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Demand for Electric Vehicles by "Hybrid Households"

Kenneth S Kurani
Thomas Turrentine
Daniel Sperling
Institute of Transportation Studies
University of California, Davis
Davis, CA 95616 USA
phone: (916) 752-6548
fax: (916) 752-6572

Abstract: The debate over electric vehicles (EVs) pivots largely on market demand: Will consumers purchase a vehicle that can be recharged at home but provides substantially less driving range than an otherwise comparable gasoline vehicle? Most previous studies forecast a small market for EVs because they find limited driving range to be a serious market barrier, and ignore or under-value some positive unique attributes. We designed an innovative mail survey and administered it to 454 multi-car households in California. The four-stage survey included a video of EV use and recharging and other informational material, completion of a 3-day trip diary and map of activity locations, and vehicle choice experiments. In addition to propulsion systems, respondents made choices of body styles, driving ranges, and other features. We found a large potential market for EVs in California. Many households are willing to adapt to limited range and find home recharging to be a large attraction. Translating the findings into quantitiative estimates, the purchases of battery-powered EVs by (multi-car) hybrid households would account for between 7 and 18% of annual light duty vehicle sales in California, not counting EVs sold to fleets and other types of households.

1. INTRODUCTION

Central to the EV debate in California and elsewhere is the fact that, for now, EVs have limited driving ranges and typically require a few hours to recharge a largely discharged battery. Questions remain as to the value of home recharging, quiet operation, zero tailpipe emissions, and ease of use; as to minimum driving ranges drivers will accept in order to get these positive attributes; and the prices at which these attributes can be provided.

It is widely believed that few people would purchase a limited-range electric vehicle. This belief is driven in large part by the perception that consumers will demand such long driving ranges that the cost of EVs will be prohibitively high. Several automobile industry and academic studies concur. We do not.

Based on our studies of alternative fuel vehicle demand conducted over the past ten years and the results we report here of a recently completed four-year, multi-staged study of electric vehicle demand, we conclude that a large number of consumers would purchase a competitively-priced electric vehicle, even when driving ranges are well under 100 miles.

1.1 Previous EV Market Studies

In the absence of data on actual sales, previous researchers have tried three methods to develop estimates of EV market potential—attitude studies, travel behavior analyses, and stated preference surveys. Analysis of these research streams presents an apparent paradox. Attitude studies show EVs to be an almost universally admired technology; travel behavior analyses show many households could use at least one limited range vehicle; but stated preference studies typically conclude that virtually no consumers are willing to buy EVs. As summarized below, we saw this paradox called for close scrutiny of the methods and findings in these studies (for details see [1]).

The problem with attitude surveys is they represent consumers' ideals and not their full decision processes[2,3,4,5]. These studies overstate demand for EVs because of the vehicles' clean, progressive image. Travel behavior analyses that address the role of limited range also overstate demand. These studies identify households with daily driving patterns that match the range capabilities of EVs[6,7,8,9]. The problem is that consumer preferences and vehicle purchases are not measured.

Most stated preference studies, in contrast, have produced very low estimates of EV demand, from zero to 2%, primarily because they estimate large average price penalties for limited range[10,11,12,13]. One recent stated preference study enhances the realism of its respondents decision context by incorporating elements of their revealed and expected vehicle purchase behavior[14,15]. While also estimating very large penalties for limited range, this study forecasts

initial EV market penetration rates of 4 to 5% within California's South Coast Air Basin.

We previously expressed our skepticism about such results. We've presented theoretical arguments[16,17] and empirical results[1,18] to support our contention that the application of econometric models to stated preference data on EV choices is premature. New technologies enable changes in established consumer practices and preferences. Consumers may be unable to envision how they would use a new technology and therefore why they would buy it. New technologies may have few analogous attributes to conventional technologies. This can cause people to overestimate or under-estimate the value of novel attributes. In the case of EVs, consumers cannot have preferences for such attributes as limited range, home recharging, zero tail-pipe emissions and other unique attributes of EVs because they have no experience with them and therefore have not constructed preferences for them.

2. RESEARCH APPROACH

2.1 A process oriented view Research into potential markets for novel products, especially those that embody new values or possess new performance attributes, must be attentive to processes. It is not sufficient to capture a snapshot of current preferences of consumers; rather we need to record the processes of preference formation and lifestyle evaluation that are put into motion by the new technology.

