Hybrids, Ethanol, Global Warming and My Next Car
(Or, How to Pick the Right Hybrid Car for You)
by Brian S. Cramer, P.E.

Why are we, as a nation, interested in more efficient automobiles? I believe that most peoples' response to that question would be something like "Well, of course it is because …" But, the reality is that there are many different reasons. And, the various cars that are being proposed each address some of the reasons. But, I am looking for the car that best addresses the issues that I am most concerned about. So, which car is it? And, how can I even know which car does what? In this article I will attempt to provide the information necessary for the reader to answer these questions. And, while I am doing that, I will also attempt to convince you that the issues I care about are also the issues you should care about.

I just visited the 2009 Chicago Auto Show. And, one thing I observed is that a lot of auto makers have stuck a hybrid drive in a giant gas sucking vehicle and declared that they had done their part to save the planet. Granted that if you absolutely NEED to have an Escalade to take your 2.4 kids to soccer practice, then a hybrid Escalade is a little better than a regular one. But, I believe that there is more to it than saving a few dollars on gas. Some of the reasons to have more efficient cars are:

- Save money on gas, and reduce the total cost of your transportation
- Reduce CO_2 emissions to save the earth
- Reduce the amount of oil we import from countries that don't like us

Priorities

When I bought my 2004 Prius I know that saving money on gas was not my reason. And, I know that the cost of gas would need to stay around $4 per gallon for a lot longer to recoup my investment. So why did I buy it? At the risk of sounding overly pious, I bought it because I believe that we need to reduce our energy usage, as a nation, to a much lower level. Wind farms and solar panels are great, but at the rate America uses energy, renewable sources will never be more than a small fraction of our generation. We need to reduce our consumption of energy wherever possible, and to the greatest extent possible. Additionally, I am convinced that if we simply didn't need oil from places like the Middle East and Venezuela, that the people who live there would have a lot less reason to hate us: no need for oil → no air force base in Saudi Arabia → no Al Qaida → no wars in Iraq or Afghanistan.

I went to the auto show to look for my next car. The Prius gets a steady 45 miles per gallon. I am not looking for an incremental improvement. I am looking for significant improvement. I am looking for a comfortable 4-passenger car that gets 60 to 70 mpg. What I saw at the auto show was a lot of companies nibbling away at the problem, while only a few were really looking to take a big bite.

One example of what I see as the deficiencies of some of the vehicles was the addition of a hybrid drive in a vehicle that can only run on regular gas. Regular 87 octane gasoline has 15% ethanol. The other 85% is gas that we get by refining crude oil that comes in supertankers from the Middle East (among other

sources). This solution, involving only a hybrid drive, will reduce our consumption of oil by about 15% to 20%. But, if the engine in the vehicle can run on E85 ethanol (85% ethanol and 15% gas), then we reduce our consumption of foreign oil by 85%. This is true even with the reduced mileage that you get using ethanol because of the savings provided by the hybrid drive. So, if your fleet of SUVs uses one supertanker of crude oil each year, and you replace the fleet with hybrids, you only need about 0.8 supertankers a year. But, if you replace your fleet with hybrid SUVs that can use E85 ethanol, then you need about 0.15 supertankers. We still only reduced CO_2 by 15% with the hybrid drive, but we reduced oil consumption by 85%!

So what have we done in this example? Instead of looking for one silver bullet to fix all our problems, we combined two improvements to get a significantly greater impact. But, this is still not good enough. We need more.

One of the improvements that is getting a lot of attention is putting the words "plug-in" in front of the word "hybrid". What this really means is that your hybrid has a bigger battery that you charge at home overnight. The result is that about your first 40 miles each day is driven in all-electric mode. (I saw cars claiming 10 to 100 miles of all-electric driving per charge.) After that your hybrid car works the way it always did.

So, if you drive less than 40 miles a day, you use no gas at all – just electricity. There has been a lot of debate as to whether this is a good thing. After all, power plants pollute. Fortunately for me, I live in northern Illinois. Almost all of our overnight base load generation is nuclear. This means absolutely no CO_2. (I am also fortunate to be an engineer, so I understand that the popular fear of nuclear power is mostly unfounded.) So, for now, I am going to simplify the problem by eliminating the variable associated with airborne pollutants from power plants.

The result of using a plug-in hybrid, for those of us with nuclear or renewable generation, is NO CO_2 for up to 40 miles a day. After the 40 miles, the hybrid drive reduces CO_2 by about 15%, while burning E85 ethanol reduces oil imports by 85%. I am feeling pretty good about this, and beginning to think that I have found my next car. But before I take the plunge, I want to check my electric bill and run some numbers.

