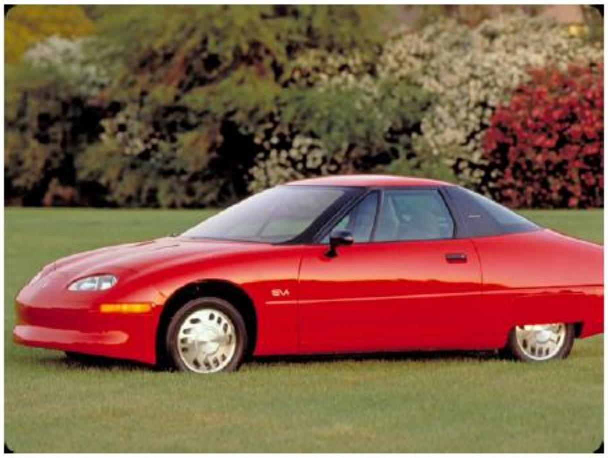
History and Status of the Battery Electric Vehicle (BEV)

By Pat Murphy, Plan Curtail



2006 GM EV1 – First Delivered December 1996

2011 Nissan Leaf – First Delivered December 2010

December 2011

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Introduction

General Motors (GM) first demonstrated an electric concept car, called the Impact, in 1990. [1] This marked the beginning of a major effort by automakers to meet the stringent emissions requirements of the California Air Resources Board (CARB), using Battery Electric Vehicles (BEVs), also referred to as zero emissions vehicles (ZEVs). Between 1996 and 2003, approximately 5,600 BEVs were manufactured. Eventually, some automakers, with support from the U.S. government, initiated a lawsuit that had the effect of neutralizing CARB's ZEV requirements. Most of the BEVs had been leased. Almost all were recalled by their manufacturers and scrapped.

A few years later, the BEV was reborn, first with the shipment of the Tesla Roadster in 2008 and later the shipment of the first volume produced BEV, the Nissan Leaf, in December, 2010. The main justification for a new family of BEVs was the replacement of lead acid and nickel metal hydride battery technologies with batteries based on lithium ion technology, which are used both in the Tesla and the Leaf. Lithium ion batteries are intended to increase the range of the cars between battery charges. But a better battery is like a better (or larger) gas tank: miles per gallon (MPG) do not change.

The current generation of BEV cars will have little effect on climate change or energy consumption. Such cars do not meet the MPG or the CO_2 emissions levels of the hybrid electric vehicles such as the Toyota Prius. As will be explained later, the Hybrid Electric Vehicle (HEV) was the real reason for the demise of the CARB program and the cancellation of BEVs of the late 1990s and early 2000s. This historical fact has been overlooked due largely to disinformation from electric vehicle advocates, car manufacturers, electric power companies, and government agencies. Now that mass production electric vehicles are available for testing, BEV MPG and CO_2 emissions can be measured relative to conventional cars and gasoline hybrids.

The 1990 Birth of the Battery Electric Vehicle (BEV)

CARB required that zero emissions vehicles (ZEVs) make up at least two percent of new car sales by 1998, five percent by 2001, and ten percent by 2003.[2] CARB's radical low emission policy was inspired by its knowledge and belief in the potential of the GM Impact. The Impact was built by GM subcontractor Aeroenvironment. GM Chairman Roger Smith demonstrated the Impact in early 1990 and was very supportive of the ZEV concept.[3] The Impact was not only an impetus for CARB policy but also the technological basis for the GM EV1, the first marketable ZEV ever built, which was delivered in late 1996. Toyota, Ford, Honda, Chrysler, and Nissan also developed and produced ZEVs to meet the CARB requirements. CARB eliminated the two percent and five percent ramp-up targets in 1996, leaving only the ten percent requirement in place for 2003. Note that "zero emissions" meant that no emissions were generated directly from the car. Emissions from power plants that produced the electricity for the car were ignored. These ZEVs were all BEVs and the terms will be used interchangeably.

In 2001, after eleven different ZEV models had been delivered, CARB proposed modifying the program to allow partial credits for extremely clean vehicles known as "partial zero emissions vehicles" (PZEV) and "advanced technology partial ZEVs" (AT PZEVs), which would have included recently delivered HEVs such as the Toyota Prius and Honda Insight. This proposed extension of the ZEV program was controversial. In

January 2002, GM, DaimlerChrysler and several California car dealers filed a federal lawsuit against CARB, alleging the new ZEV rules violated a federal law barring states from regulating fuel economy in any way. In October 2002, the federal government filed an amicus brief on behalf of the plaintiff automakers.

In response, CARB changed the ZEV mandate to eliminate many of the requirements, at which point automakers stopped building and leasing the ZEVs. GM reclaimed the EV1s from their lessees and recycled all of them except for a few museum models. Toyota sold some RAV4 EVs to the public and a small number are still being driven today. The manufacturers, models, and numbers of ZEVs built are shown in table 1. (The "On Road Today" numbers were prepared in 2006).

Company and Model	Leased/Sold	On Road Today
Toyota RAV4 EV	1,485	820
Ford Ranger EV	1,312	400
GM EV-1	800	0
Ford Postal Van	495	0
Chevrolet S-10 Electric	450	55
Ford Think City	440	100
Honda EV Plus	300	0
Chrysler EPIC	207	5
Nissan Altra	130	0
Nissan Hypermini	50	0
Toyota eCom	15	0
Total All Models	**5,599**	**1,380**

Table.1: Zero Emission Vehicles Produced and Still in Use[4]

Much of the criticism about BEVs was based on their relatively short driving range between charges, along with the lack of public battery charging facilities. Drivers were supposedly concerned that they would be stuck somewhere with depleted batteries because of these limitations. The EV1 (and some other BEVs) were first built with lead acid batteries and later with nickel metal hydride batteries, which—although an improvement over lead acid batteries—still had a very limited range. Whether this was the main reason for the small number of sales is not known. However, this is important because the current renewed focus on the BEV comes from the availability of the new lithium ion battery technology. Should "range anxiety" not be the reason for low sales in the 1996–2003 period, a lithium-based product line may not generate volume sales.

Measuring EV MPG in the 1990s – kWh per 100 miles

When the original CARB ZEV program began in California, better automobile gas mileage or reducing CO_2 emissions was not the main objective. The Los Angeles area was badly affected by smog, and the hope was to move emissions from the tailpipes of the cars to the faraway smoke stacks of electric power plants. Note that 80 percent of electric cars sold in the U. S. during the CARB ZEV period were in California. Thus, MPG was secondary to low emissions in the cities.

Mileage ratings have been available on car window stickers since 1975. Their purpose was to provide an MPG for every automobile model sold. The original format provided separate numbers for city and highway driving. Later these were combined into a third number, which was a weighted average of city and highway MPG. Figure 1 shows the original, simple label. The two mileages are given as well as MPG ratings and caveats on driving patterns and other conditions that affect MPG.