We examine household consideration of EVs within the context of several processes. First, households move through developmental phases called life cycles. These life cycles are defined primarily by presence of children, age of children, age of heads of household, number of heads of household, and employment or retirement status of household members. Second, people build self images and self-identity through reflexive processes. The expression of such processes are lifestyle choices, many of which are manifested as consumption and activity participation choices. Third, living within a socio-economic, land use and transportation *milieu* that places a premium on mobility and flexibility, many households engage in an ongoing process of managing a fleet of multiple household vehicles. In the case of EVs, respondents must determine whether they must, whether they can, and whether they are willing, to manage household travel according to the different attributes of electric and gasoline vehicles.

2.2 Identifying and sampling hybrid households A household that combines electric and gasoline vehicles in its stock of vehicles is one example of a *hybrid household.* In contrast to a hybrid vehicle which combines multiple propulsion systems in one vehicle, a hybrid household chooses two or more vehicles with different types of propulsion systems and then allocates household travel according to the different characteristics of those vehicles.

We defined and sampled a group of *potential hybrid households* whose existing vehicle purchase behavior and vehicle stocks indicate they may be more amenable to hybridizing their vehicle holdings. Our sample of potential hybrid households met the following criteria: own two or more vehicles; buy new vehicles; own one 1989 or newer vehicle *and* one 1986 or newer vehicle; and at least one of their vehicles was not be a full sized sedan, van, sport-utility vehicle or pick-up truck. The ages of recruited participants were matched to the age distribution in the California new car market. We filled quotas for minivans, sports utility vehicles, and sedans based on recent proportions of those vehicles in the California new vehicle market. Also, we matched the split of foreign and domestic makes (50/50 in California) of the most recently purchased vehicle.

A total of 740 households were recruited in 6 metropolitan areas of California: the San Francisco Bay Area, Sacramento, Fresno, Santa Barbara, Los Angeles and San Diego. Participants were paid a $50 incentive because of the time demands of the survey. Of the 740 households recruited, 454 completed the study, yielding a response rate was 61%. The relatively high rate of completion in this study gives higher confidence that the sample was not biased to those interested in alternative fueled vehicles.

In this study, we designed experiments to test what we call the *hybrid household hypothesis*:

Assuming a vehicle can start each day with its full range, a driving range limit on that vehicle will not be an important barrier to its purchase by a hybrid household.

3. SURVEY INSTRUMENT DESIGN

The survey instrument was divided into four parts and was designed to be completed over several days to encourage critical evaluation of the options. The four parts are summarized below.

Part One: Initial survey of household vehicle holdings, purchase intentions for next new vehicle, demographics, and environmental attitudes.

Part Two: Three day travel diary for two household vehicles, a map on which the household plotted their activity locations, and a survey of the

travel and refueling behavior of the two primary drivers.

Part Three: Informational video and reprinted articles from major media that explain and demonstrate distinct refueling and recharging routines, emissions and other new features of compressed natural gas, battery powered electric, hybrid electric and neighborhood electric vehicles.

Part Four: Choice experiments related to their next vehicle purchase. We explain this section in greater detail immediately below.

3.1 Vehicle choices in the survey Part Four of the questionnaire consisted of two vehicle choice scenarios in which respondents were asked about their next expected new vehicle transaction. Each scenario was a distinct experiment. Situation One was a test of the hybrid household hypothesis. It involved a choice between conventional, gasoline-fueled vehicles and limited ranged, home-recharged, electric vehicles. Situation Two was designed as one plausible future market scenario, designed primarily to test a corollary of the hybrid household hypothesis—that demand for EVs can be segmented by demand for driving range—and to explore the lower boundary on the demand for range. Six vehicle types were offered: reformulated gasoline, compressed natural gas, hybrid electric, two types of freeway capable battery electric, and a neighborhood battery electric.

Summary descriptions of the range, speed and price features of the vehicles offered in the choice situations are shown in Table 1. We chose these attribute values and recharging or refueling options to reflect the needs of our hypothesis tests, as well as technological realities and possibilities. All vehicle features not discussed below were generic to all vehicle propulsion types. The names we chose for different range classes of EVs reflect the activity analysis framework underlying our analysis of vehicle purchases. "Neighborhood" EVs provide access to local activities that can be accessed without travel on freeways or expressways. "Community" EVs fill a geographically larger routine activity space. "Regional" EVs are intended for even wider ranging daily travel.

