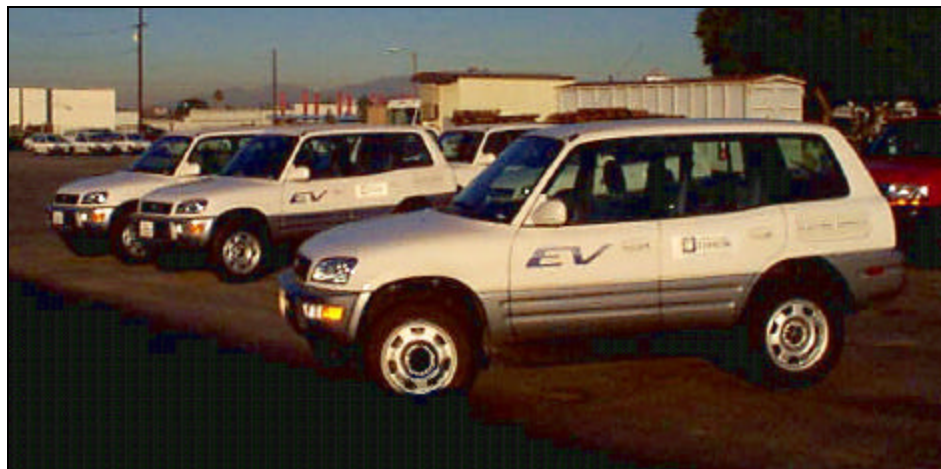


INEEL/EXT-2000-00100  
March 2000

***Field Operations Program  
Toyota RAV4 (NiMH)  
Accelerated Reliability  
Testing – Final Report***



**J. Francfort  
J. Argueta  
J. Smith  
M. Wehrey**

**Field Operations Program  
Toyota RAV4 (NiMH)  
Accelerated Reliability Testing - Final Report**

**J. Francfort<sup>1</sup>  
J. Argueta<sup>2</sup>  
J. Smith<sup>2</sup>  
M. Wehrey<sup>2</sup>**

**Published March 2000**

**Idaho National Engineering and Environmental Laboratory  
Automotive Systems and Technology Department  
Idaho Falls, Idaho 83415**

**Prepared for the  
U.S. Department of Energy  
Assistant Secretary for Energy Efficiency and Renewable Energy  
Under DOE Idaho Operations Office  
Contract No. DE-AC07-99ID13727**

---

<sup>1</sup>INEEL/Bechtel BWXT Idaho, LLC.

<sup>2</sup>Southern California Edison



## EXECUTIVE SUMMARY

The U.S. Department of Energy's Field Operations Program evaluates electric and other advanced technology vehicles in real-world applications and environments. Information generated by the Program is targeted at fleet managers and others considering the leasing and deployment of advanced technology vehicles. The Program subjects vehicles to several types of performance and operations tests; this report only addresses the accelerated reliability testing of three Toyota RAV4s by Southern California Edison (SCE). Vehicles subjected to accelerated reliability tests are driven in "normal" environments with the goal of each vehicle accumulating 25,000 miles within 1 year. For additional information on testing and other Program activities, visit the Program's web site at <http://ev.inel.gov/sop>.

SCE personnel used the three RAV4s primarily as commuter vehicles. Each vehicle was driven an average of 478 miles per week, with daily roundtrip commutes ranging from 60 to 120 miles. An additional 20 to 30 miles per vehicle, per day were also driven for daytime activities (lunch, business meetings, etc.). During the 1-year test period, the three vehicles accumulated 20,060, 24,561 and 25,643 miles respectively (23,421 miles average). The largest difficulty with placing miles on the vehicle is finding sufficient driving time. (The vehicle with the lowest mileage was damaged while being transported on a flatbed truck at a test track.)

The three vehicles all performed very well and all of the drivers reported high confidence in the accuracy of the state-of-charge meters. Except in hot weather, about 5 hours was required for a full charge. The RAV4 is equipped with a charging timer, allowing charging to commence at night when the air and vehicles were cooler. The drivers did report a minor problem with the interlock for the conductive connector. However, Toyota has started providing the RAV4s with inductive connectors and chargers, and this will be the Toyota standard in the future. The three vehicles ranged from 87 to 108 miles per charge and it appeared that the higher the ambient temperature, the longer the range. Energy use averaged 2.5 miles per AC kWh (0.4 AC kWh per mile). Besides the normally scheduled 6-month preventive maintenance, the only repairs included three tire punctures, the replacement of a leaking brake booster pump, and the before-mentioned damaged caused while a vehicle was towed to a test track.

As a testament to SCE's faith and commitment in the RAV4s, they have 245 RAV4s in active fleet service. These vehicles have been driven over 2 million miles. SCE has a total of over 300 active electric vehicles of various makes and models, and their total electric vehicle fleet experience is 3.5 million miles.



# CONTENTS

EXECUTIVE SUMMARY.....	iii
ACRONYMS.....	vii
1. INTRODUCTION.....	1
2. TEST PROTOCOL.....	3
3. TEST IMPLEMENTATION .....	4
4. VEHICLE PERFORMANCE.....	6
5. ENERGY USE.....	11
6. VEHICLE MAINTENANCE AND REPAIR.....	14
7. TIRE WEAR.....	15
8. CONCLUSION.....	16
Appendix A—Toyota RAV4 Electric Vehicle Memory Effect Investigation.....	A-1

# FIGURES

1. Some of Southern California Edison’s Toyota RAV4s being charged with a Yazaki conductive connector. ....	2
2. ABB kilowatt meter installed on a RAV4. It is located on the front of the passenger side of the RAV4. ....	5
3. 240V electric outlets with NEMA 14-50 receptacles .....	5
4. Electric Vehicle Supply Equipment (for charging) mounted on a cart. (from the Electric Vehicle Infrastructure Company). ....	5
5. Accumulated (monthly) mileage for the RAV4 test vehicles. ....	6
6. Monthly mileage accumulated for each vehicle.....	7
7. Urban Pomona Loop range testing results. Vehicle 2 was not tested during fall of 1998. ....	8
8. Range testing results for the three RAV4s. The bottom scale is the average temperature at test time and the left scale is the range result in miles. ....	10
9. AC kWh demand for Vehicle 3 (24 hours).....	13

