achieving 0-80.5 km/hr (0-50 mph) in 12 seconds. Its mid-term goal (within 10 years) is to achieve 0-96.6 km/hr (0-60 mph) in 9 seconds. A USABC cost constraint is to provide these levels of performance at a per-car cost of less than \$4,000 for batteries.

FUEL ECONOMY (electrical efficiency)

Two types of range tests are commonly performed by IATF: a circuit on secondary roads and an urban circuit.

A 48.3 km (30 mile) circuit on secondary roads was driven twice. Maximum range achieved was 49.9 km (31 miles) and the CSLAB car required towing back to the IATF facility after one of the two range tests. Maximum battery draw down achieved in the range tests was 57 Amp Hours (Ah) according to the dashboard-instrument. The vehicles entered reduced-power mode at around 40 Ah and the CSLAB car was driven to exhaustion in the reduced-power mode.

The 1.6 km (1 mile) urban circuit proved to be the most efficient, but provided the shortest 'range, achieving only 16.1 km (10 miles) before the test was halted. It was necessary to halt this test when the CSLAB car could no longer maintain an average speed of 48.3 km/hr (30 mph) on the circuit. This test was conducted at 7.2'C (45'F). In the analysis section of the draft report compiled by IATF, fuel economy based on the urban circuit was recorded as a 22.5 km (14 mile) range that consumed 6 kWh, which included the qualifying 16.1 km (10 miles) in the urban circuit.

IATF personnel in their evaluation included commuting. Only IATF personnel living within the cold-weather driving range of the CSLAB car participated in this portion of the evaluation. Overall, IATF personnel accumulated 247.8 km (154 miles) of driving during their week-long evaluation, including 27.4 km (17 miles) for the acceleration tests.

The IATF Director observed that the short- and mid-term single-charge range goals of USABC are 160.9-201.2 km (100-125 miles) and 321.7 km (200 miles), respectively.

OTHER EVALUATION ELEMENTS

Numerous customary IATF automobile-evaluation elements were NOT performed because they were duplicative of IATF's recent evaluation of the 1996 Geo Metro Sedan. Routine and emergency handling and braking from 96.6 km/hr (60 mph) under wet and dry pavement conditions were not addressed. Evaluators did not comment on the reduced trunk space of CSLAB. IATF personnel commented informally about the differences in dashboard instrumentation, noting especially the added complexity of a preheat controller, which was successfully reset by IATF personnel for their daily commute schedule(s)

ANALYSIS & COMMENT BY IATF ANALYST, E.A. Petersen

IATF ran a series of tests to assess the vehicle's energy efficiency using controlled track procedures, and local commutes. Accessories were used to provide heating and defrosting. Energy consumed by accessories is

included in the aggregate quantity used by the vehicle. Listed below is a summary of the IATF results, along with data obtained by ConnDOT for the month of January, and the manufacturer claims.

Ambient Temperature *C('F)	Data Source	Time Period	Miles Driven km (mi)	kWh consumed	km/kWh (mi/kWh)	Cost/km* (cost/mi)
7.2(45)	City Course	NA	22.5 (14)	6	3.75 (2.33)	\$0.023 (\$0.037)
-5.6(22)	Accel.Testing	NA	27.4 (17)	9	3.04 (1.89)	\$0.028 (\$0.046)
-15 to 7.2(5-45)	Overall @ IATF	NA	247.8 (154)	76	3.27 (2.03)	\$0.026 (\$0.042)
-8 to 10(17.6-50)	ConnDOT data	11/95	957.6 (595)	297	3.22 (2.00)	\$0.027 (\$0.043)
-15 to 12(5-53-6)	ConnDOT data	12/95	928.6 (577)	381	2.43 (1.51)	\$0.035 (\$0.057)
-15.5 to 17 (4.1-62.6)	ConnDOT data	1/96	862.6 (536)	337	2.56 (1.59)	\$0.034 (\$0.054)
-5.5 to 18 (22.1-64.4)	ConnDOT data	2/96	804.7 (500)	256	3.14 (1.95)	\$0.027 (\$0.044)
-6.4 to 30.7 (20.5-87.3)	ConnDOT data	3/96	978.5 (608)	292	3.35 (2.08)	\$0.026 (\$0.041)
			Manufacturer's Claims (range)		8.95-12.4 (5.55-7.70)	\$0.010-\$0.00 (\$0.015-\$0.011)

*Note: Average cost per kW across the country: \$0.086

IATF estimates the fuel economy of a conventional gasoline-powered 1995 Geo Metro (1.3 liter, three-speed automatic) at 8.1 km/l (19 mpg) on the City Course and 12.3 km/l (29 mpg) overall, city/highway. With gasoline at \$0.32/l (\$1.20/gallon), cost per kilometer (per mile) on the City Course is \$0.040/km (\$0.063/mile) and \$0.061/km (\$0.041/mile) for an overall average.

Under ideal conditions the manufacturer claims a capacity of 9.6 kWh for the lead acid batteries. This would provide a range of 96.6 km (60 miles) with an efficiency of 10.1 km/kWh @ 72.4 km/hr (6.25 miles/kWh @ 45 mph). Typical IATF driving in cold weather drained the battery pack in approximately 48.3 km (30 miles), operating at an efficiency of 3.27 km/kWh (2.03 miles/kWh). Surprisingly, this would indicate a battery storage capacity of 14.5 kWh, well beyond that stated by Solectria. The measurement of input energy is responsible for the disparity between the two parties. IATF measures the total input energy (from the wall socket to the car.). In reality, only a portion of the input energy gets to the motor. In recharging alone, consumed energy is by the batteries and the energy management system. The batteries themselves have a storage efficiency of only 75%. Very cold weather can also place a significant burden on the energy management system that maintains battery-operating temperature. When parked, the vehicle must always be recharging for the

energy management system to work properly. As substantial as these losses are, the manufacturer does not include them in their efficiency claims.

Incidentally, once the vehicle is in motion, additional parasitic losses come into play: motor efficiency (typically 85-90%), motor controller efficiency, tire rolling resistance, drive train friction, brake drag, accessory power usage, and wind drag. Some of these items are quite significant. For instance, the efficiency will drop in half from 32.2 km/hr to 112.7 km/hr (20 mph to 70 mph), due to wind and mechanical drag alone.

The manufacturer says their electric vehicle tends to operate more efficiently in low speeds and city type of driving, whereas internal combustion vehicles do better at higher speed/steady state conditions. The only exception is hard acceleration, wasteful in energy to both types of vehicles.