The driving range for EVs depended on the body style of the vehicle, battery options and charging options. The lower energy storage requirements associated with shorter ranges and smaller body styles could be met with lead-acid batteries commercially available at the time of the survey. Higher energy storage requirements associated with larger body styles and longer ranges would typically require more advanced batteries. The prices that we stipulated for the periodic replacement of battery packs and for longer range battery options were based on consultations with battery manufacturers regarding expected mass production prices.

The driving range options we offered for natural gas and hybrid EVs were shorter than have already been demonstrated. However, our primary objective was to construct tests of household response to driving range and refueling/recharging options, not to guess exact specifications of possible future vehicles. By choosing the ranges we did, we created vehicles that could offer fast, ubiquitous away-from-home refueling, but had ranges similar to the battery EVs.

In Table 1, we also provide an example of how prices were used in the study (see Table notes for details). The prices include purchase incentives. As an example, in Situation Two participants were offered a price of $15,500 for a basic trim level, regional electric, sub-compact sedan (130 mile range)—for which they had to calculate that the final cost to them would be $11,500. Accordingly, such an EV is priced $5,500 more before incentives, and $1,500 more after incentives than its gasoline-powered counterpart. The actual price "paid" by our respondents is a function of their choice of vehicle propulsion, body style, trim level and other options.

Some reviewers have criticized these EV prices for being too low. We chose these prices for several reasons. First, our intention was to maximize the information about household response to driving range limits and home recharging, while incorporating elements of realism. We intentionally designed the overall vehicle price structure to reduce the importance of up-front purchase price in the choice between different vehicle types. This seemed reasonable given the likelihood that most EVs will be leased, at least initially, thereby spreading the cost over several months or years. Moreover, actual purchase prices will likely be reduced by government incentives worth thousands of dollars. Such incentives are already available, reflecting the social value placed on private decisions to reduce environmental and energy security costs. Also, if buyers will accept lower ranges than has been widely acknowledged in the public debate, as we find they will, the size and therefore cost of battery packs and EVs can be greatly reduced. If the hybrid household hypothesis is supported, then we will have established that households are willing to specialize their vehicle holdings according to the unique

Table 1 Range, speed and sample prices of vehicles in the choice situations

Situations and Vehicle Type:	Driving Range, miles	Top Speed, mph	Comparative[1] Prices, $x1000 (includes incentives where applicable)
Situation One:			
Electric Vehicle[2]	80 or 100; 100 or 120	80	10.0 - 19.9
Gasoline Vehicle	–	–	10.0 - 18.9
Situation Two:			
Neighborhood Electric Vehicle (NEV)	40	40	3.5 - 7.1
Community Electric Vehicle (CEV)[2]	60 or 80	75	8.0 - 16.8
Regional Electric Vehicle (REV)[2]	120 or 140; 130 or 150	85	11.5 - 22.1
Hybrid Electric Vehicle (HEV)[2, 3]	140 or 180	85	14.0 - 24.9
Natural Gas Vehicle (NGV)[4]	80 or 120	(see note 5)	9.5 - 19.9
Reformulated Gasoline Vehicle	-	–	10.0 - 18.9

[1]Comparative prices in this table are calculated for a sub-compact sedan—other body styles have higher prices. The lower price limit is for the lowest trim level and no other options added. The upper limit is for the luxury trim level plus all applicable engine, transmission and energy storage options except four wheel drive. Both limits include the purchase incentives for the different vehicle types. In Situation 1, the purchase incentive for an EV is $4,000. In Situation 2 the purchase incentives are: $1,000 for NGVs and HEVs; $2,000 for NEVs: and $4,000 for CEVs and REVs.

[2]Vehicle range depends on body style and choice of battery options.

[3]The battery-only driving range options are either 40 or 80 miles.

[4]Range depends on choice of one or two fuel cylinders.

[5]Comparable to existing gasoline vehicles.

performance of different propulsion systems. If that fact is established first, then reasoned arguments can be made as to whether our price assumptions represent attainable vehicle development targets.