10. AC kWh demand for Vehicle 3 (two weeks)..... 13  
11. Part of Southern California Edison’s fleet of RAV4s..... 16

**TABLES**

1. Profile of vehicle users..... 4  
2. Periodic range testing results for the three RAV4s..... 9  
3. ABB AC kWh meter and mileage data..... 12  
4. Tire tread measurements..... 15

## ACRONYMS

AC	Alternating current
DOE	U.S. Department of Energy
ETA	Electric Transportation Applications
EVSE	Electric vehicle supply equipment
EVTC	Electric Vehicle Technical Center
F	Fahrenheit
INEEL	Idaho National Engineering and Environmental Laboratory
kWh	kilowatt-hour
mm	Millimeter
NEMA	National Electrical Manufacturers Association
NiMH	Nickel metal hydride (battery)
QVTs	Qualified Vehicle Testers
SCE	Southern California Edison Company
SOC	state-of-charge





# **Field Operations Program Toyota RAV4 (NiMH) Accelerated Reliability Testing - Final Report**

## **1. INTRODUCTION**

The Field Operations Program and its predecessor, the Site Operator Program, were established by the U.S. Department of Energy (DOE) to implement electric vehicle activities dictated by the Electric and Hybrid Vehicle Research, Development and Demonstration Act of 1976. In the ensuing years, the Program has evolved in response to new legislation, interests, and technologies. The Program's goals include evaluating electric vehicles in real-world applications and environments, advancing electric vehicle technologies, developing infrastructure elements necessary to support significant electric vehicle use, and increasing the awareness and acceptance of electric vehicles. Personnel of the Idaho National Engineering and Environmental Laboratory (INEEL) manage the Field Operations Program. To support the field evaluation of electric vehicles, during 1996 DOE selected two Qualified Vehicle Testers (QVTs) through competitive bids. One of the QVTs is Southern California Edison Company (SCE). The other QVT is a consortium led by Electric Transportation Applications (ETA), with other members consisting of Arizona Public Service, Salt River Project, and Potomac Electric Power Company. For a more complete description of Program activities, Program reports, and test results, visit the Program's website at <http://ev.inel.gov/sop>.

One of the field evaluation tasks of the Program is the accelerated reliability testing of commercially available electric vehicles. These vehicles are operated with the goal of driving each test vehicle 25,000 miles within 1 year. Since the normal fleet vehicle is only driven approximately 6,000 miles per year, accelerated reliability testing allows an accelerated life-cycle analysis of vehicles. Driving is done on public roads in a random manner that simulates normal operations. Data is collected and reported through the INEEL.

This report summarizes the accelerated reliability testing of three nickel metal hydride (NiMH) equipped Toyota RAV4 electric vehicles by the Field Operations Program and its testing partner, SCE. The three vehicles were assigned to SCE's Electric Vehicle Technical Center (EVTC) located in Pomona, California, and were assigned vehicle numbers 24191, 24192, and 24193 (referred to in this report as Vehicles 1, 2, and 3). The vehicles were randomly selected from SCE's RAV4 fleet. At the time of this writing, the SCE fleet had 245 RAV4 electric vehicles.

The purpose of SCE's involvement in evaluating electric vehicles, electric vehicle chargers, batteries, and related items is to support their safe and efficient use and to minimize potential utility system impacts. The following issues support SCE's testing activities:

- As a fleet operator and an electric utility, SCE uses electric vehicles to conduct its business.
- SCE must evaluate electric vehicles, batteries, and charging equipment to make informed purchase decisions.

- SCE must determine if there are any safety issues with electric vehicle equipment and their usage.
- SCE has a responsibility to educate and advise its customers about the efficient and safe operation of electric vehicles.



**Figure 1.** Some of Southern California Edison's Toyota RAV4s being charged with a Yazaki conductive connector.

## 2. TEST PROTOCOL

During 1997, test procedures were developed to govern the conduct of the Field Operations Program. Specifically, in October 1997 SCE developed the “Accelerated Reliability Testing Procedures” for the Field Operations Program. These and all of the Program’s test procedures are available from the Program’s Internet web site at <http://ev.inel.gov/sop/newMenu3.html>. These procedures define the specific requirements for the operation, maintenance, and ownership of electric vehicles; and guide the conduct of the accelerated reliability testing of the three RAV4s. ETA, DOE, and the INEEL provided input to the test procedures. Each vehicle placed into testing was evaluated in accordance with the Accelerated Reliability Testing Procedures.

### 3. TEST IMPLEMENTATION

To accumulate 25,000 miles within 1 year of testing, SCE assigned the vehicles to employees with long commutes that lived within the vehicles’ maximum range. With charging at home and at the workplace, high daily mileage could be achieved. Occasionally, the normal drivers did not use their vehicles because of vacation or business travel. In that case, SCE attempted to find other personnel to continue the test.

**Table 1.** Profile of vehicle users.

Vehicle Number	1	2	3
Normal round-trip commute (miles)	60	120	82
Other daily mileage - lunch, business, etc. (miles)	50 (1-2 times per week)	20 - 30	10 - 40
Average weekly mileage	410	501	524

All of the vehicles were equipped with on-board kilowatt-hour meters to record the vehicles’ energy use. The meters recorded charging start times and duration, and they support vehicle charging system diagnostics in case of difficulties. The meters can store up to 6 months of data when recording at 15-minute intervals; however, they were downloaded quarterly. The meters were programmed so that the date, time, and average energy demand were recorded for each 15-minute interval. The total energy for each interval was also calculated after the meter information was downloaded. The data was compiled and processed for SCE’s quarterly Electric Vehicle Fleet Status Report and the Field Operations Program’s web page.

SCE’s EVTC developed a meter installation specifically for electric vehicles. Using a type A1T-L single-phase kilowatt-hour (kWh) recording meter from ABB corporation, EVTC engineers removed the meter from the ABB-supplied base and installed it in a National Electrical Manufacturers Association (NEMA) enclosure. This enclosure allows installation for most vehicles and electric vehicle supply equipment (EVSE) hardware. SCE reached an agreement with Toyota to install and operate the meters. No vehicle modification was necessary for meter installation (Figure 2).

