“Living with a BEV: A Survey of User Experiences"

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Abstract:

This paper summarizes a survey of drivers, focusing on the capability, reliability and failures of privately owned Toyota RAV4-EV’s, a pure battery electric vehicle (BEV). It is based on work originally done in 2006 and presented at the CARB Technical Review in Sacramento and now updated in 2007 [1]. It is organized as follows: we overview some demographics and the survey approach used, a typical usage profile, charging, and the failures and defects experienced are discussed. We continue with support services, a discussion on the NiMH batteries, and finally the aftermarket RAV4Info accessory, used to supplement the standard factory instrumentation and its capabilities.

Keywords: Battery Electric Vehicles, RAV4-EV, RAV4Info, zero emissions, reliability.

1. Introduction

The RAV4-EV was produced by Toyota Motor Corporation partly as a result of the passage of the California Air Resources Board (CARB) Zero Emissions Mandate (ZEV), starting in with the 1997 model. The cars were initially only released as commercial leases yet in early 2002 they were sold to private parties as well. The very limited production and availability of these cars was not well publicized. Repeatedly, many citizens remark that they had no idea this car existed when they encounter an owner today. In the spring of 2006 CARB invited various groups to participate in the ZEV Technology Review in September. It was their desire to gauge the public response to the ZEV vehicles which initiated this survey. It represents user data, coupled with direct experiences from the drivers. Collecting meaningful data can be done only with significant participation. The initial goal was quickly exceeded, with ultimately 132 vehicles being represented, of which 116 were from individual drivers. Deciding what data to collect and then creating an email survey with the requirement that less than 10 minutes would be required to complete and return was only the beginning. The responses from vehicle owners represented approximately one third of the 330 privately held units and were tabulated via spreadsheet. Further follow-up for clarifications and subsequent updates were done by telephone.

1.1 Demographics

Some 33% of all private vehicle drivers responded to my request to participate in the survey; the model years were mostly 2002, with some of the final 2003 units and a couple from 2001. All of these models were essentially the same product with only differences being the firmware in the electronic control units. Nothing of major consequence differentiated the samples. Drivers varied in age and income, retired, working - all across the spectrum. Vehicles averaged about 10,000 miles of driving per year, which admittedly is below both state and national statistical averages of more than 13,600 miles [2].

Table 1: Distribution of RAV4-EV models built

Model Year	1997	1998	1999	2000	2001	2002 and 2003
Build, total	69	359	255	106	160	238 leases, 101 sales

There are approximately 340 private cars sold and leased, with an over 500 additional commercial fleet population included still on the road today. Drivers surveyed are universally satisfied with this product offering. The public fleets considered this information to be confidential and hence were excluded, except for their total miles driven. At the time of the survey, owners had collectively driven over 5 million ZEV miles which translates to approximately 2,900 fewer tons of carbon dioxide released (assuming the CA average of 17 mpg and 19.54 lbs per gallon). These miles driven replace gasoline powered miles, and so are miles with which we don't create an environmental burden.

1.2 Driver usage profile

When asked what the primary intended purpose of the car was about a quarter stated that it was for commuting, two-thirds said it was their primary car, while about ten percent stated that it was their only car. Owners stated that 103.1 miles was their average range, with a standard deviation of 11.6 miles on either side of that average.

Most families in America could have both gas and electric cars. From our survey we find they choose (80% of the time) to use their electric car whenever possible, even when drivers *did* have access to gas car. America doesn't need to do a "one to one replacement" of gas cars with a BEV. Drivers simply preferred taking their RAV for the vast majority of total annual family miles driven. The point they demonstrate is one of choice. America's goal should be not to replace all gas cars, since BEVs don't fit in all applications with current technology. In the past year, with steady high gasoline costs, that choice may be indicative of the economics involved.

1.3 Charging is not a limitation, but a privilege.

Respondents note the extreme convenience of home-based grid-charging, and interestingly - fully 50% drive their RAV4-EV also use grid-intertied time-of-use (TOU) metered solar arrangements. These vehicles are solar powered vehicles, aptly called SPV's. BEVs are the only cars today that can use renewable power sources. Removing gasoline driven cars from the road in addition to powering a BEV from stationary renewable solar energy maximally reduces ones carbon footprint. (This possibility seems to be America's best kept secret!) For some we learned that the car came first, then they sought to reduce their carbon footprint, while for others they already had solar and then decided to get the car to use the excess electricity they generated. With the California Solar initiative, the synchronicity of EVs and PVs will make it more attractive for consumers.