Recharging and refueling options varied by vehicle type. We stipulated that some electric vehicles, such as Neighborhood and Community EVs in Situation Two, could only recharge at home. Other EVs, notably the longer range Regional and hybrid EVs, could be purchased with optional "fast charging." We described fast charging as requiring 20 minutes to restore 80% of a full charge and being available at the equivalent of a gasoline station. A final EV recharging option available for all EVs was solar charging. This was described as adding 10 miles range or completely supplying electricity demand for air conditioning on sunny days. Natural gas vehicles were offered with the option of buying or leasing a home refueling appliance—a small compressor that refuels a natural gas vehicle at home overnight. They could either buy the compressor for $2,500 or lease it for $60 per month. This home refueling capability would be in addition to refueling at fuel stations.

As a final note on differences in vehicle offerings, in both choice situations we offered electric vehicles only in the body styles we expect them to be offered in during the next few years. These *EV body styles* include sports cars, small sport-utility vehicles, small (sub-compact) sedans, compact sedans, mid-size sedans and minivans. Gasoline and natural gas vehicles were offered in the full range of body styles, including full sized sedans, pick-ups, vans and sports utility vehicles.

4. RESULTS

4.1 The hybrid household hypothesis is supported We found strong support for the hybrid household hypothesis—that a driving range limit on one household vehicle will not be an important barrier to the purchase of an EV by a potential hybrid household. Choice Situation One was designed specifically to test this hypothesis. The scenario allowed participants to choose either a limited—80 to 120 miles—range, home rechargeable electric vehicle

or a conventional gasoline fueled vehicle. In fact, 46% of respondents said they would purchase an electric vehicle as their next new vehicle. This finding suggests that multi-vehicle households who buy new vehicles and own at least one vehicle of the body styles in which EVs are likely to be offered, will seriously consider owning at least one limited range vehicle (assuming that vehicle is home-rechargeable and is priced within a few thousand dollars of comparable body-style and trim level gasoline cars).

How could this response to EVs be so high? The answer, as we discuss below, has two parts: once they have thought about how they might use an EV within their stock of vehicles, many multi-vehicle households discover that a range limit (somewhere within the range options offered) on one household vehicle is simply not a binding constraint on their travel, and some attributes unique to EVs become more attractive once a household has made this determination.

4.2 Demand for driving range Clearly, more range implies greater value than less range, but how much greater? Based on the proviso that additional increments of range are expensive, and on the results from our PIREG interviews[1] and those reported below, we believe that once households discover a reduced range with which they are comfortable, they will not pay significantly higher prices to acquire more.

In the more detailed choice scenario of Situation Two, consumers were provided an expanded variety of vehicle propulsion types and driving ranges. The results were striking. As shown in Table 2, a total of 37% of our sample chose a vehicle, be it electric or natural gas, with a range of 130 miles or less. Even more dramatically, 65% chose vehicles with ranges of 180 miles or less.

Many households chose vehicles with very low ranges, when the vehicles were offered at lower prices. For instance, 4% chose inexpensive Neighborhood EVs, and another 12% chose relatively inexpensive Community EVs with ranges of 60 to 80 miles. We see a market segmented by ranges acceptable to different households, with some ranges much lower than previously reported.

These results stand in stark contrast to stated-preference studies. We ascribe the difference, primarily to our use of complex decision tasks that require households to explore travel and lifestyle implications of EVs and provide opportunities for households to begin to construct preferences for driving range and home recharging. The difference is also explained by our efforts to forgo representations of average consumers, and to target a segment of the market whose vehicle purchase behavior is more amenable to the process of hybridizing their vehicle holdings.

The willingness of some drivers to buy lower ranges is further demonstrated by examining changes in range choices between Situation One and Two. Many who had chosen a gasoline vehicle in Situation One, chose electric vehicles with ranges of only 40 to 60 miles in Situation Two. More dramatically, 46% of the

Table 2 Range choices in Situation Two

Vehicle Type	Range, miles	Number of Households Choosing Type and Range	Percentage of Households Choosing Type and Range
Neighborhood EV	40	19	4
Community EV with Type I batteries	60	10	2
Community EV with Type II batteries	80	18	4
Natural gas vehicle with single tank	80	28	6
Natural gas vehicle with double tank	120	60	13
Regional EV with Type I batteries[1]	120/130	52	12
Regional EV with Type II batteries[1]	140/150	63	14
Hybrid EV with Type I batteries	140	6	1
Hybrid EV with Type II batteries	180	37	8
Reformulated gas vehicle	300	154	34
Total		447	100