240-V electric outlets with NEMA 14-50 receptacles were installed at the drivers’ private residences. The typical installation is shown in Figure 3. EVSE units (from either SCI Systems or Electric Vehicle Infrastructure) were prepared for the users to use at their residences by mounting them on carts (Figure 4). The units had NEMA 14-50 plugs, allowing easy connection to the electrical service. After the infrastructure was installed, the drivers were instructed in the operation of the electric vehicles and informed of the Accelerated Reliability Testing procedures and requirements.



**Figure 2.** ABB kilowatt meter installed on a RAV4. It is located on the front of the passenger side of the RAV4.



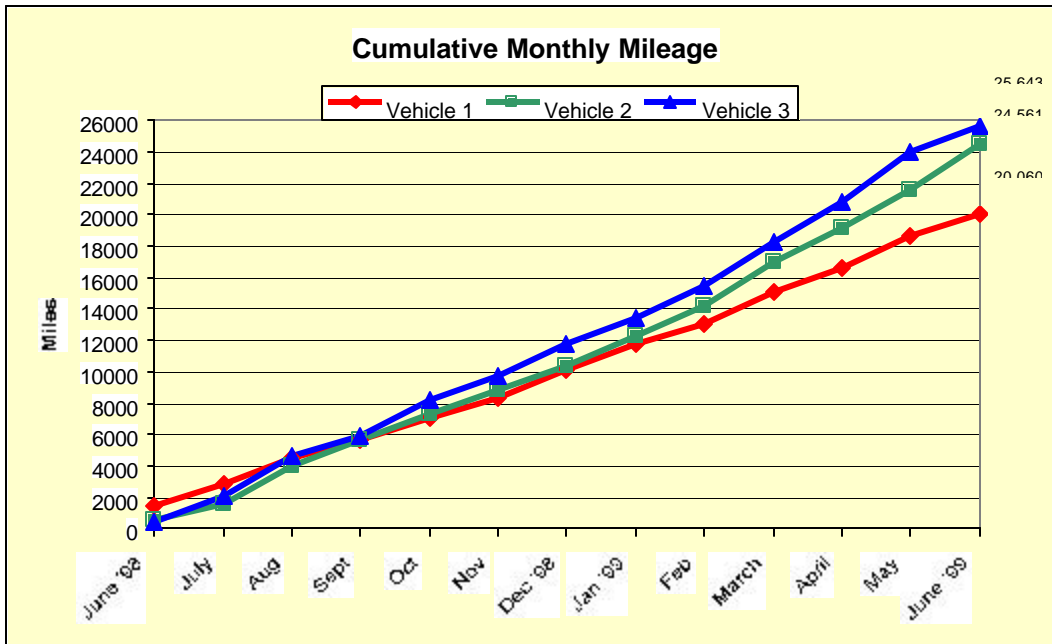
**Figure 3.** 240V electric outlets with NEMA 14-50 receptacles



**Figure 4.** Electric Vehicle Supply Equipment (for charging) mounted on a cart (from the Electric Vehicle Infrastructure Company).

## 4. VEHICLE PERFORMANCE

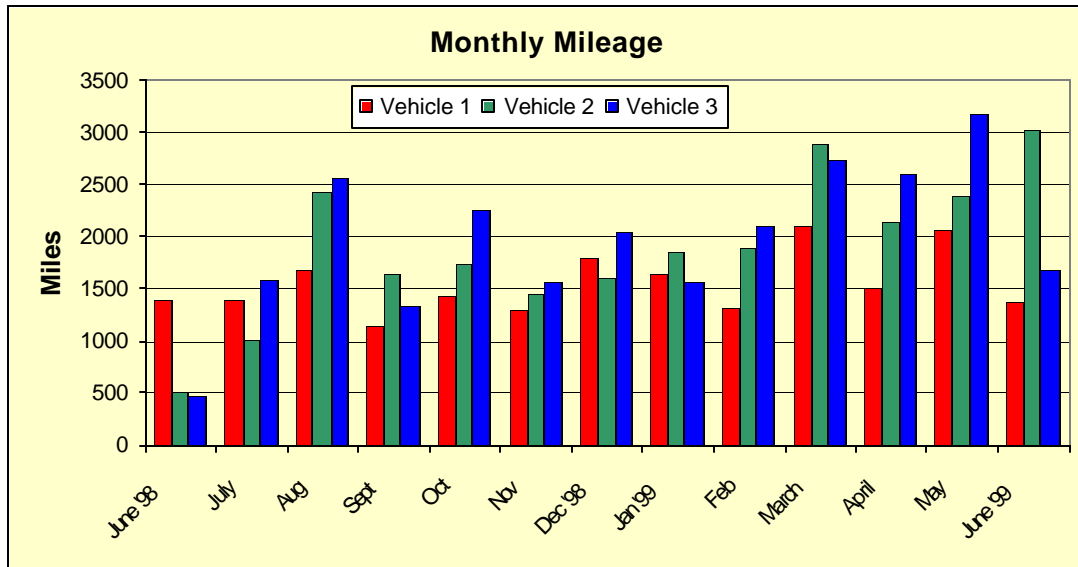
The final odometer readings for the three RAV4s for the year ended June 30, 1999 were 20,060 (Vehicle 1), 24,560 (Vehicle 2) and 25,643 miles (Vehicle 3). The miles accumulated each month is shown in Figure 5. The monthly mileage, as shown in Figure 6, varied by as much as 1,800 miles when the vehicles were in service. This variance was generally not due to the vehicle being out of service or unavailable; more miles were accumulated when personnel and time were available to drive extra cycles, and it was lower if the primary driver was unavailable (vacation or travel). All of the vehicles were new when testing began in late June 1998, with 8 to 17 miles on the odometers.



**Figure 5.** Cumulative (monthly) mileage for the RAV4 test vehicles.

Two (Vehicles 2 and 3) of the three vehicles made the goal of 25,000 miles (on average). The third (Vehicle 1) did not reach the goal, but it was not due to any failure of the vehicle (which worked flawlessly). Vehicle 1 was out of service for two weeks after an accident; the vehicle was struck on the roof and windshield by a tree branch while being transported on a flatbed truck. (The vehicle was being transported to a test tract for a periodic range test.)

The only problem the RAV4 drivers had was finding enough time to drive the vehicles. The driver for Vehicle 1 had a normal commuting distance of about 60 miles, which was much shorter than the others were (Table 1). Also, the other two vehicles were stationed at a facility where other employees could drive extra miles during the day. The vehicles were also occasionally taken away from the users for short periods for interim performance testing or preventive maintenance.