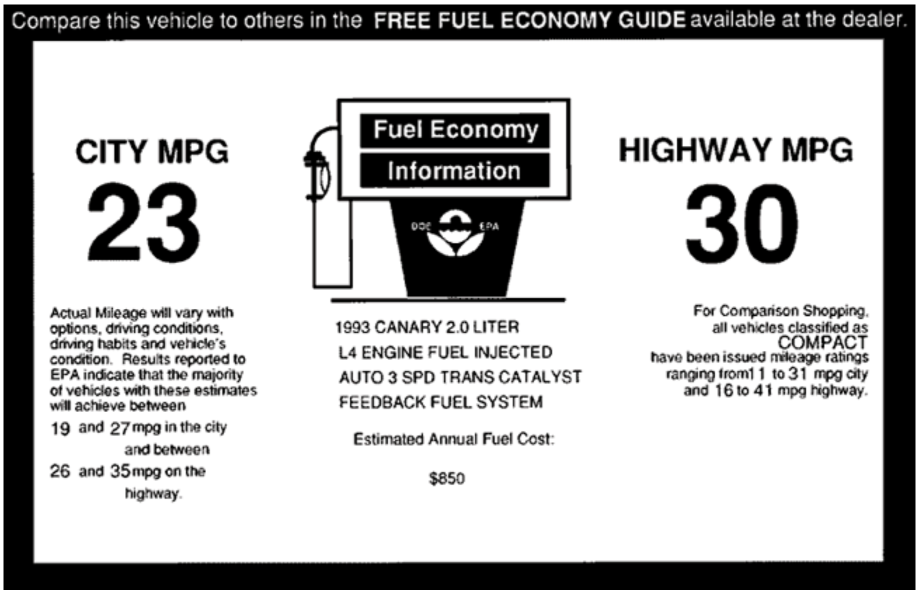

Figure 1: Early MPG Window Label (Sticker)[5]

The MPG claims of the late 1990s' BEVs, including some of the cars listed in table 1 are important to understand in order to determine the possible MPG improvements made by contemporary BEVs. For analyzing the cars of the CARB era, I have selected the still operational Toyota RAV4 EV; some are still being driven on a daily basis. The RAV4 EV was chosen rather than the more well known GM EV1 because all EV1s were recycled and none are available for testing.

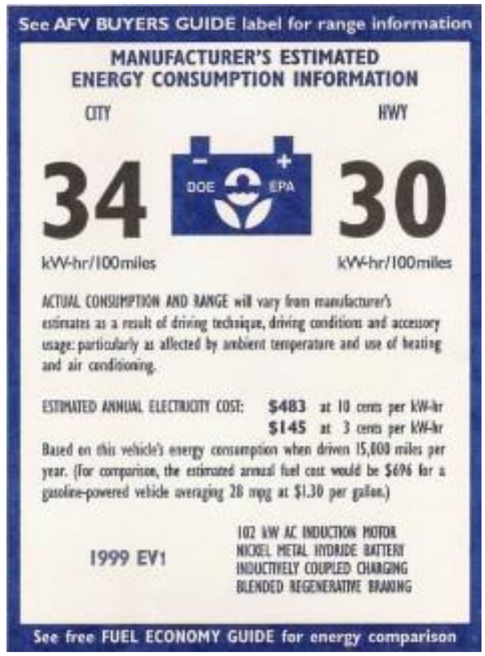

Figure 2: Original GM EV 1 Window Sticker

Figure 2 shows the original car window label for a 1999 GM EV1,[6] and figure 3 shows the window label for a 2002 RAV4 EV.[7] Note that the MPG information is given as kW-hr per 100 miles, a representation that is different from the labels for gasoline or diesel cars, which show miles per gallon. (See fig.1.) This has led to consumer confusion. In using kW-hr per 100 miles, a higher number implies a less efficient car. Using the familiar MPG method, the higher number implies a more efficient car. The EV1 was a less efficient car than the RAV4 EV on city driving, as shown by its 34 kW-hr/100 miles compared to 27 kW-hr/100 miles for the RAV4 EV. The EV1 was a more efficient car for highway because its 30 kW-hr/100 miles is lower than the 34 kW-hr/100 miles of the RAV4 EV. Consumers must carefully consider the format of MPG values to determine the fuel economy.

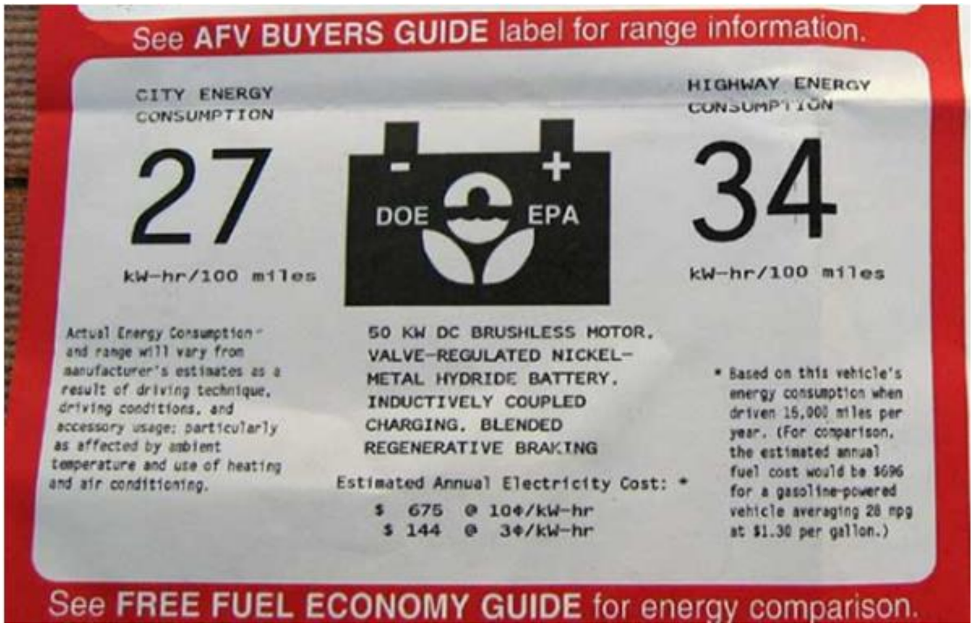

Figure 3: 2002 RAV4 EV – Original Window Label

These early BEV labels show the miles delivered from kilowatt hours (kW-hr) consumed. No matter how it is written, kW-hr per miles or miles per kW-hr, it is a true scientific measurement of the amount of electrical energy to drive a certain distance. Over time, the designation kW-hr was shortened to kWh. From here on in this report, the more recent designation of kWh will be used.

Misrepresenting MPG: The BEV MPGe Rating

The EPA at some point devised a method of converting the "kWh numbers per 100 miles" on the BEV window labels, as shown in figures 2 and 3, to a "Miles per Gallon" MPG format. Figure 4 is an example of this methodology applied to the 2003 RAV4 EV, which was obtained from the fueleconomy.gov website. Later the measurement was changed to "Miles per Gallon Equivalent," abbreviated as MPGe. For some years, the "equivalent" qualifier was not included, but merely implied. Today the term is common on the most recent EPA labels.