[1]Range of Regional EV is also dependent on body style.

households who had chosen a gasoline vehicle in Situation One, chose a shorter range electric, hybrid electric or natural gas vehicle in Situation Two. Across all vehicle types, 32% of households chose a shorter range vehicle in Situation Two than they had chosen in Situation One. They did so presumably because additional range had little value to them. We note that these choices of shorter ranges cannot be explained solely by the low prices of Neighborhood and Community EVs. Half the households who chose a shorter range vehicle in Situation Two than they had in Situation One, also chose a vehicle that cost more. We conclude that households will make choices from across a spectrum of range possibilities; so long as additional increments of range are expensive, demand for EVs and other limited range vehicles will be segmented by demand for driving range.

4.3 The value of novel EV attributes: Home recharging Home recharging is the single most valuable attribute of EVs for many households. When choosing a vehicle in Situation Two, households made choices of refueling/recharging capabilities and locations. Over half the households (54%) chose vehicles which refuel or recharge at home (EVs plus NGVs with home refueling). Among households that chose an NGV, 27% chose to buy the home refueling appliance, despite the fact this option was priced at $2,500; another 13% chose to lease this capability for $60 per month. These "point" values do not allow us to calculate elasticities, but they indicate some households place high value on avoiding fueling stations. Prior studies have documented a dislike of gasoline stations[1]. This suggests to us that home recharging and refueling are a highly valued attribute of electric (and possibly natural gas) vehicles.

4.4 Environmentalism in electric vehicle purchase decisions It has been assumed by many that the market for EVs, at least initially, would largely be environmentally motivated consumers; that is, early buyers of EVs would place very high value on, and therefore pay a premium price for, the low emissions of EVs. We find this is not a necessary condition of the early market. We relate two measures of environmentalism to choices between electric and gasoline vehicles in Situation One. Questions regarding environmental attitudes were asked in Part One of the survey, prior to any information or questions about EVs.

One question measured the percieved lifestyle impacts of environmental problems. By focusing on EVs as one transportation option within a hybrid fleet of vehicles, we observe that even households disinterested in environmental issues choose EVs. Three-fourths of the households responded that environmental problems are either the greatest crises of our time or are among are biggest problems. A strong belief that lifestyle changes are warranted to solve environmental problems was associated with a greater likeliness of choosing an EV. However, even among people who do not believe environmental problems are particularly pressing, more than a third chose an EV as their next new vehicle.

We came to a similar finding with the question, *How much more are you willing to pay for products which don't pollute compared to products which do pollute?"* The possible responses ranged from 0% to 100% more. We found neither a well-ordered nor statistically significant relationship between willingness to pay more for goods that are less polluting and the choice between an EV or gasoline vehicle in Situation One. Even among those relatively few people willing to pay virtually nothing more for non-polluting products, a substantial number chose EVs.

Households' activity schedules and vehicle purchases are not simply travel choices, they are also lifestyle expressions. We have just concluded that, while EVs will allow expression of pro-environmental values and lifestyle choices, such values are not a necessary pre-condition in the initial market.

5. QUANTIFYING THE HYBRID HOUSEHOLD MARKET

The hybrid household hypothesis is supported strongly by the evidence in this study. We conclude that across the variety of range choices offered in our study, many *potential hybrid households* find a range that represents an inconsequential drawback. Further, any disadvantage is more than offset in their minds by the positive attributes of home recharging and "greenness" (and possibly other attributes we have not yet explored).

To establish the relevance of this conclusion from our choice experiments to the real world of markets and mandates, we translate our findings into estimates of new car market shares for the state of California. To do so, we must determine what proportion of light duty vehicles sales is represented by potential hybrid households. We divide annual light duty vehicle sales into four segments: commercial and government fleets; single vehicle households; potential hybrid households; and multi-vehicle, non-potential hybrid households.

We estimate that *potential hybrid households* buy between 35 and 40% of all new light-duty vehicles sold in California every year. If, as was the case in our first choice situation, 46% of potential hybrid households choose an EV, then we expect 16 to 18%

of annual light-duty vehicle sales would be limited range electric vehicles sold to potential hybrid households. If a wider variety of range options and propulsion types were offered, the results of our Situation Two translate into annual market shares of 23 to 26%.