**Figure 6.** Monthly mileage accumulated for each vehicle.

The RAV4 drivers used the vehicles for almost all of their driving needs during the test year; the only limits were range and terrain. Longer weekend excursions required using the family’s gasoline-powered car. The lack of public charging stations compatible with the RAV4’s Yazaki conductive connector affected the users occasionally; one-way travel was limited to only half the available range if no charging was available at the destination. Any mountainous driving would dramatically increase energy use. Instead of eight to fifteen miles range per division on the RAV4’s state-of-charge (SOC) gauge, in the mountains it was two to three miles when driving uphill. According to the SOC gauge, at the most, approximately 20% of the energy used going uphill could be regained with regenerative braking when going downhill. All of the drivers had confidence in the vehicle’s SOC gauge and were comfortable estimating the available range.

Charging time was not a major impediment to vehicle availability. Charging was usually very predictable, reliable, and relatively brief (about five hours for full charge – except in hot weather). When charging in hot weather, the RAV4s would sometimes stop charging before reaching full SOC due to high battery temperatures. Also, charging time was increased as cooling fans operated longer. However, the RAV4 is equipped with a charging timer that allows users to manage charging times. This timer was very effective in managing hot weather charging by allowing delayed charging until late at night.

One precaution that should be taken, according to the RAV4 drivers, was to make sure the charging coupler was fully and securely inserted into the vehicle charge port. On one occasion, the coupler was inserted into the receptacle, but not so far enough to lock the thumb latch. The voice announcement on the EVSE (model ISC-200 from *Electric Vehicle Infrastructure*) indicated that charging was beginning; however, since the coupler was not latched, charging did not begin. The user found that the vehicle had not charged when he returned.

The thumb latch is Toyota’s interlock device for telling the vehicle whether the coupler is connected. It is possible to release the thumb latch, which interrupts (or prevents) the charging process, and leave the coupler in the vehicle. The vehicle will also allow the driver to drive the vehicle with the coupler still attached. This can lead to damage of the EVSE equipment or the cable being ripped out if the EVSE is fastened to a structure. SCE fleet users damaged several of

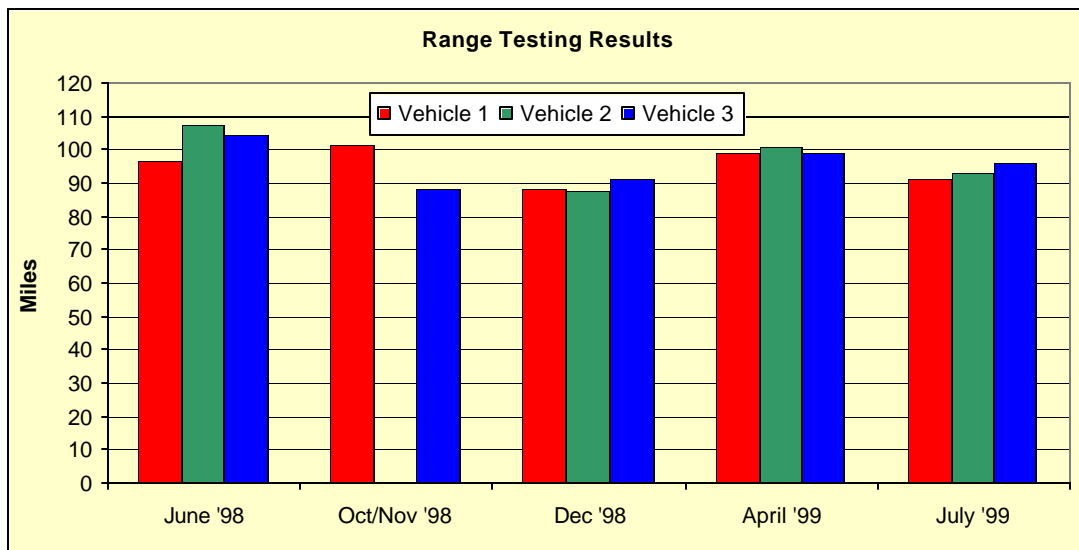


SCE's EVSE units in this fashion; none of the participants in the reliability test damaged an EVSE unit or attempted to drive with the charge coupler attached. Toyota's interlock device for the Yazaki conductive connector apparently does not comply with SAE recommendations for preventing the vehicle from being driven with the coupler attached and requires driver caution. All three test vehicles came equipped with the conductive connector. It should be noted that Toyota has announced that future RAV4s will be equipped with inductive connectors.

The RAV4s were range tested when they were delivered to SCE and during subsequent evaluations. Testing was conducted on the "Urban Pomona Loop" (a city driving route of approximately 20 miles with about 50 traffic signals and stop signs) with minimum payload (driver only) and no auxiliary loads. Most of the tests (Figure 7) were conducted with all three vehicles following each other in order to minimize the effects of varying ambient conditions, traffic, and driving style. The final ranges listed in Table 2 are the mileage readings when reaching the "stop condition" (flashing charge light).

As seen in Table 2, the range for all three vehicles varied from 87.5 miles to 107.5 miles. The reasons for the variation in range are not completely clear. However, the most obvious possibilities are declining battery capacity, the effect of ambient temperature on battery capacity, and the so-called "memory effect." Although the range varied directly with ambient temperature (Figure 8), the data was not clear enough to make a definite conclusion; several causes probably contributed.