1.3.1 Public Charging

The success of the public charging infrastructure continues, after being initially established throughout the state by cities and municipalities during the era of the CARB ZEV mandate. It is currently maintained by the Electric Auto Association volunteers (http://electricauto.org) is enjoyed by over 90% of RAV4 drivers, though very few go beyond their normal driving horizon (distant destinations far from home) where they would have to rely on a charger (or bring their own along). Only the more adventurous drivers who carefully plan their long distance jaunts drive around the state and hence rely on the public infrastructure. They number in the single digit percentile here. Use of the pubic charging facilities for extending the possible driving horizon occurs on average of 34.6 times per year for drivers, with some using it daily, and others not at all.

Figure 1: Conductive and inductive high powered charging stations

Figure 1 represents an example of public infrastructure (Sacramento Airport), with conductive and inductive charging stations to accommodate both RAV4 and other production BEV drivers.

Figure 2: The inductive charger (1/2 of required assembly, remainder is in RAV4-EV)

The photo in Figure 2 is of the TAL 2000 Small Paddle Inductive charger, included with each RAV4-EV. These are 208/240 VAC powered units, and require the equivalent of an electric dry connection in residential installations.

An important point we noted was that the average person uses their car where they need public infrastructure (>90% use the public infrastructure). What we found is that virtually all drivers charge at home. Even though public charging is generally free to use, nearly all go home at night. About 1/3 of the people use those home chargers while traveling away from home, on the road. A connection to the grid while on the road is nice, and some resourceful drivers go to extremes to get to their destination using it.

It is a convenience to have a known charge available at the far end of a trip, to lessen the concern of running out of energy. That concern is diminished as familiarity with the car's consumption characteristic grows, given ones driving style. A rule of thumb quickly developed that optimal driving delivers about 1% of range reduction for every mile driven around town. If prolonged freeway driving is done, keeping to between 50 and 60 miles per hours saves significantly. Calculations show that the difference in energy consumption between somebody driving at 50 mph and 70 mph is over a third - in any car (gasoline or BEV), that difference coming primarily from aside pushing the air mass at higher speed.

Another interesting revelation from the survey: one RAV4-EV is entirely powered by electricity produced from methane, recovered from dairy farm operations in Northern CA. Excess electricity is fed back to the grid, much like with solar and wind generation.

Even though it may seem awkward compared to home charging, regular use of the public infrastructure is enjoyed by >90% of those surveyed. Extending driving horizon via public infrastructure is enjoyed, on average over 30 times per year which translates to nearly three times a month.

Unfortunately, this two-part charging scheme used on the RAV4-EV results in a more expensive and complicated approach than is necessary. Charging stations already are inherently prone to vandalism, yet another less expensive approach should be considered for all future production cars. Fully integrated on-board charging is more flexible and can be easily designed to function from common 110 volt as well as 208 and 240 volt sources which are so ubiquitous in America. By some estimates, only less than 0.08% of American households do not have access to electricity.

An “Electron Highway” has been under construction in California for the last 4 years, with public access charging stations already in place today at regular intervals from San Francisco to Reno along Interstate-80. Under construction largely with private funds, the EAA is now aiming at uniting San Diego with Seattle. While many gaps remain, the ability to expand ones EV driving horizon by using such infrastructure has enticed many drivers to explore America at a leisurely pace, without having to use liquid fuels.

1.3.2 Traveling statistics collected

Respondents taking trips that are greater than one hundred miles do so 14 times per year, on average. Longest BEV trip: 1200 miles, average, 183.7 miles, round trip. About 50% of drivers charge en-route, 75% do so only at their destination, one in three bring along their home charger as a portable charger, three quarters use public infrastructure while on such a trip, and lastly, 12% use recreational vehicle (RV) sites and campgrounds. Such RV sites provide access for several thousand locations for RV and camping enthusiasts nationwide.

2.0 Failure and defect analysis.

All complicated machines tend to fail for some reason or another, be it faulty workmanship, poor material quality, or sub-optimal design. A failure is defined here as anything that was not expected and that resulted in inability to continue without outside assistance.