The MPG values shown in figure 4 are very impressive—a combined average of 112 MPG! This is particularly impressive because the gasoline- only 2003 RAV4 MPG mileage rating was only 24 MPG, implying an improvement ratio of five to one between a gasoline and BEV version of the same car. This led some people to think that the BEV version of the RAV4 represented an extremely radical improvement in energy efficiency. The label also claims similar improvements in the reduction of greenhouse gas emissions.

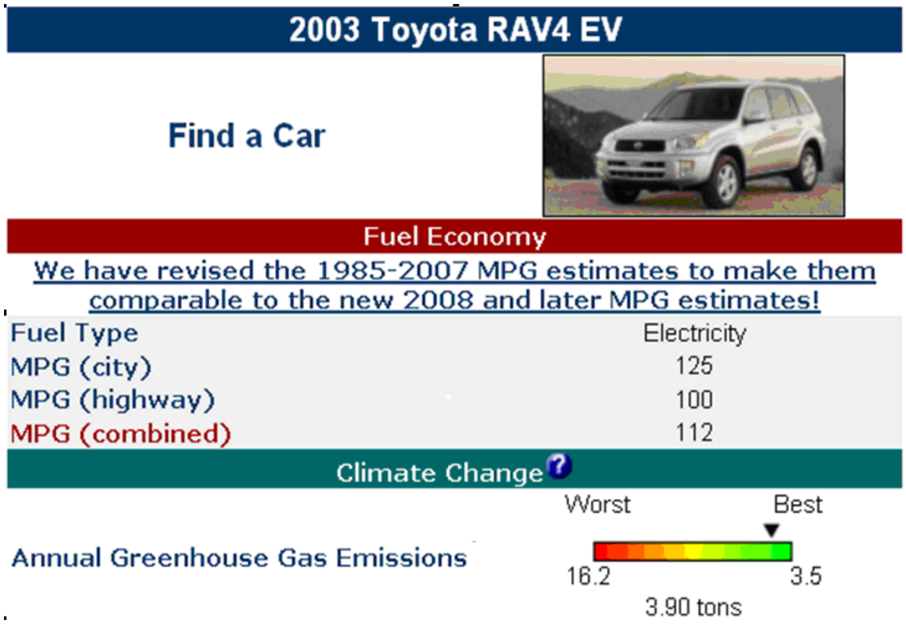

Figure 4: Early RAV4 EV MPG from EPA's fueleconomy.gov Website [8]

Trying to construct a history of EPA MPG analysis for BEVs is not easy. The EPA periodically changes the MPG numbers for older cars on its website. Moreover, the EPA has removed the earlier EV MPG numbers from its website so historical reconstruction is difficult. Such EPA changes to the 2003 RAV4 EV performance numbers need to be clearly defined for complete understanding of fuel economy ratings. Fortunately, the EPA website contains the older Yearly Fuel Economy Guides,[9] which were published in hard copy and which contain some of the original numbers. Analyzing these guides provides a continuity of comparison, while the interactive aspects of the website tend to discount historical data.

The 1999 Fuel Economy Guide, published in October 1998, was the first guide to show electric vehicles. Six distinct BEVs were listed. The GM EV1 was included but did not have an MPG number. The Honda EV plus, the Ford Ranger Electric, the Dodge Caravan and the Plymouth Voyager contained energy consumption data. The RAV4 EV was not included until the 2000 and 2001 guides, which listed the RAV4 EV numbers as 29 kWh/100 miles for city and 37 kWh/100 miles for highway. There were only three BEVs listed in the 2000 guide and four listed in the 2001 guide, signifying the decline of the BEVs programs. In the 2002 guide, the MPG fuel consumption numbers for the four BEVs listed in the 2001 guide were eliminated. In the 2003 guide, the RAV4 EV numbers were 27 kWh/100 miles city and 34 kWh/100 miles highway, the values on the 2002 RAV4 EV window label shown in figure 3. These are the numbers used in table 2. No other BEVs were listed in 2003. The Fuel Economy Guides contained no BEV information from 2004 to 2008.

There were no numbers published in the Fuel Economy Guides after 2003 for the RAV4 EV. This reflected the decline in BEV interest that began when CARB changed its ZEV program. In 2009, the Tesla electric car first appeared but no kWh per 100 miles was given. The Chevrolet Leaf first appeared in the 2011 guide. In this guide, the kwh/100 miles are included as well as an MPGe, number. At some point, the EPA changed the MPG ratings for the RAV4 EV on its website. The current rating (December 2011) on the EPA website for the 2003 RAV4 EV is 39 kWh for city and 49 kWh for highway (Figure 5).[10]

Figure 5: Current RAV4 EV MPG Rating

Initially, the EPA established the kWh/100 miles for the original BEVs. Probably around 2003, MPG was added. Sometime later, probably in 2009 or 2010, the EPA began using MPGe.

Getting from kWh to MPGe the Wrong Way

The EPA conversion process from “kWh for 100 miles” to MPG and later to MPGe needs to be understood. I will explain this process using information in table 2. The RAV4 EV is used in this explanation. Because there are two sets of EPA MPG numbers, two versions are listed, V1 being the RAV4 EV shown in figure 3 (27 kWh city/34 kWh highway per 100 miles) and V2 being the RAV4 EV shown in figure 5 (39 kWh city/49 kWh highway per 100 miles). Only the combined mileage is used rather than combined, city, and highway in order to simplify the explanation. RAV4 EV V1 combined mileage is the average of 27 and 34 (30) while RAV4 EV V2 combined mileage is taken from the label in figure 5.

Col. 1 Car Year/ Model	Col. 2 Mode	Col. 3 kWh/ 100 miles	Col. 4 kWh/ mile	Col. 5 Miles/ kWh	Col. 6 33.7 kWh MPGe
2003 RAV4 EV V1	Combined	30	0.30	3.33	112
2003 RAV4 EV V2	Combined	43	0.43	2.33	78

Table 2: 2003 RAV4 EV EPA Mileage, Versions 1 and 2

The first column of table 2 shows the car year and model. Because two sets of MPG numbers have been provided by the EPA for the RAV4 EV, two entries, labeled 2003 RAV4 EV V1 and 2003 RAV4 EV V2, are listed. The second column (Mode) lists the method of computing mileage—in this case only the combined mileage for city and highway driving is noted. The third column (kWh/100 miles) shows the kWh measurements from the two 2003 RAV4 EV labels—30 kWh/100 miles for the RAV4 EV V1 value average from the two numbers in figure 3 and 43 kWh/100 miles from the number in figure 5. The fourth column (kWh/mile) derives the kWh consumed for a single mile by dividing the number in column 3 by 100. Column 5 (Miles/kWh) is obtained by inverting the value from column 4, that is, dividing the number "1" by the value in column 4. This changes the numbers from the "kWh/mile" format (column 4) to a "miles/kWh" format (column 5), which is a representation similar to the conventional MPG of gasoline. Columns 1 through 5 are taken directly from the electric performance data given on the car label (see fig. 4 and 5) or derived from those data.