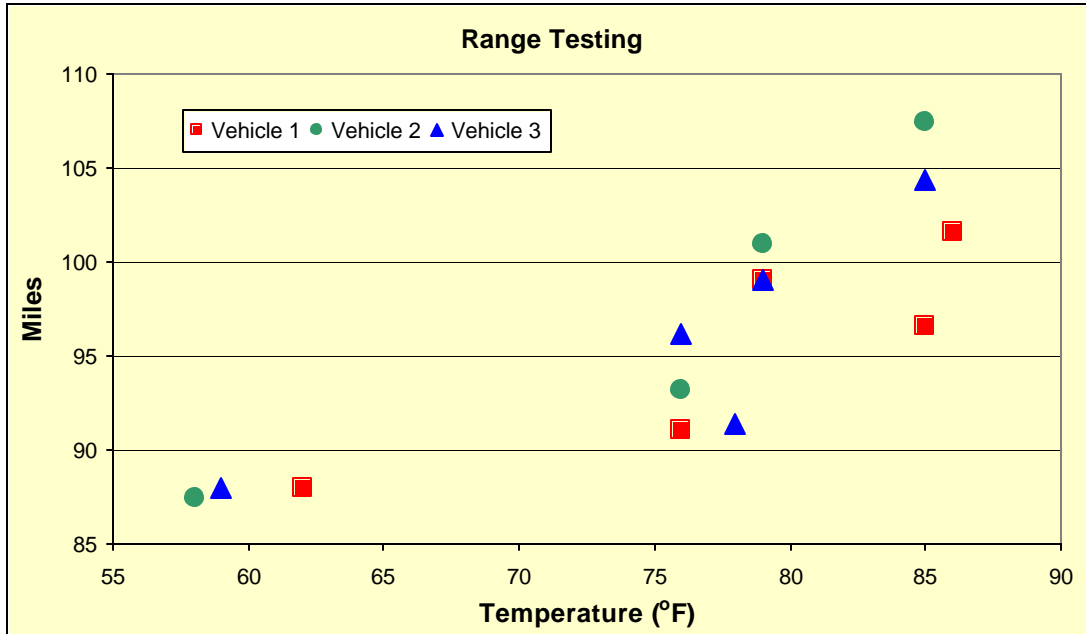
A special investigation was conducted at the end of the test period to examine the memory effect of the Panasonic NiMH battery in the Toyota. Two of the vehicles were selected and tested initially for range. For 1 month, one vehicle was driven only short distances, and one was driven to full range each time. Final range tests showed a small, but noticeable effect. In relative terms, the range of the short-drive vehicle declined 5.6%. For further details, a summary of the test is included in Appendix A, at the end of this report.



**Figure 7.** Urban Pomona Loop range testing results. Vehicle 2 was not tested during fall of 1998.

**Table 2.** Periodic range testing results for the three RAV4s.

Vehicle No.	Date	Odometer (miles)	Average Temperature (F)	Range (miles)
<b>1</b>	6/26/98	8	85	96.6
	10/5/98	5,733	86	101.6
	12/3/98	8,446	62	88.0
	4/14/99	15,744	79	99.0
	7/1/99	20,056	76	91.1
			Average Range	95.3
			Standard Deviation	5.6
<b>2</b>	6/26/98	10	85	107.5
	12/3/98	9,010	58	87.5
	4/14/99	17,533	79	101.0
	7/1/99	24,560	76	93.2
			Average Range	97.3
			Standard Deviation	8.8
<b>3</b>	6/29/98	17	85	104.4
	11/30/98	9,679	59	88.0
	12/29/98	11,458	78	91.4
	4/14/99	19,248	79	99.0
	7/1/99	25,643	76	96.2
			Average Range	95.8
		Standard Deviation	6.4	
		Overall Average Range	96.0	
		Overall Standard Deviation	6.4	
		Minimum	87.5	
		Maximum	107.5	



**Figure 8.** Range testing results for the three RAV4s. The bottom scale is the average temperature at test time and the left scale is the range result in miles.

Regardless of the cause of lower range, it is a concern to the users when they can no longer drive as far as they used to, and complaints were recorded to that effect. Early in the test, one driver could make the home and work 82-mile round trip without charging; several months later the vehicle no longer had sufficient capacity for the round trip without charging. The drivers drove most of their miles on the freeway and experience showed (fleet use, EVTC testing, and EVAmerica baseline performance testing) that range can be significantly lower on the freeway. The EVTC test vehicles have demonstrated as much as a 14% range reduction for Freeway Loop drives (with 65 mph speed limits) compared to Urban Pomona Loop drives. The EVAmerica testing also demonstrated a 22% reduction in range at higher speeds when the constant speed 60 mph and 45 mph test results are compared. The reasons for the lower highway efficiency includes the RAV4's low aerodynamic efficiency; its relatively low mass compared to heavier electric vehicles, which means the effect of accelerating during urban drives is less of a factor; and the higher energy discharge rate that occurs during freeway driving.

Drivers found that they could greatly extend range by altering driving style. By accelerating slowly, coasting downhill, and driving slower than the flow of traffic, drivers could get 75% more range per SOC gauge division than when driving rapidly (14 miles per division versus 8 miles).

Acceleration tests were also conducted periodically. At a drag strip, accelerations were timed at various SOC positions. Like peak power testing on the bench, these tests try to measure the power capabilities of the traction battery. The results seemed consistent, and no conclusions could be made about the health of the battery from these tests besides the fact that vehicle power control was evident. In an effort to provide consistent power throughout the battery's state of charge range, the vehicle controller may be configured to restrict power at relatively high SOC levels.

## 5. ENERGY USE

Table 3 shows the monthly energy usage and road mileage for the three vehicles. The first 1 or 2 months of data were estimated due to technical problems getting kWh meters installed and programmed correctly.

The average number of charging events was about two per day for all three vehicles, which coincides with the assumed user commuting profile of charging at home and work. For Vehicle 2, the time spent charging off-peak (2100 to 1200) was close to the time spent charging on-peak (1200 to 2100). For Vehicles 1 and 3, 61% to 63% of charging energy was used off-peak. The difference is a matter of the lifestyle of the users and also of their budgets, as the drivers were responsible for home charging expenses. None of the drivers had special metering at their residences to qualify for SCE's electric vehicle off-peak charging rates; instead, they took advantage of charging at SCE facilities whenever possible. A monetary incentive to charge off-peak (the best way for utilities to influence load management), would probably have altered the results. Figures 9 and 10 show the typical daily and weekly charging profiles for Vehicle 3. Vehicle 3 (Figure 9) was charged in the morning at work, starting at approximately 0800, and again at home, starting at about 1830. Vehicle 3 typically was not charged on the weekends (Figure 10), which implies that it was only used for short drives (or none) during the weekends. The data suggests that most of Vehicle 3's use occurred during the workweek and the charging was regular and mostly off-peak.