In comparing the Toyota provided BEV technology with the routine automotive failures seen at dealer repair depots or other auto repair facilities, nothing remarkable is to be noted. It is important to underscore that the fundamental hardware and software design is over ten years old. All vehicles suffer from collisions or other fates resulting in removal from service, but none for reasons of BEV component failures. No failure was repeated multiple times on any vehicle, indicating improper isolation of the root cause. This is a tribute to the dealer diagnostic support services. Only routine maintenance issues were noted, while some were 'curious'. For example, the final drive lubrication was spotted in the bottom of the electric motor chamber, due to a seal failure in several cars. They were quickly repaired under warranty. Surely the analysis in Japan resulted in some recommendation unbeknownst to us, as customers.

A Field Replaceable Unit (FRU) is a large collection of parts, sometimes called an assembly, which may be more expensive to replace than the failed piece within, but saves considerable service time. Troubleshooting to component level is generally not practical nor does it make economic sense today, so instead, a group of closely coupled or easily accessible parts are lumped together, thereby making up a FRU. FRU choices are made during final pre-product launch stage of manufacturing. Considerations such as likelihood of failure, cost of part, general availability (lead time) of part, etc. are weighed before a final list of parts required for stocking is dispatched to service centers. Often the service center must purchase parts and maintain inventory for the duration of support life. In the case of the RAV4-EV, with rare failures, these situations must be carefully considered.

Table 2: Defective FRU frequency from RAV4-EV surveys

Defective FRU *	Frequency
Charge port cooling fan	8
Rectifier assembly (shorted capacitor)	4
Battery Management ECU (computer)	3
Traction motor inverter	3
Tires misaligned	3
Heat pump	2
Motor seal leak	2
Traction pack	2
Main system relay	1

Rear wiper motor	1
Dash brake lamp on	1
Electric power steering pump	1
Master brake cylinder	1
Overcharging situation (charger)	1
Regeneration caused cut-out	1

Failures such as broken windshield glass, flat tires, discharged auxiliary 12V battery, squeaking brakes are not unique to this car and constitute the higher defect counts in collected survey data. They have been removed from this table so as to focus on BEV-unique components.

2.1 Top offenders

At the top of the list, on eight occasions: the charge port fan; the port is air cooled by a small electric cooling motor which repeatedly failed on a fan sub-assembly, possibly due to excessive heat. The FRU is the entire charge port which contains a special, expensive piece of ferrite (used as the coupling transformer 'core'). Replacement of the fan with an equivalent unit has been done on several occasions, instead of paying for the entire charge port which today amounts to an "out of warranty replacement cost", with substantial savings. If this vehicle were in full production, this failure would surely be reduced by Toyota issuing a Production Change Order (PCO), with intent to improve air flow for the fan motor, thereby immediately reducing the overheating and increasing the reliability.

Next in line, four times: the rectifier assembly fails when an internal high voltage capacitor develops a short circuit. Placed across the charge port secondary windings, it is probably subjected to serious transients, judging by the component rating and construction. To replace that part could only be done via special order from the Toyota factory directly to an authorized dealer. The supplier would not sell to non-Toyota personnel. After FRU removal, the replacement of the capacitor is an estimated five minute procedure, worst case.

With three occurrences each:

- The RAV4-EV contains four computers (electronic control units), of high complexity with hardware and firmware for specialized operational instructions. Hence, a higher than normal annualized failure rate is likely to be noticed. Luckily, their replacement is simple for a technician to do. One infrequent replacement is the battery management system ECU, the one that tends to the traction pack over its lifetime, during charging as well as during discharging. Computer module swap-outs are in order whenever a tiny defect reveals itself.

- The traction motor inverter has also failed, resulting in a tow truck being called. This is the high powered circuit that converts DC battery power to a three phase motor excitation, and consists of several large (expensive) pieces of silicon
- Front tire misalignment from the factory caused premature wear on the special low rolling resistance tires. This might have been caused during transit to the USA or after arrival. Normal tire life varied all over the map, with an average being about 3 years and 35,000 miles.

The remaining items were seemingly random failures occurring only one or two times each. Overall, the highest (8 failures) still calculates to be a 6% failure rate. The rectifier and all other less frequent failures fall exactly on the 3% threshold for this sampling. This threshold is one that textbooks teach as "typical rate" for a mature product defect in full production.

2.2 Post Sales Support

Problems with support services fell generally into three categories:

- Problems with Toyota,
- Problems with Toyota obtaining parts,
- Problems with the home charging station.

While a few dealerships gave exemplary service, some had not seemed fully on-board with the program. Difficulties with dealership service were solved by going elsewhere. Word of mouth travels quickly.