Column 6 is calculated by multiplying the kWh of electricity contained in a gallon of gasoline (33.7 kWh per gallon) times the Miles/kWh entry in column 5. Note that the resulting numbers in column 6 of this table are almost identical to the EPA MPG numbers in figure 4 and 5, justifying the methodology. The EPA tends to use its own method of rounding and truncating: sometimes values are rounded up by one arbitrarily, for example the 100 MPG for highway in figure 4 versus the 99 MPG for highway in column 6 of table 2. Thus, exact correlation is not to be expected.

It is not clear why the EPA did not choose to use the same measures, miles per energy (gasoline or electricity), rather than use one method for gasoline and another for electricity. Possibly the EPA chose to make the final numbers look as similar to MPG as possible, for example, by making them two digits. Energy consumption on the label for kW-hrs/100 miles is shown in two digits. In terms of kWh for an electric car, MPG is a single digit, typically 2–3 miles per kWh. Whatever the case, it is easy to get confused by the different methodologies.

Figure 6: 2011 Nissan Leaf MPG Information from EPA Website

People interested in MPG improvement over some time period will want to compare the early RAV4 EV of the late 1990s with modern models of electric cars, such as the contemporary Nissan Leaf, in order to determine the efficiency improvements in electric car motors. This will be done by comparing the MPGe of the first cars measured 13 years ago with the MPGe of contemporary BEVs. The MPGe of the latest contemporary BEV, the Nissan Leaf, is listed as 99 MPG, according to the EPA fueleconomy.gov website (see fig. 6).

The kWh for 100 miles information from the Leaf is added to table 2.2 to derive table 3. Compared to the original BEV (RAV4 EV V1) estimates (fig. 3 and 4), the Leaf shows a decline in MPG. But compared to the more recent numbers for RAV4 EV V2 (fig. 5), MPG has improved. It is still possible to compare existing RAV4 EVs with the Leaf to provide an updated comparison.

Col. 1	**Col. 2**	**Col. 3**	**Col. 4**	**Col. 5**	**Col. 6**
Car Year/ Model	**Mode**	**kWh/ 100 miles**	**kWh/ mile**	**Miles/ kWh**	**33.7 kWh MPGe**
2003 RAV4 EV V1	Combined	30	0.30	3.33	112
2003 RAV4 EV V2	Combined	43	0.43	2.33	78
2011 Leaf	Combined	34	0.34	2.94	99

Table 3: 2003 RAV4 EV (V1 and V2) and Leaf EPA MPG

It could be argued that such a comparison of past and present BEVs is a moot point. However, it is important to compare the improvement in electric motors between 1997 and 2010 with the improvement in gasoline engines over the same period. If we assume the 43 kWh/100 miles as accurate for RAV4 EV V2 mileage, then the increase in MPGe between that car and the Leaf is about 25 percent or about 1.5 percent per year, which is close to historical MPG improvements for gasoline cars. [11, 12] If we assume the RAV4 EV V1 number, there has been no improvement—the MPGe has declined.

Getting from kWh to MPGe the Right Way

The BEV MPG numbers are impressive but unfortunately misleading because the EPA method does not include the energy required to generate the electricity used in the BEVs. The energy in electricity that is used to power a battery car comes from a power plant that typically burns coal, natural gas, or oil. In its calculation, the EPA does not consider the energy lost in generating electricity, which is about two-thirds of the total energy burned. The EPA is ignoring the laws of thermodynamics of electricity generation. To have an accurate comparison would require that the electric MPGe number be divided by approximately three to take this loss into account.

The method of calculating BEV MPG or MPGe seems consistent for both the EVs of the late 1990s and early 2000s as well as for the newer electric cars, such as the 2011 Leaf. One might wonder why the EPA does not use an accurate representation. It is not because the EPA is unaware of the laws of thermodynamics—it is fully aware that two-thirds of the energy from coal, natural gas, or oil in a power plant is lost in heat. The EPA notes:

> The average efficiency of fossil-fueled power plants in the United States is 33 percent and has remained virtually unchanged for four decades. This means that two-thirds of the energy in the fuel is lost—vented as heat—at most power plants in the United States.[13]

Two terms are frequently used when explaining the loss – “source energy” and “site energy.” These are discussed in another EPA paper entitled “Energy Star Performance Ratings Methodology for Incorporating Source Energy Use.”[14] This paper explains that most of the source energy (coal or natural gas at the power plant) is lost in the heat generated at a power plant and therefore the site energy (electricity at the plug) is only a fraction (about one-third) of the original source energy. Although this particular EPA paper describes energy use in buildings, it is relevant to cars because essentially all electric cars are and will be typically charged from an electric outlet in a house, an office building, a garage, or some other physical location. In one sense, BEVs can be viewed as new appliances in our homes and offices. For us to accurately account for the energy used to power our electric cars, e.g. charge the car batteries, it is necessary to include the source fossil fuels energy with the site energy of electricity. No matter how high the efficiency of the electric devices using electricity, whether it is a car or a blender, total energy efficiency is reduced by inefficient generation and transmission.

Including source energy and its losses will allow a more accurate measure of MPGe for BEVs. An MIT report on EV mileage[15] gives the efficiency of electricity generation as 32.8 percent and the efficiency of electricity transmission as 92.4 percent. Multiplying the two MIT numbers gives a total efficiency of 30.3 percent, slightly less than the EPA estimate of 33 percent. If the EPA car window stickers were accounting for energy loss in generation and transmission of electricity, the MPG equivalent number would not be 33.7 kWh per gallon of gasoline, but 10.2 kWh per gallon of gasoline (30.3 percent of 33.7 kWh). Table 4 is constructed to compare the inaccurate method with this more accurate one. This table is developed by adding an additional column to table 3. This more accurate MPGe, in column 7, is much lower than the misleading values in column 6 of table 4.

Col. 1	Col. 2	Col. 3	Col. 4	Col. 5	Col. 6	Col. 7
Car Year/ Model	**Mode**	**kWh/ 100 miles**	**kWh/ mile**	**Miles/ kWh**	**33.7 kWh MPGe**	**10.3 kWh MPGe**
2003 RAV4 EV V1	Combined	30	0.30	3.33	112	34
2003 RAV4 EV V2	Combined	43	0.43	2.33	78	24
2011 Leaf	Combined	34	0.34	2.94	99	30

Table 4: RAV4 EVs and Leaf with Adjusted Ratio of kWh to Gallon of Gas

The information in column 7 represents a far more accurate way of determining MPGe than the information in column 6 does because it takes into account the energy losses associated with generation and transmission or, putting it another way, it takes into account source energy loss in making electricity. Comparing column 7 to column 6 shows how the electric car performance is overstated.