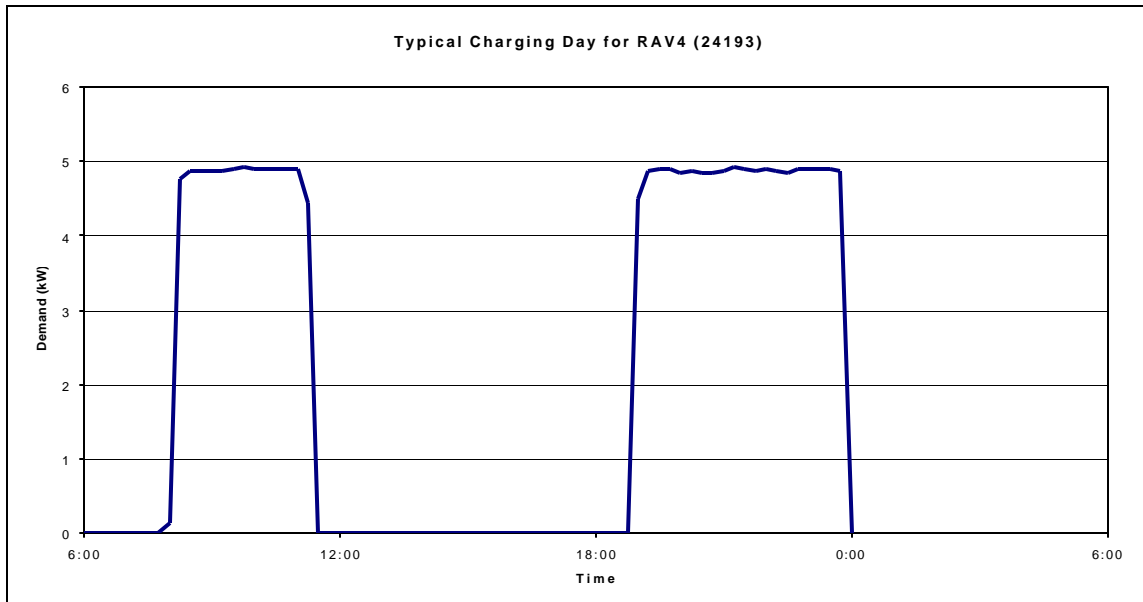
The average time spent on charge for the three RAV4s was just under 3.5 hours. EVTC vehicle testing has determined that the time to fully charge a conductive RAV4 from 0% SOC is about 6.5 hours while EVAmerica testing determined it is was about 6.75 hours. Sometimes the drivers interrupted charging when adequate SOC was available for trips. Vehicle reliability, and the drivers' trust in the SOC gauge, combined with their knowledge of the vehicles, made it easy to estimate remaining ranges.

The average number of miles driven per charging event was 42.4, about half of the available range. The energy usage averaged 2.5 miles per AC kWh (0.4 AC kWh per mile), which is within the range observed while testing other RAV4 electric vehicles under similar payload and auxiliary load conditions at the EVTC.

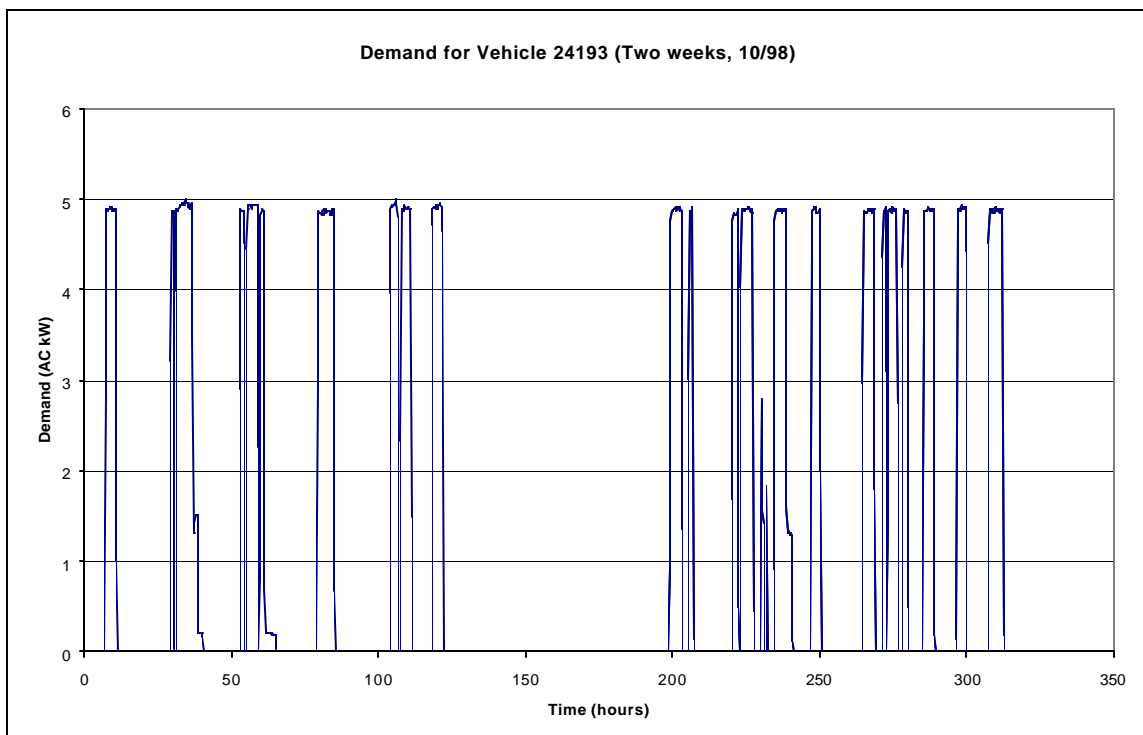
**Table 3. ABB AC kWh meter and mileage data.**