Long lead times for replacement parts would surely have been reduced - had full production commenced on any reasonable scale. Some unique body panels took longer than others after an accidental impact with lead times were sometime 4-6 weeks. Only about one quarter of those surveyed mentioned this, with the remainder stating that they hadn't encountered any such needs.

2.2.1 Home charger failures

Home chargers were not integrated as a complete on-board charging system - much like today's EVs, which simply need a plug (large or small). Unfortunately, the two-piece charger arrangement used after Toyota abandoned its earlier simpler conductive approach in 1999 now meant that if the car was driven too far away from a charger, it needed to be towed back. In practice this ill-conceived design becomes cumbersome if long distance traveling is attempted, which necessitated including a bulky sixty-six pound wall-mounted charger supplied with the vehicle. Today's fresh piece of paper designs use totally on-board, self-contained chargers, allowing more freedom while traveling. Drivers were aware of such limitations, and many still not deterred from traveling with their charger. In retrospect, this scheme was more expensive and created more difficulties from start to finish than the perceived safety issue it solved. Consumers have long been well versed in the power and dangers of electricity.

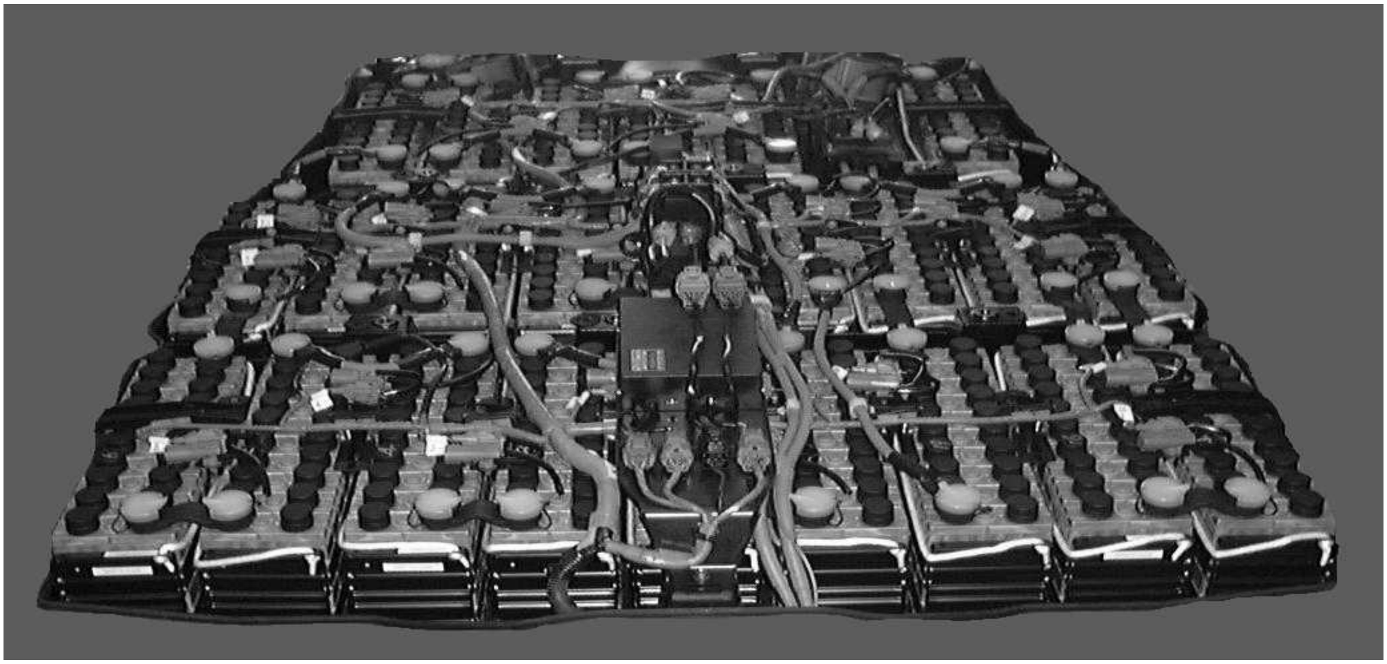
2.2.2 Roll-away damage

More than three out of four owners had no charger issues, but several had roll-away damage while parked on an incline. A 'roll-away' is when the vehicle starts moving before the driver intends it to. The RAV4-EV will not allow the drive system to energize if the charging paddle is still inserted in the charge port. If the key is turned to the start position, the green 'READY' indicator on the dash will not come one, nor will the car produce the normal 'beep' to announce readiness to select a gear. But the car could freely roll. Parking on an incline and forgetting to unplug before departure can allow the paddle interconnection cable to try to restrain the cars movement, to the point where the weight of the car is tensioning it. Sometimes the paddle released from the charge port and hit the hard surface below, cracking its casing. On occasion operation was inhibited, while on others carefully taping the pieces together allowed for continued use. To repair these now damaged chargers meant a return visit from the installer and for some the irritation and irregularities experienced during the purchasing process still echoed. The supposedly 'required professional installation' of the charger before being allowed to take initial delivery still frosted some respondents years later, while others defiantly and successfully performed self-installation.

3.0 Batteries: The Achilles heal of the BEV

The Nickel Metal Hydride traction battery used in the RAV4-EV was made by Panasonic EV, and dubbed the model EV-95, to represent its amp-hour capacity rating. It is essentially a second generation NiMH, an improvement (higher capacity) over the ECD model used in the GM EV-1 Gen II. The traction pack performs admirably, when air cooled as here and is arranged as three rows positioned underneath the cabin area beneath the floorboards. Weighing about 1000 pounds, it has an energy capacity of 26 kWh, and provides over 100 freeway miles at 65 miles per hour in good condition. Even with over 100,000 miles, this pack still can deliver this same kind of freeway performance. Traveling in mountainous areas means incorporating energy expenditures of about 10% for every 1000 feet of elevation climbed. (Regeneration helps mitigate those losses when descending, however.)

Figure 3: Frontal view of RAV4-EV air-cooled traction pack