This is still not the most accurate comparison to gasoline cars because it does not include the energy penalty associated with refining gasoline from oil nor does it include the energy transportation costs of moving gasoline from refinery to gas station. Oil refining and surface transportation from the refinery to a gasoline station are analogous to power plant generation of electricity from coal or natural gas and the transmission of this electricity from the power plant to buildings (typically) via the grid. However, the energy loss for refining oil into gasoline is much less than the energy loss for converting coal or natural gas to electricity. The same MIT report on EV mileage[16] that shows electricity generation and transmission efficiency to be 30.3 percent also addresses the energy lost in shipping oil across the oceans, refining it, and transporting the gasoline to the gasoline station. The efficiency of oil refining to gasoline and the transporting gasoline to filling stations is 83 percent, that is, 17 percent of the energy is lost in transporting oil and converting it to gasoline. This efficiency can be incorporated into table 4 by dividing 10.2 kWh (the value in column 7) by 83 percent, providing a more accurate and complete ratio of energy efficiency of 12.3 kWh. This decreases the performance of the gasoline car relative to the electric car. Table 5 incorporates this change.

Col. 1	Col. 2	Col. 3	Col. 4	Col. 5	Col. 6	Col. 7
Car Year/ Model	**Mode**	**kWh/ 100 miles**	**kWh/ mile**	**Miles/ kWh**	**33.7 kWh MPGe**	**12.3 kWh MPGe**
2003 RAV4 EV V1	Combined	30	0.30	3.33	112	41
2003 RAV4 EV V2	Combined	43	0.43	2.33	78	29
2011 Leaf	Combined	34	0.34	2.94	99	36

Table 5: RAV4 EVs and Leaf, Including Energy for Gasoline Refining/Transport

The average value for the combined option for the two RAV4 EV versions in this scenario is 35 MPG. (That is, 41 MPG plus 29 MPG divided by 2). This is about 50 percent better than the 24 MPG of a conventional gasoline 2003 RAV4, recognizing the somewhat higher efficiency of power plants over gasoline engines that prevailed in the late 1990s. It is far less than the 3–4 times improvement implied by EPA numbers.

The Leaf is more efficient than the RAV4 EV, reflecting electric drive technology improvement. It is also aerodynamically more efficient and weighs somewhat less. Because there are two numbers for the RAV4 EV, a complete comparison is not possible. An estimate of 15–30 percent more efficient is probably a reasonable one. It would be useful for the EPA to make this comparison between an existing RAV4 EV that is still in use and a new Leaf.

This analysis is very important in evaluating BEVs. We do not know how MPGe was calculated in the early years of the BEVs built in the late 1990s. Possibly owners just considered the measure of kWh/100 miles and made no attempt to compute an MPGe. The EPA began using this in 2009 or 2010 but, as has been shown, in a misleading manner.

BEVs versus HEVs – Then and Now

A popular 2006 documentary film, *Who Killed the Electric Car?,* [17] described the creation, deliveries, and subsequent destruction of the early BEVs of the 1990s. It focused specifically on the GM EV1, first delivered in late 1996. The film considered the roles of automakers, governments, and consumers. (In late 2011, the director of the film, Chris Paine, produced a follow-on documentary entitled *Revenge of the Electric Car*.) *Who Killed the Electric Car?* argued that a huge blunder was made when the seven automakers stopped building BEVs in the early 2000s. GM in particular was treated harshly for canceling its EV1 program. The film implied that GM made only minimal efforts to sell the car and acted inappropriately in other ways. But the real killer of the EV in the late 1990s was not incompetence or malfeasance on the part of GM and other car companies nor the U.S. government, but rather the Toyota Prius (introduced in the U. S. in 2000), the Honda Insight (introduced in the U. S. in 1999), and later the Honda Civic Hybrid (introduced in the U. S. in 2002). It is quite likely that later versions of HEVs will have the same impact on the fledging BEV industry.

The U.S. government played an indirect role in the success of the Toyota and Honda hybrids. In 1993, the government and the three major U.S. automakers (GM, Ford and Chrysler) formed the Partnership for a New Generation of Vehicles (PNGV) to develop advanced high-mileage diesel hybrids.[18] This program was limited to American car manufacturers. Partially in response to being excluded from the PNGV, Toyota began its own hybrid project (G21) in 1994. At about the same time, Honda began the development of the Insight hybrid. The Toyota G21 concept car was shown in 1995 and in 1997 the Prius, developed from the G21, went on sale in Japan, with first year sales of 18,000. In August 2000, the Prius was launched in the United States as a 2001 model, with a price of about $20,000. There were 5,562 Prius sales in the United States during the August–December 2000 period, roughly the same number as all the EVs shipped during the 1996–2002 period. U.S. Prius sales were 15,556 in 2001 and 20,119 in 2002. Figure 7 shows the success of the Toyota and Honda hybrids (HEV) compared to the many BEV offerings.

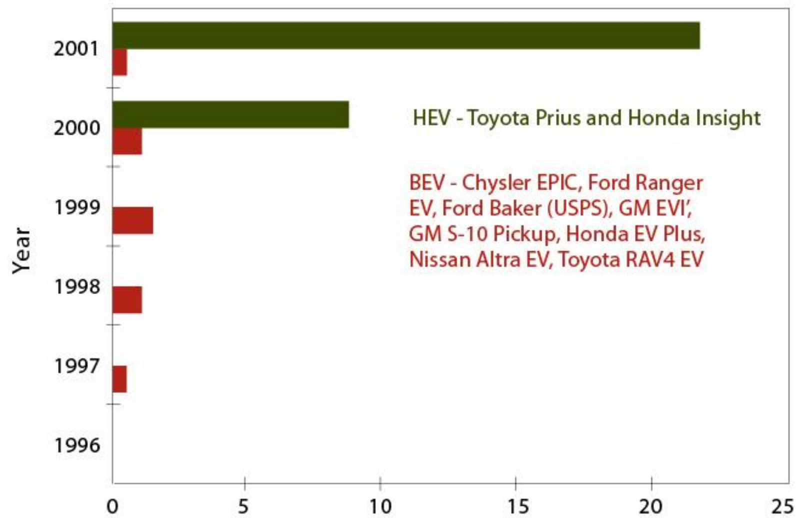

Figure 7: Comparison of ZEV and Hybrid Sales/Leases

In the ensuing three years, hybrid sales increased rapidly. (See fig. 8).[19] Today, hybrids have become a major force in the United States. And as of mid-2011, over 3 million hybrids had been added to the car fleets of the world, a far cry from the few thousand BEVs that have now been scrapped.

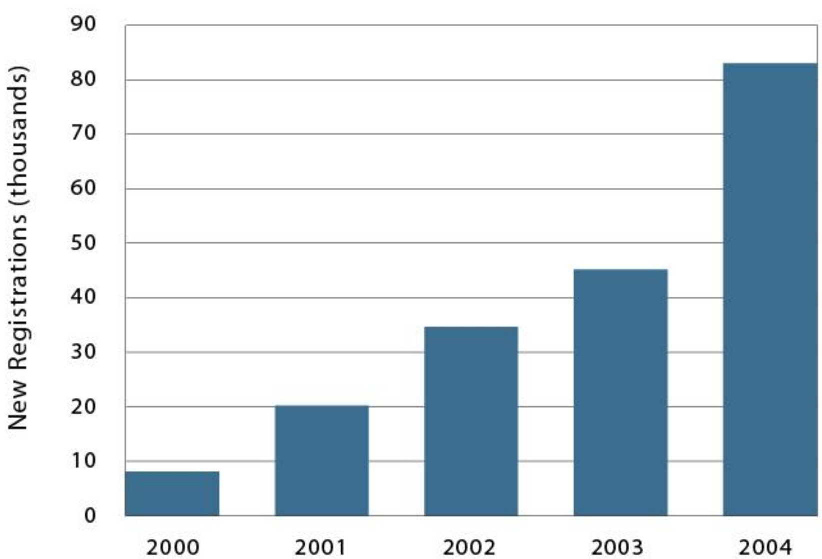

Figure 8: First Five Years – Hybrid Sales, U.S.