Vehicle No.	Month	Number of days with charging activity	Total OFF Peak (kWh)	Total ON Peak (kWh)	Charging Events	Average time on charge (hrs)	Monthly mileage	Average Miles/Charging Event	Average Miles/AC kWh	AC kWh/mile
<b>24191*</b>	June (est.)	7	46.50	108.50	7	5.00	387	55.29	2.50	0.400
	July (est.)	27	527.98	440.79	66	3.06	2,397	36.32	2.47	0.404
	August	20	346.79	290.04	42	3.34	1,679	39.98	2.64	0.379
	September	20	329.48	208.41	39	3.12	1,140	29.23	2.12	0.472
	October	22	85.72	374.28	36	2.92	1,420	39.44	3.09	0.324
	November	25	398.25	173.15	46	2.85	1,294	28.13	2.26	0.442
	December	24	466.14	342.62	56	3.29	1,792	32.00	2.22	0.451
	January	25	451.80	250.10	53	2.78	1,640	30.94	2.34	0.428
	February	21	374.53	148.69	43	2.56	1,305	30.35	2.49	0.401
	March	27	440.68	325.31	54	3.00	2,085	38.61	2.72	0.367
	April	28	490.28	227.12	51	3.20	1,507	29.55	2.10	0.476
	May	28	584.46	223.42	59	3.14	2,054	34.81	2.54	0.393
	June	29	638.21	160.50	61	3.00	1,360	22.30	1.70	0.587
	<b>Totals</b>	<b>303</b>	<b>5,181</b>	<b>3,273</b>	<b>613</b>	<b>3.17</b>	<b>20,060</b>	<b>34.38</b>	<b>2.40</b>	<b>0.425</b>
<b>24192**</b>	June (est.)	8	61.50	143.00	8	5.00	509	63.63	2.49	0.400
	July	18	175.77	235.80	26	3.68	1,018	39.15	2.47	0.404
	August	26	545.08	354.70	50	4.06	2,423	48.46	2.69	0.371
	September	21	333.99	308.34	38	3.97	1,635	43.03	2.55	0.393
	October	24	338.85	351.67	42	3.79	1,745	41.55	2.53	0.396
	November	24	322.01	295.14	36	3.92	1,451	40.31	2.35	0.425
	December	23	301.61	273.75	37	3.55	1,599	43.22	2.78	0.360
	January	22	404.40	319.10	40	3.88	1,866	46.65	2.58	0.388
	February	21	334.18	359.01	37	4.05	1,895	51.22	2.73	0.366
	March	26	437.67	632.45	59	3.92	2,889	48.97	2.70	0.370
	April	26	367.00	437.96	46	4.09	2,134	46.39	2.65	0.377
	May	26	444.42	533.52	58	3.95	2,391	41.22	2.44	0.409
	June	28	520.73	485.36	60	3.96	3,005	50.08	2.99	0.335
	<b>Totals</b>	<b>293</b>	<b>4,587</b>	<b>4,730</b>	<b>537</b>	<b>3.99</b>	<b>24,560</b>	<b>46.45</b>	<b>2.61</b>	<b>0.384</b>
<b>24193***</b>	June (est.)	7	57.00	133.00	7	5.00	475	67.86	2.50	0.400
	July	22	393.66	266.06	33	4.34	1,592	48.24	2.41	0.414
	August	27	679.65	299.88	64	3.20	2,554	39.91	2.61	0.384
	September	21	426.95	133.34	38	3.30	1,334	35.11	2.38	0.420
	October	25	654.04	157.64	33	4.95	2,247	68.09	2.77	0.361
	November	26	441.99	216.09	36	3.68	1,574	43.72	2.39	0.418
	December	27	482.37	240.10	41	3.83	2,029	49.49	2.81	0.356
	January	24	305.68	338.88	44	3.31	1,573	35.75	2.44	0.410
	February	24	416.03	282.18	50	3.11	2,089	41.78	2.99	0.334
	March	28	481.61	510.29	67	3.25	2,734	40.81	2.76	0.363
	April	27	542.51	323.40	53	3.74	2,593	48.92	2.99	0.334
	May	25	547.18	398.64	62	3.54	3,177	51.24	3.36	0.298
	June	25	537.05	257.49	51	3.57	1,672	32.78	2.10	0.475
	<b>Totals</b>	<b>308</b>	<b>5,966</b>	<b>3,557</b>	<b>579</b>	<b>3.76</b>	<b>25,643</b>	<b>46.44</b>	<b>2.66</b>	<b>0.382</b>

\*ABB meter 02 143 068 installed on 7/16/98 with odometer reading of 1,441mi. In service with user 7/2.  
\*\*ABB meter 02 143 074 installed on 7/10/98 with odometer reading of 509mi. In service >7/10.  
\*\*\*ABB meter 02 143 073 installed on 7/10/98 with odometer reading of 475mi. In service with user 6/30.



**Figure 9.** AC kWh demand for Vehicle 3 (24 hours).



**Figure 10.** AC kWh demand for Vehicle 3 (two weeks).

## **6. VEHICLE MAINTENANCE AND REPAIR**

Vehicle 3 had a leaking brake booster pump, which was replaced (zero days out of service). Vehicle 1 sustained damage to the roof and windshield when it was struck by a tree branch during transport aboard a towing vehicle; bodywork and a replacement windshield returned it to service within two weeks (repair conducted by the towing company). The vehicle was not being towed due to an on-road failure; it was being towed to a testing track for acceleration testing. No other repairs were performed besides the repair of tire punctures on Vehicle 3 (left front tire, twice) and Vehicle 2 (right rear tire).

Regular preventive maintenance was scheduled at 6-month intervals. However, not all of the vehicles were serviced on time due to scheduling conflicts with the drivers and the mechanics. Vehicle 2 received preventive maintenance during January 1999; Vehicle 1 during June; Vehicle 3 during July. Because the drivers did not have any problems with the vehicles, it was easy to forget about preventive maintenance (which consisted mostly of safety and function tests and inspections, and tire rotation). Besides the preventive maintenance functions, the only other attention the vehicles required was keeping the tires properly inflated and adding brake fluid once to vehicle number 3. The addition of brake fluid was related to the previously mentioned leaking brake booster pump problem.

## 7. TIRE WEAR

The tread depth was measured for all three vehicles at the end of the testing and compared to a new tire of the same model. The results are shown in Table 4. The tread depth was measured at the center groove of the Bridgestone Ecopia tires for the three vehicles and the new tire.

The three reliability vehicles completed the test year with the original set of tires. Vehicle 3 had two punctures on the left front tire, which were repaired. Vehicle 2 had one puncture on the right rear tire, which was repaired. Vehicle 1 had preventive maintenance a few weeks before the end of test and a front to rear rotation, so approximately 700 miles were driven with the front tires on the rear. Vehicle 2's tires were rotated in January 1999. In the table, "front tire" corresponds to the position the tires were in for most of the test period for Vehicle 1. The tires were not rotated for Vehicle 3. Note that even though Vehicle 2 had the recommended tire rotation after 6 months, the front and rear tire wear was still uneven.