Not all the types of EVs chosen by households in Situation Two have been demonstrated. The mid-size body style, longer range regional EVs were based on battery technologies not yet commercially available, but expected to be available by the year 2000[19]. Limiting our estimates to currently demonstrated EV technologies, our results indicate there is still more than adequate potential markets for electric vehicles to have exceeded the former 1998 CARB mandate for sales of ZEVs in California (with the price assumption we imposed). These vehicles include small (sub-compact) and compact sedans, wagons, sport-utility vehicles, pick-up trucks and sports cars with driving ranges of 60 to 150 miles and mid-size body styles with ranges of 60 to 80 miles. The market potential for these vehicles would be 7% of the total light-duty vehicle market. This estimate does not include any sales to fleets, nor does it include any sales to households who lie outside our sample.

6. CONCLUSIONS

We identified a substantial market for reduced range, home recharged electric vehicles among a particular group of multi-car households. Though we provide quantitative estimates of sales to this market segment, these numbers should be viewed as illustrative of market responses, not as forecasts. Actual EV purchases could be far more or less, depending on prices, vehicle performance, marketing strategies, government incentives and rules, and ultimately, on whether consumers regard the EVs offered to them as a affordable, viable options within a variety of transportation services.

What we can say with confidence is the following. The vehicle choices made by our respondents support our central hypothesis. The fundamental differences between electric and gasoline vehicles in our choice experiments were driving range, home recharging and emissions—purchase prices in particular were designed to overlap between vehicle types. We conclude that any disutility of reduced range is more than offset by the value of home recharging (as stated in the hypothesis) and possibly zero emissions. We break down the responses to these three attributes of EVs as follows.

First, we believe the environmental image of EVs will have a greater impact on information search and choice set formation than on choices between vehicles within that choice set. While we find, along with others[20], strong concern for the environment, the role of motor vehicles in degrading the environment, and the need to make some corresponding lifestyle changes, we did not find in previous work[1] that those concerns translate into willingness to pay thousands of dollars more for clean vehicles. But environmental factors will play an important role in the search process for new vehicles. In testimony to CARB, a respected auto industry analyst points out that "the current car buyer is confronted with more than 900 available models of new cars and light trucks...the typical buyer will actively consider only 6 vehicles and actually shop to compare only 3"[21]. Our research suggests that the positive environmental image of EVs will put them on the short list of a large number of buyers.

Second, home recharging is probably the most valued novel attribute of EVs. The willingness of many buyers to spend many thousands of extra dollars for an EV, given their reduced range and our belief that environmental attributes have more to do with choice set formation than with choices from that set, can best be attributed to the attraction of home recharging.

Third, any disutility of reduced driving range in one (and possibly more) household vehicle is small for most multi-car households. Many critics would contend that electric vehicles must achieve ranges higher than 150 miles to be commercially viable. But we find evidence in our studies that the marginal utility of range beyond 150 miles for home rechargeable vehicles will be small—in our studies, any household that can adapt to any reduced range, adapts to a range of 150 miles or less. We argue that the utility of short range, home rechargeable EVs lies primarily in their complementary, not competitive, relation to vehicles that have over 300 miles range and quick, ubiquitous refueling—in their ability to diversify transportation services and lifestyle expressions in hybrid households.

Further, so long as additional range is relatively expensive, the market for EVs will be segmented by demand for driving range, with some households preferring vehicles with ranges a low as 40 to 80 miles. A large number of households opted for a short range EV when familiar long range gasoline vehicles were available. It is precisely this willingness of households to choose shorter range vehicles that opens up the market to electric vehicles than can be built and sold based on technology not too different from what is available as this is written in 1996.

A successful market launch depends on designing EVs that do respond to consumer preferences for the novel attributes of EVs, and do not attempt to

duplicate all the performance attributes of gasoline vehicles. Likewise, research should focus less on new batteries that provide longer range (i.e., higher specific energy and energy density), and more on improved battery cycle life, energy management, and manufacturing costs. So long as the belief persists that EVs must mimic the long range and short refueling times of gasoline cars, the EV market will be stalled, at least until the commercialization of fuel cell electric vehicles. Failure to recognize the market for truly reduced range EVs will unnecessarily delay the introduction of EVs and possibly lock us into an unnecessarily expensive future.

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