I have argued that the HEVs from Toyota and Honda killed the BEVs made by seven carmakers in the late 1990s. The same thing could happen today. A comparison of a contemporary HEV and contemporary BEV will be useful in determining of this view is realistic. The ideal comparison is between the Leaf BEV and a high MPG gasoline car such as the Prius. This comparison might be challenged as unfair, arguing that a fairer comparison would be between a BEV and conventional gasoline car. My perspective is that the Prius is at its core a gasoline car representing a major improvement over conventional gasoline cars; in essence, it is a new gasoline car architecture with significantly better MPG. It is a gradual evolution, which may lead to the demise of the conventional gasoline car in the not too distant future.

Figure 9: MPG for Prius and MPGe for Leaf

Figure 9 is an EPA comparison of the 2011 Prius and the 2011 Leaf. Table 2.5 shows the combined mileage of city and highway driving, using the EPA's conversion ratio of 33.7 kWh per gallon of gasoline and the more accurate conversion ratio of 12.3 kWh per gallon of gasoline. Because we have corrected the calculations for the Leaf, it behooves us also to correct the calculations for the mileage of the Prius with the 17 percent refining/transport penalty discussed earlier. Thus, the Prius comparable mileage might be 44 MPG (50 times .86). Table 6 shows the results of the corrections.

Car	Quoted MPG	Correction Factor	Actual MPGe
Leaf	99 MPGe	0.36	36 MPGe
Prius	50 MPG	0.87	44 MPGe

Table 6: MPGe Comparison of 2011 Leaf and 2011 Prius

One can argue that the Leaf may be 25 percent more efficient than earlier BEVs like the RAV4 EV and its distance between charges will be much higher. But the 2011 Prius has improved its MPG by 20 percent over the 2000 Prius. Thus, the MPG differential between the older and newer BEVs may be no better than the MPG differential between the older and newer versions of the Prius. The Leaf is in its first year of manufacturing, which puts it at a disadvantage to the Prius. On the other hand, Prius sales in 2011 have suffered because of the damage done to Toyota manufacturing plants as a result of the earthquake and tidal wave that occurred in early 2011. In 2011, Prius sales in the U.S. totaled 136,463 units while Leaf sales totaled 9,674 units. [20]

CO_2 Emissions of BEVs – Inaccurate and Accurate Calculations

Another way of comparing electric cars to gasoline cars is to determine the CO_2 generated by each type of car and derive the MPG or MPGe from this number. Consider the following thought experiment to compare the RAV4 EV to the gasoline RAV4. To get the MPG of the gasoline-only RAV4, one needs only to add a gallon of gasoline to an empty tank and drive the car until it stops when the tank is empty. To get the MPG of the RAV4 EV, one could take a gallon of oil to an oil fired power plant, and use it to generate electricity to charge the RAV4 EV battery, which is highly impractical and probably impossible. However, oil is a common fuel for power plants and information is available on its use. This would allow a more exact comparison.

I have challenged EPA's methodology relative to MPGe and argued that its numbers are misrepresentative. Unfortunately, its numbers for CO_2 emissions are also misrepresentative. And the counterarguments I will develop use information from the EPA and Department of Energy (DOE) to make my case.

Much can be learned from reviewing the recent EPA window labels for electric cars as was done for the earlier BEVs. In November 2010, a new temporary label was developed by the EPA for the Leaf because the car was scheduled to ship in December 2010. (See fig. 5.)

Figure 10: November 2010 EPA Label for Electric Vehicles

The November 2010 interim label shows the city, highway, and combined MPG or, to be more precise, the MPGe, using the erroneous ways of calculating described earlier. The very small print near the bottom of the label contains the statement "MPGequivalent:

33.7 kW-hrs = 1 gallon gasoline energy." This is the first time that the EPA has added this comment to the window sticker. As previously noted, the EPA first added the same statement to its 2011 Fuel Economy Guide. This is fortunate because the EPA is now being more forthcoming with useful technical information. Nonetheless, I cannot help but comment on the extremely small print as compared to the size and boldness of the fonts for MPGe and cost.

For the first time in window sticker history, CO_2 information has been added to the window label. It is hard to imagine that information can be presented in a more difficult way than the MPGe, but the label achieves that. The CO_2 values are on the right-hand side of the label. The value of 0 is displayed in a bar representing a range of CO_2 emissions. Underneath this is a line that reads "CO_2 g/mile (tailpipe only)." The window sticker has added a new component, CO_2 emissions from the tailpipe, which is zero because the emissions from the power plants that generate the electricity used in the car are not included. Rather than ignoring CO_2 emissions, the EPA now states boldly that there are none. This is as misleading as the 99 MPGe.

Prior to the release of the November 2010 window sticker, the EPA had initiated a major project for an entirely new set of labels for upcoming alternative fuel vehicles, such as cars fueled by hydrogen, ethanol, compressed natural gas, diesel fuel, and electricity. The schedule did not provide a window sticker for the Leaf and Volt in sufficient time to make them available before shipments. Thus the November 2010 sticker was an interim one. In May 2011, the EPA published a wide-ranging new set of labels that included a replacement for the November 2010 labels. The electric vehicle version is shown in figure 11.

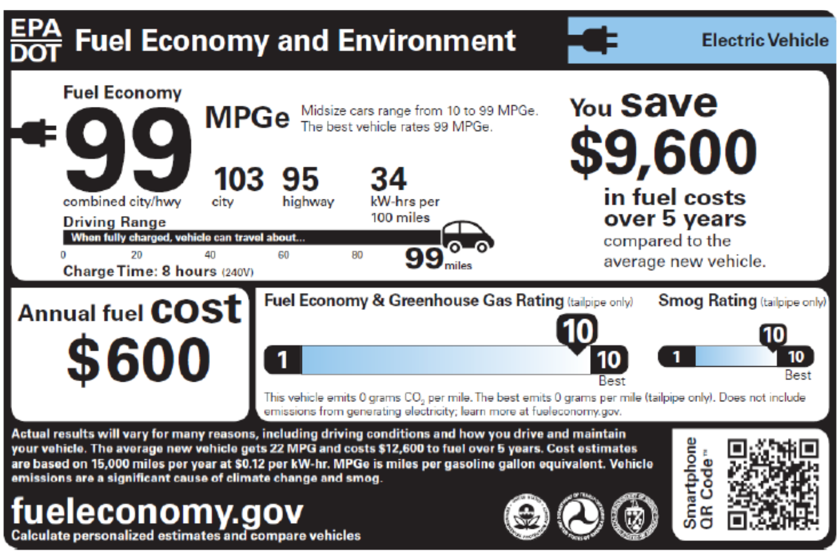

Figure 11: May 2011 New EPA Label for Electric Vehicles

The CO_2 message on this label, as compared to the November 2010 label, reads "This vehicle emits 0 grams CO_2 per mile. The best emits 0 grams per mile (tailpipe only). Does not include emissions from generating electricity; learn more at fueleconomy.gov." In the lowest part, there are two other messages: "MPGe is miles per gasoline gallon equivalent" and "Vehicle emissions are a significant cause of climate change and smog." The message that the BEVs generate no emissions is a bit longer. Unfortunately, the

EPA removed the November 2010 “MPGequivalent: 33.7 kW-hrs = 1 gallon gasoline energy” message, replacing it with “MPGe is miles per gasoline gallon equivalent.”