As shown in the table, tire life can vary greatly. These vehicles were used mainly for commuting to work and for work-related travel for the three SCE employees. The estimated life of the front tires is between 26,600 and 50,000 miles.

**Table 4.** Tire tread measurements.

	New tire	Veh. 1	Veh. 2	Veh. 3
Usage (miles)	11	20,245	25,000	26,090
Average Tread Depth – Front (mm)	6.2	2.7	2.4	3.8
Average Tread Depth – Rear (mm)	6.2	5.1	4.8	5.7
Average Tread Depth – To Tread wear Indicator, Front (mm)	4.3	1.1	1.0	2.2
Average Tread Depth – To Tread wear Indicator, Rear (mm)	4.3	3.5	3.4	3.6
Front Tread Used (Based on New Tire) (mm)	NA	3.5	3.8	2.4
Estimated Miles per millimeter of Tread for Front Tires	NA	5,784	6,579	10,871
Estimated Miles Usage Remaining for Front Tires	NA	6,363	6,579	23,916
Total Estimated Usable Miles for Front Tire	NA	26,608	31,579	50,006



## 8. CONCLUSION

The RAV4s proved to be very reliable and useful over the 1-year test period and the drivers were very happy with them. The average range per charging event, as well as the energy efficiency achieved (miles per AC kWh), were below the capabilities of the vehicle as demonstrated in EVTC testing. However, this is dependent on how the vehicles are operated (and perhaps driver education and mission selection). At the conclusion of the reliability testing, all three vehicles remain in the same type of service and in good operating condition. As of March 2000, each of the three vehicles has been driven approximately 35,000 miles.

As mentioned in the introduction, as of this writing SCE has 245 RAV4 electric vehicles in its fleet (Figure 11), with almost 2 million miles driven. These vehicles are used in the daily operations of SCE to conduct company business. They have become an integral part of the SCE fleet, and their reliability is critical. The large number of RAV4 electric vehicles in the fleet attest to the faith SCE has in the vehicle to reliably complete company missions. This trust is a result of experience, as well as the knowledge obtained from the high-mileage Accelerated Reliability testing program.



**Figure 11.** Part of Southern California Edison's fleet of RAV4s.

## **Appendix A**

# **Toyota RAV4 Electric Vehicle Memory Effect Investigation**

## **Summary**

An investigation was conducted to examine the so-called “memory effect” of the Panasonic NiMH battery in the Toyota RAV4 electric vehicle. Two vehicles were selected and tested initially for range. For 1 month, one vehicle was driven only short distances, and one was driven to full range each time. Final range tests showed a small, but noticeable effect. In relative terms, the range of the short-drive vehicle declined 5.6%.

## **Procedure**

Two of the three vehicles from SCE’s DOE Reliability Test were selected for the investigation. Vehicle number 24191 (“Vehicle 1”) started with 21,900 miles and vehicle number 24192 (“Vehicle 2”) had 26,650 miles. Vehicle 1 was normally driven for shorter drives (roughly 50% DOD) for most of its history, while Vehicle 2 was regularly driven further (deeper discharge to roughly 70% DOD) for each charge.

All driving was conducted on the “Freeway Pomona Loop.” Initial range tests were conducted. For each range test, the two drivers drove together in order to minimize differences due to the effects of driving style, ambient temperature, and traffic conditions. Speed was kept at as close to 65 mph as traffic and safe operation would allow. Vehicles were configured identically with payload, auxiliary equipment usage (radio only), and window position (slightly open). Driving continued until reaching the stop condition – the flashing of the battery charge light on the dash – at which point the drivers would separate and return to the EVTC.

After the initial range tests, cycling operations commenced. Since Vehicle 1 was normally driven on shorter drives, it was assigned to daily full discharge drives (one drive and charge per day) to see if its range would improve. Vehicle 2 was assigned a regimen of 25 to 35 mile drives (25% to 40% discharges) twice per day with charging in-between.

After three weeks, final range tests were conducted.

## **Results**

The results are shown in Table 1, below. Vehicle 2 had an initial range that was 2.7% greater than Vehicle 1. The range of both vehicles increased at the final range test. The increase was 10.6% for Vehicle 1, but only 4.6% for Vehicle 2. Vehicle 2 had a final range that was 2.9% less than Vehicle 1. The relative range of Vehicle 2, then, declined 5.6%. The average ambient temperature was 13% greater for the final range test, and the average speed was 12.2% less; this will be discussed in the next section.

**Table A-1.** Test Results.

	Vehicle 1 (Full Discharge Drives)	Vehicle 2 (Shallow Discharge Drives)	Percent Difference	Average Temp. °F	Average Speed
Initial Range	74.5	76.5	+2.7	69	51.2
Final Range	82.4	80.0	-2.9	78	45.0
Percent Change	10.6	4.6	5.6	13	-12.2

## Discussion

There could be several reasons why the range increased for both vehicles. One reason could be the lower average speed. This was caused by the drivers encountering traffic for a few miles. However, because a subsequent test achieved essentially identical results at a higher average speed, we can eliminate this factor in this case.

Another reason is higher ambient temperature. One of the goals of the project was to eliminate the temperature factor from the investigation. Unfortunately, that is a difficulty with “real-world” testing. The increased ambient temperature of the final test may be the most logical reason that the range increased for both cars. To a point, it can increase the operating efficiency of the vehicle and battery system; this has been seen before. This will require further investigation to determine the effect of temperature alone on range. For now, it is worth an improvement of about 5%. In that case, the range of Vehicle 1 increased a corrected 5.6%, and the range of Vehicle 2 declined an estimated 0.4%.

## Conclusion

The results show clearly that the range for the deep discharge vehicle increased much more dramatically than the vehicle that had its discharge restricted. In this case, any memory effect that Vehicle 1 had was eliminated by the deep discharge regimen it was subjected to. If the temperature factor could have been controlled, the shallow discharge vehicle may have seen an actual decline in the available range. A “memory effect” of a combined 5.6% was shown when comparing the two opposing vehicle strategies. In other words, with occasional deep discharges, your vehicle may provide over 5% more range than if it was always shallowly discharged.