This may be the first photo many owners have ever seen of their RAV4-EV traction pack. It spans the width of the car, underneath the passenger compartment, and lowers the center of gravity to reduce the rolling.

3.1 Aging and capability changes

Of drivers surveyed, 91% reported no change in capability since the car was new, 9% reported some loss. Of those, their reported loss was characterized as "less than 10%". After five years of faithful service, two drivers experienced need for traction pack battery service, but the circumstances were a bit unusual. They were repeatedly driving to near total pack discharge (down to 3 percent State of Charge (SoC), average) while discharging at up to twice the standard capacity (2C) which mapped perfectly with the stated manufacturer's cycle life expectations in their specification. This was due to daily freeway driving at 65 mph, climbing two 600 foot grades, morning and evening. Two different vehicles (a 1998 vintage Honda EV+ and a Toyota RAV4-EV) represented this experience from one particular driver. In subsequent questioning, most of the others lived at elevations, and admitted to practicing less than optimal battery charging routines.

Revisiting some of those owners originally surveyed in mid-2007, two had sold their vehicle, taking advantage of high resale values, albeit with slightly reduced battery capability due to not following the acknowledged proper charging protocol. Subsequent battery reconditioning restored most of the original functionality, but we suspect longevity of those packs may have been compromised somewhat.

3.2 Degradation from sitting

An internal combustion engine when left for long periods of time can deteriorate, with fuel fouling and etc. In a BEV, prolonged periods of non-use might see a deterioration of maximal range if lead-acid technology were used. Those batteries need regular exercise to maintain capability. In the NiMH battery employed in this car, no such degradation was ever noted. If left in the cold winter of western Pennsylvania or at the LAX airport while owners were away, full capability was immediately available upon resumption of service. Amazingly, the self-discharge rate of a healthy pack is about 0.1% per day, at any state of charge. This is clearly much slower than stored hydrogen (for comparison to FCEV's). After a 3 week out of the country vacation, my personal experience was a ~2% loss in SOC.

In general, when it comes to EVs - Toyota has removed the battery variable "from the ownership equation" with this RAV4-EV. Transparent behavior has been the rule.

4.0 Aftermarket accessories for the RAV4-EV

RAV4Info is a hardware and software package which was developed by a 3rd party as a tool for drivers and sold as an aftermarket device specifically created for this car. Many drivers use it so supplant the standard instrumentation. The internal OBD-II interface data stream is tapped and decoded for display on an off the shelf Palm Pilot ™ hand held Personal Digital Assistant (PDA). Other commercial off-the-shelf (COTS) products can not read the extended instruction set that Toyota used specifically for this car, and are useless. Many drivers have found out that there is not much to learn using those tools. With RAV4Info, a much more precise readout of, for example, the state of battery charge is possible (top screen, large numbers), along with various other operational parameters deemed to be important. The software takes care of the protocol emulator as well as the data interpretation routines, and presentation formatting. The package does not interfere with any normal functions of the car, and is transparent to the operation while driving. The internal bus is isolated from the OBD-II interface, and not all operational parameters can be observed, as done with the Toyota Hand Held Tool (HHT), the tool used in all dealership service bays.