If one goes to the fueleconomy.gov website, moves the mouse pointer arrow to the item farthest to the right, New Window Sticker, and, after the drop-down menu appears, selects “Beyond Tailpipe Emissions,” a calculator will appear. Entering a ZIP code and choosing the Leaf from another drop-down menu will result in a value for the ZIP code and a national value for the country at large. The CO_2 value for the Leaf for the national grid is 230 g/mile. The response to the query also notes that there are zero tailpipe emissions.

This new window sticker and the Beyond Tailpipe Emissions calculator have information for only the Leaf and the Chevrolet Volt. To get the CO_2 emissions for the Prius, the Find a Car option must be selected.[21] Selecting a 2011 Prius provides data that show it generates 3.8 tons of CO_2 emissions annually. The label notes that this is for 15,000 miles driven annually. The calculation for Prius emissions is (3.8 * 2000) / 15,000 lbs/mile = 7,600/15,000 lbs/mile = .507 lbs/mile = .507 * 453.6 grams/mile = 230 grams/mile. Table 7 adds this information to table 6 in order to compare the Leaf and Volt for both MPGe and CO_2 emissions.

Car	Quoted MPGe	Correction Factor	Actual MPGe	CO_2 g/mile
2011 Leaf	99 MPGe	0.36	36 MPGe	230
2011 Prius	50 MPG	0.87	44 MPGe	230

Table 7: MPGe and CO_2 Grams/Mile Comparison of 2011 Leaf and 2011 Prius

It is useful to continually check the various ways the EPA presents information. Double checking EPA information for inconsistencies is vital. In the case of the Prius, CO_2 emissions can be calculated in a different manner. A Prius driven 15,000 miles per year at 50 MPG uses 300 gallons of gasoline. Each gallon of gasoline weighs 19.4 pounds; 300 gallons weigh 5,820 pounds or 2.9 tons—a number lower than the 3.8 tons for the Prius listed on the EPA website. A gallon of gasoline contains 8,788 grams of CO_2. [22] 300 gallons of gasoline contains 2,636,400 which, for the 15,000 miles driven, generates 176 grams per mile, less than the value derived in table 7. As time goes by, the EPA may clear up these discrepancies. Nonetheless, the point is made that the Prius and Leaf are very similar in MPG and CO_2 emissions.

It is also useful to verify the Leaf number. Another alternate to comparing the large power plant efficiency to the car engine efficiency is to use measures of CO_2 emissions generated, which are well documented both for power plants and cars. In terms of electric power plants, 1.42 pounds or 689 grams of CO_2 are created when generating a kilowatt hour of electricity from the national power grid.[23] So a Leaf gets 2.94 miles per kWh (table 3). Dividing 689 grams by 2.94 miles per kWh gives 234 grams/mile. This number is very close to the 230 grams/mile from table 7.

One DOE report summarizes CO_2 emissions from a wide variety of different power trains and fuels. Table 8 shows the summary from that report of today’s classes of current gasoline vehicles, HEVs, and BEVs. Note how close the emissions of the HEV are to those of the BEV (235 to 230). This verifies the argument that the two cars are similar in emissions generation as discussed in the derivation of table 7.

Fuel	Grams of CO_2-Equiv. per Mile
Gasoline (Today's Vehicles)	450
Gasoline (new vehicle)	340
HEV	235
BEV	230

Table 8: G.R.E.E.T. CO_2 Data for Various Car Classes[24]

The information developed in this section is shocking when compared to the formal numbers on the window sticker provided by the EPA and blessed by the Department of Transportation (DOT) and the DOE. The Leaf label implies near 99 MPG and no CO_2 emissions. Yet this analysis shows the Leaf to be somewhat less in MPG and no better in CO_2 than the most popular hybrid gasoline car, the Prius.

I have previously noted that history may repeat itself and the current BEV vehicles will have limited success due to competitive current HEVs, just as the early BEV vehicles of the late 1990s were limited by the success of early Prius, Insight, and Civic. There has been a long hiatus in BEV development. The current BEVs are second-generation developments while the Toyota Prius is in its third generation. The Leaf and Prius are roughly the same size, weigh about the same, and are both categorized as mid-sized vehicles. The Prius is evolving into a family of vehicles, with both larger and smaller versions.

Today, we are seeing significant MPG improvements in HEVs, which have increased 20 percent since the first versions were available. A new and smaller version of the current Prius, called the Prius c, will ship in 2012. The Prius has shown that enhanced gasoline engines have improved as much as or more than BEV power trains. The Prius continues to ship in much larger numbers than the Leaf, although the Leaf is in a startup phase. HEVs seem to use less energy and no more CO_2 than comparable BEVs. What will consumers pick? Possibly it will be based on economics, the CO_2 emissions being too close for a moral choice.

The intent of this CO_2 analysis is to support my claim that the ratios for the RAV4 EV to RAV4 gasoline mileage given by the EPA are dramatically overstated—five to one for the earlier ratings and three to one for the later ratings. CO_2 emissions certainly give a better perspective on the emissions from burning the fuels either in the tank or power plant. This analysis has shown that RAV4 EVs are more efficient than RAV4 gasoline cars, not by a factor of three to five, but by a factor of 20–40 percent. The reason these BEV examples are more efficient than the gasoline version is that power plants are more efficient in converting fossil fuels to electricity. Power plants are about 35 percent efficient while gasoline engines are 20–25 percent. So an electric vehicle has an advantage, at least as compared to cars built in the late 1990s, in this case the regular RAV4. The same argument applies to the Leaf.

A Question of Credibility

The country is investing massive amounts of money in electric vehicle technology. Since the economic slump of 2008 and 2009, the U.S. government has expended $5 billion into the electric vehicle sector with $2.4 billion of this allocated to battery projects.[25] It has been a keystone of the Obama administration. Americans are inundated with green marketing efforts extolling the virtues of electrifying the nation's transportation system. Underlying this movement is a fundamental belief that electrified vehicles will get substantially better mileage than current vehicles by a factor of at least three times. The previous sections show that this hyperbole has existed since the EPA began rating electric cars in the late 1990s and continues today.

In August 2009, GM began a public relations campaign to convince people that its forthcoming Chevrolet Volt, a plug-in hybrid rather than a BEV, would get 230 MPG. At that time GM was under the control of the U.S. government, having been recently rescued from bankruptcy by a bailout package. Presumably, government officials knew that GM was making this kind of claim and did not object. Nissan responded to this claim by announcing that their new Leaf would get 367 MPG. This hyperbole from both manufacturers was not well received, and a flurry of critical responses appeared. One impartial analysis by Paul Weissler showed the derivation of the numbers.[26] Another critical argument showed the derivation using something the DOE calls the "doesn't use petroleum" incentive adjustment (analogous to a CAFE bonus for flex-fuel vehicles).[27, 28] Essentially, Nissan and GM found an obscure reference in a Federal Register entry that allowed them to increase their MPG claim to the point of being ridiculous. This approach was in the law but its intention was not to determine the CAFE number for a specific car, but rather dealt with car fleet mix. [29, 30]

The EPA responded with a statement about the Volt (it did not comment on the Leaf) saying:

> EPA has not tested a Chevy Volt and therefore cannot confirm the fuel economy values claimed by GM. EPA does applaud GM's commitment to designing and building the car of the future—an American-made car that will save families money, significantly reduce our dependence on foreign oil and create good-paying American jobs. We're proud to see American companies and American workers leading the world in the clean energy innovations that will shape the 21st century economy. [31]

Certainly the EPA knew that the mileage claims for both the Nissan Leaf and the Chevrolet Volt were inaccurate but equivocated in order to support government BEV policy. Note that the analysis that shows the misrepresentations references information that resides on an EPA website.

After the negative reactions, the unrealistic MPG numbers were withdrawn. But this event, and in particular the wording of the EPA response, does not give hope that transparency about electrification will be better than the transparency associated with the financial instruments that have caused such damage to our economy in recent years. Both GM and Nissan were pilloried by the many followers of car technology, and their MPG claims were derided. Unfortunately, the EPA supported these claims in their statements.

Emissions measurement and reporting is vital for the complete understanding as well as for the credibility of the government agencies responsible for the label. The credibility situation has not improved in the last two years as evidenced by the May 2011 label announcement and the documentation that explains the label development. The reason is spelled out in an extensive report that covered the labels. The referenced document notes:[32]

> Automotive associations, electric vehicle associations, electric utility companies, and nearly all automakers who commented on this topic supported the proposal to include only tailpipe GHG emissions on the label and provide more detailed information on upstream GHG emissions on a website. Automakers typically stated that labels have always reflected vehicle performance only and have not addressed upstream petroleum emissions, that they have no control over upstream emissions, and that *including electricity upstream GHG emissions on the label could discourage future sales of EVs and PHEVs.* (Italics mine.) EV and PHEV advocacy organizations generally supported the proposal as well, also citing that past label designs focused exclusively on vehicle performance and arguing that regional differences in electricity feedstocks make it impossible to provide a single upstream GHG emissions value for EVs and PHEVs that would be meaningful to consumers. One environmental group supported the proposal but argued for a more prominent display of the text indicating that the values are tailpipe-only.
>
> Nearly all environmental groups, academics, a federal lab, and non-electricity fuel advocacy groups who commented on this topic opposed the proposal and endorsed the concept of including upstream GHG emissions on the label. *The primary argument was that providing tailpipe-only GHG emissions would be confusing and/or misleading, as some consumers might infer that operating a vehicle on grid electricity has no greenhouse gas emissions impacts, and that this could lead to adverse consumer purchase decisions if "zero emissions" was an overriding selling point for a consumer.* (Italics mine.)

This decision to exclude source energy and source emissions was a critical one. The latest window stickers include the logos for the EPA and the DOT, as well as for the DOE. It was a government choice, probably made under great pressure from automakers and utility companies. Although the argument for excluding source emissions suggests that the more accurate information could be found on the website, it is difficult to find and remains confusing. Even on the new label website, the information is not clearly explained although the actual facts are found on other EPA websites referenced in this document. The ruling document notes that the issue about source versus site measures is significant and that later versions of the label may change in order to deal with the differing positions.

The issue is what this will do to the faith and trust of the American people if the MPGe for electric vehicles is shown to be false government marketing. It will be particularly significant if it can be shown that alternatives are being ignored or de-emphasized.

Conclusion

It has been 21 years since the demonstration of the Impact concept car by GM, which led to the ZEV program of the California Air Resources Board and the development and manufacturing of a few thousand BEVs by seven automakers. A new effort toward vehicle electrification is now being made based principally on a battery technology that stores more electricity per unit of weight. But the battery is not the issue. It is in one sense the equivalent of solving the problem of low MPG cars by adding a larger gas tank. The issue is not the distance one can drive without refilling a tank or recharging a battery but the emissions that are caused by this driving. The threat of global warming is far more significant than the geopolitical implications of Middle East oil or the declining oil supplies becoming apparent with Peak Oil or the flow of petrodollars out of the country. As such, what matters is the total analysis from source fuel to tailpipe emissions. The BEV tragedy is that supporters of alternate technologies mislead the public to support their technical beliefs.

The current generation of BEV cars will have little effect on the climate change problem. Cars typically last about 14 years. The existing power plant infrastructure will still be here in 14 years, with minor modifications, when the current electric car population is being recycled. During this 14-year period, there will not be a massive number of carbon sequestration additions to the existing coal plants. Even if wind and solar continue to grow at a 50 percent annual growth rate, there may still not be enough renewable energy to supply a large BEV fleet of cars.

People have not yet grasped the idea that it is the source power that matters, not the site power. It is the power plant, not the device at the end of the transmission line. The efficiency of the power plant is more important than the efficiency of the electric motor in the car. The issue is not the cost of the device, that is the car, but the cost of the fuel for operations and the capital costs for power generating plants. Unfortunately, the U. S. has lost a significant amount of time—about a decade—largely because of the hype and disinformation of unscrupulous marketers, utilities, DOE, DOT, and the EPA.

However, there is positive action being taken. Arrayed against these institutions and salespeople are companies such as Toyota and Honda who have historically built more efficient cars. The Insight (versions 1 and 2), the Prius, the Civic, the Camry, and the upcoming Yaris and Fit subcompact hybrids will form the basis for high-MPG cars long after the current crop of BEVs joins the EV1, RAV4 EV, and the other CARB models at the recycling center.

I am a strong supporter of all forms of alternative energy, particularly the ones that have a record of successful implementations such as wind and solar PV. But their success to date does not suddenly mean that electrification of transport is the optimum solution. It may well be so in the future but not in this decade. Carbon sequestration may also work in a few decades while wind and solar may achieve deep penetration in the 2020s and beyond. At that time, electric vehicles may make more sense. In the meantime, hybrid gasoline vehicles will achieve better performance, as the Priuses' record shows. Whatever the case, as we proceed wisely multiple paths, we need transparency and honesty from our government agencies and car companies. So far, both are in short supply.

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