4.1 The SoC screen and deep discharging

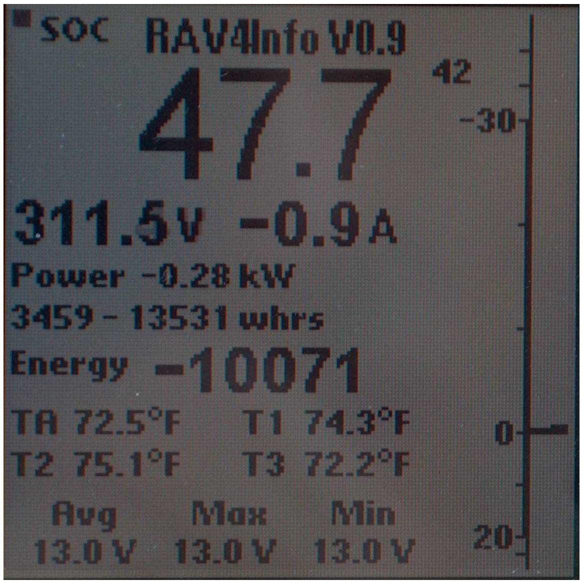
By utilizing the touch screen surface, the large digits can alternatively display pack voltage, current drawn, power delivered, or state of charge (100% when full, 0% when empty). What does it mean when the SoC readout hits zero? Can one drive anyway? Yes, but clearly without the full performance capabilities of a fully charged pack. Under those conditions, if current drawn causes the pack voltage to sag below about 242 volts, an angry orange 'turtle' icon appears on the dash, accompanied by its loud annunciation. Relaxing the accelerator pressure makes the turtle retreat. In the early days for the car's experience, the firmware that controlled the acceleration rate allowed for more aggressive acceleration. To reduce the excessive tire wear, this feature was retired. At low states of charge, the available reserve capacity is used up, and acceleration will be reduced when in "turtle" mode.

Slowly changing parameters such as battery state of charge (SoC), battery temperature and the average, maximum and minimum battery module voltages are displayed. Energy use numbers are useful for gauging the severity of hill climbing on grades. Differences in driving at moderate speeds and charging down a freeway at full speed become apparent. Clearly many drivers don't care about such numbers, but for some, the utility overrides the cost for others. The factory analog meter display of SoC on the dash has been 'linearized' via software in the top 50%, and didn't track accurately until about the 50% discharge level, always reading about 5-8% higher than actual SoC based on the raw data presented on the RAV4Info screen.

4.1.1 System design considerations

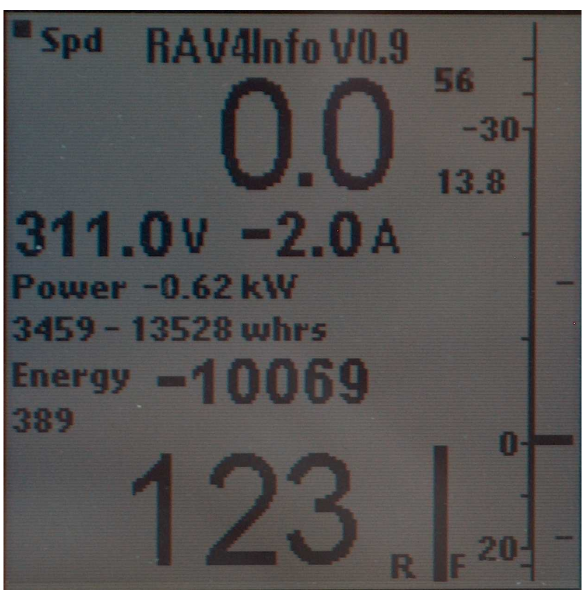
The nominal system voltage is 288 Volts; when fully charged, the charger turns off at around 350 volts, which one could consider the 'ceiling' voltage level. The 'floor' or lowest voltage after which the turtle mode (reduced performance) is reached is about 242 volts. Having this large headroom makes for good battery life. Conversion EV's using lead-acid technology do not have the ability to reach such high system voltages due to the lower density of the battery chemistry. As a result, deep discharges are the norm during operation, and too frequently descending to those discharge levels severely shortens their battery life. Here, even at 242 volts, the traction pack still packs a lethal wallop yet still can allow a much reduced performance to drivers who need to creep home on a flat surface at low speeds. Others who live on a hill may actually inflict damage which results in reduced longevity for the pack. RAV4-EV service technicians at local fleet service centers recommended to periodically deep discharge the pack by driving until SoC levels of less than 15% are reached. This means that once every month, daily drivers should discharge the pack deeply to this level, to allow the software to "recalibrate" where the 'floor' really is. Several drivers noted that after months of repeatedly discharging only to 60% or 70% and recharging to full, that their available drivable range was reduced significantly. Resolution of this amounted to driving around their neighborhood, in close proximity of their charger until well into the night.

Figure 3: RAV4Info SoC screenshot



The second screenshot (figure 4) represents the Spd (Speed) screen as the electronically derived vehicle speed is displayed in large number. This speed display tracks very well with GPS units, while the analog speedometer typically reads 2-4% high at freeway speeds.

Figure 4: RAV4Info SPD screenshot at a stop.



The screenshot depicts a 123 wHr per mile of energy use and illustrates friction brake (F) depression. Regenerative braking (R) is a separate bar graph representation.

4.2 Regenerated energy

By electronically switching the three phase motor on the RAV4-EV it can function as a generator, capturing kinetic energy and converting it back to direct current with which to recharge the traction pack. This can significantly enhance driving range under the right conditions. On the SoC (State of Charge) screen on top, the 3459 number represents the number of watt-hours of regenerated energy since the last full charge (when the display manually gets reset to zero, along with the odometer being reset). The total energy used at this 47.7% full state of charge is 10071 w-Hrs. It can be seen that nearly one quarter of the total energy moved into and out of the battery comes from kinetic energy recaptured. With simple number manipulation: 3459/13531 = ~25%. On a freeway trip to Sacramento from the Bay Area, the number is much smaller, as there are no stops. This display here represents primarily in town driving, with the energy intensive start/stop driving that requires accelerating and decelerating the vehicle mass each time.

So how ‘well’ do people drive their BEV? Their average DC energy used from the battery, per mile driven is 245 wHr/mile, with a high value of 340, a low of 112, and a median of 250, with a standard deviation of 184. The total AC energy used per mile is derived and approximately 15% higher; so scaling numbers this would be about 281 wHr/mi. This includes the charger losses. Clearly the numbers represented here depend on the driving style, yet are a good baseline of real world use by everyday drivers.

Many drivers strive for efficiency, anticipating stops (by coasting) and since there is no compression braking in this car, simply lifting ones foot from the accelerator pedal provides a remarkably slow loss of speed. To better simulate gasoline car coasting, Toyota engineers included a gentle engine braking mode (EB) which can be activated from a button on the console mounted shifter lever. That engages a small constant amount of regenerative braking, visible on the display both in numerical and graphic form using the bar graph on right hand side.

The largest secondary load is the heat pump (in the summer as an air conditioner, in the winter as a heating mechanism). This is powered directly from the high voltage traction pack, as is the heated windshield system (HWS) providing virtually instantaneous defrosting of the windshield during colder weather at the press of the so labeled dash-mounted button. Additional comfort is supplied by popular driver and front passenger heated seats, each similarly activated. The 2003 models no longer included these two features, ostensibly due to the high cost to create the special windshield. Drivers suffering windscreen impacts from road debris have found out that the window replacement is particularly expensive, yet is usually covered under their insurance. All other loads (electric power steering, power brake booster are powered from the output of the DC-DC converter which functions as the fourth traction pack load, and recharging the conventional PbA battery which helps to buffer the lights, wipers, etc.

Driving the RAV4-EV with its relatively large frontal cross sectional area during stop and go driving produces some interesting numbers. It is a relatively heavy vehicle (3400 pounds) so current consumption varies depending on the terrain. The EV-95 NiMH battery is specified to deliver 95 Ah, and completely flooring the accelerator on a level roadway will draw 180 amps. This is about the 2C rate of discharge. In traffic, current draws of 20-50 amps are typical. The car glides effortlessly and needs no further coaxing; it is easy initially to over speed until one get's accustomed to it behavior. Climbing steep hills is effortless, with modulated peak currents ranging from 110 to 150 amps, depending on traffic pressures. Carefully watching ones current consumption tends to slow ones driving speed.

5.0 RAV4 drivers overall perception of the car

Owners overwhelmingly appreciate the vehicle functionality and reliability. The large carrying capacity and the ease of loading and unloading cargo are mentioned repeatedly. The fact remains that for over five years, drivers report pleasure having to do no periodic maintenance to the car. They comment that it translates to a significant annual time and money savings. To date the predictability and durability of the NiMH battery technology is unmatched. Nearly half-dozen private drivers have topped 100,000 miles driven to date, with only tire changes needed. Those drivers notice no significant change in their stated freeway driving range expectations.

5.1 Fueling at home a significant plus

There is today an even greater fuel cost differential compared to last year, as the California average gasoline cost per gallon has been significantly higher than the national average for a better portion of the calendar year. There is the commensurate time saved by home charging. All drivers are loath having to detour to their neighborhood gasoline filling station, now that refueling at home is a reality for them. There are less than 180,000 of those filling stations nationwide, while virtually all of the approximately 98 million residential households have electricity available. No special infrastructure needed for these drivers. A vast majority of the drivers surveyed did not take advantage of public charging infrastructure, as they knew their range was limited. The application for this vehicle best fit those with driving requirements that were modest (less than 100 miles per day). Only the more adventurous drivers would carefully plan long distance jaunts across the state seem to use the public infrastructure.

Some drivers noted that having no tailpipe emissions was important to them and their children, while others felt that contributing with a significantly lower carbon footprint than the average American was important.

There is a very short learning curve as the car is extremely simple to operate.

We can safely conclude that there are absolutely no technology limitations seen in this implementation example of a factory produced battery electric vehicle. All failures and defects are significantly less, or in rare cases at worst, very comparable to the gasoline version of the same car.

5.2 eBay surprises

As leases expired, some owners pressed to buy out their residual value and many noted that the RAV4-EV had become an unexpected investment asset. During the past year the popular eBay auction website saw final selling prices well over the original purchase price in nearly a dozen transactions. This is understood simply to be the market forces at work. Several original owners had passed their vehicles into the hands of eager purchasers, reaping rewards which even high-end European luxury sports car owners can not generally match. The used car market for the RAV4-EV has truly been a surprise and differs significantly from ICE cars. Initially the list price was $42,510 plus taxes and registration. Loosely following eBay final prices, all sales throughout 2006 have been above the original out-of-pocket dollar amount paid, which included the three year CARB ZEV rebate and the one time Federal credit (total: $13,000). The highest to date has been $67,300 which has been approached (but not equaled) several times. More than a dozen sales to date have been over $45,000. Several survey respondents stated they sold their cars due to their particular financial situations, others were moving away from the area where dealer service was possible (though they admitted no service was needed up to that point), along with various other reasons, none of which had to do with dissatisfaction or insurmountable problems with the vehicle. This has been an unexpected bonus largely due to the demand and the lack of available cars. The public seems to know the technology works and can find details of other full sized BEV's produced during the years of the ZEV mandate on the Internet [5].

6.0 Conclusions

- The RAV4-EV provides drivers with a good value and pleasant driving experience.
- The manufacturing process demonstrated by Toyota is mature and well executed.
- Driving this car is as natural and as easy to use as a gasoline powered car in terms of maneuverability, acceleration, handling, parking, care.
- This product is a textbook example of manufacturing quality control with failures below the 3% level for the worst (most frequently failing) component.

- The technology implemented is over 10 years old, over 100 million ZEV miles have been driven using it, in real world consumer use, thereby underscoring the viability and the strength of the approach used. No more 'research' is needed, just higher production quotas.
- Users frequently commented that the RAV4 has been the best car ever owned. The dependability is remarkable, considering that for about 10% of surveyed drivers it is the only car they own, their sole daily driver. If long trips need to be taken other options mentioned were renting a hybrid, flying, and joining with others in a carpool.

Given the indisputable environmental and national security benefits of shifting even a small fraction of our many petroleum-driven miles to the electric grid, and given the outstanding performance of the RAV4 EV with NiMH batteries - it is a *tragedy* that this choice does not exist in the market today. CARB and Toyota should celebrate this product success and take steps to allow Californians to choose whether to drive on petroleum or electricity. Plug-in cars provide that choice, and as battery and energy storage technology continues to inevitably improve, the inclusion of electricity in the transportation of tomorrow is inescapable.

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Author

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