Fuel Cost per Mile (CPM)

I have time-of-day billing on my electric service. This means that my electric rate changes every hour to a market price. It allows me to plan my electric usage for when the cost is low. Unfortunately, if I miss and use a lot of electricity when the price is high… Let's just say that the highs are really high. I can end up paying anywhere from 2¢ to 25¢ per kWh.

There were two cars that I saw that went out on a limb and quoted numbers as to charging times, currents, or cost figures. They were the Mitsubishi iMiEV (an EV, not a hybrid) and the Chevy Volt. (I should point out that the Chevy people vehemently deny that the volt is a plug-in hybrid. They call it an extended range something-or-other. But, it looks to me like a series hybrid with plug-in capability.) Both

cars have a 16kWh lithium-Ion battery. So, I will split the difference between their expected charging times for my cost analysis. The results look like this:

- 15A at 120V: 10 hours = 18 kWh
- 15A at 240V: 4.5 hours = 16.2 kWh

So, I am going to go with 17 kWh to charge the battery. That corresponds to a 94% efficient charging system. If I time it just right and pay 2¢ per kWh to charge the car, it will cost me 34¢. That is less than 1¢ per mile. If I were to pay 10¢ per kWh (about the normal fixed rate around here), it will cost $1.70. That is 4¼¢ per mile. (Chevy claims a national average of 80¢ to charge the battery, or 2¢ per mile.) But, what does that mean in terms of the total fuel cost of operating the car?

The Chevy Volt is targeting 40-50 mpg when running on the motor/generator after the overnight charge is depleted. 50 mpg can be equated to a fuel cost per mile (cpm) if you assume a cost of gasoline. If gas is $3.00 per gallon, 50 mpg corresponds to 6¢ cpm. As noted above, the electric "fuel" costs from 1¢ to 4¼¢ cpm. For a conventional 50 mpg car to have a fuel cost of 1¢ cpm, the gas price would have to drop to 50¢ per gallon. So, the fuel cpm of operating an EV will be dependent on the kWh's needed to charge the battery and the price of your electricity. While the fuel cpm of operating a plug-in hybrid will also be dependent on the mpg in hybrid mode and the cost of gasoline.

Further, your overall cpm for a hybrid will depend on how far you drive each day. If I presume that I pay 4.6¢ per kWh to charge the car and $3.00 per gallon of gas, and my car gets 50 mpg on gas with a 40 mile all-electric range on a 17 kWh charge, I can create Table 1 of fuel cpm. This table is actually a spreadsheet that can be used to determine the fuel cpm and hybrid equivalent mpg for any vehicle, with any fuel prices, and any usage pattern.

40	All-Electric Range
17	kWh's per Charge
$ 0.046	Price of Electricity ($/kWh)

50	Hybrid Mode Mileage (mpg)
$ 3.00	Price of Fuel ($/gal)

Miles Driven per Charge	All-Electric Miles	All-Electric cpm	All-Electric "Fuel" Cost	Hybrid Miles	Hybrid mpg	Hybrid Fuel Price	Hybrid Fuel Cost	Total Fuel Cost	Average Fuel cpm	Equivalent mpg
10	10	$ 0.020	$ 0.20	0	50	$ 3.00	$ -	$ 0.20	$ 0.02	153
20	20	$ 0.020	$ 0.39	0	50	$ 3.00	$ -	$ 0.39	$ 0.02	153
30	30	$ 0.020	$ 0.59	0	50	$ 3.00	$ -	$ 0.59	$ 0.02	153
40	40	$ 0.020	$ 0.78	0	50	$ 3.00	$ -	$ 0.78	$ 0.02	153
50	40	$ 0.020	$ 0.78	10	50	$ 3.00	$ 0.60	$ 1.38	$ 0.03	109
60	40	$ 0.020	$ 0.78	20	50	$ 3.00	$ 1.20	$ 1.98	$ 0.03	91
70	40	$ 0.020	$ 0.78	30	50	$ 3.00	$ 1.80	$ 2.58	$ 0.04	81
80	40	$ 0.020	$ 0.78	40	50	$ 3.00	$ 2.40	$ 3.18	$ 0.04	75
90	40	$ 0.020	$ 0.78	50	50	$ 3.00	$ 3.00	$ 3.78	$ 0.04	71
100	40	$ 0.020	$ 0.78	60	50	$ 3.00	$ 3.60	$ 4.38	$ 0.04	68
110	40	$ 0.020	$ 0.78	70	50	$ 3.00	$ 4.20	$ 4.98	$ 0.05	66
120	40	$ 0.020	$ 0.78	80	50	$ 3.00	$ 4.80	$ 5.58	$ 0.05	64
130	40	$ 0.020	$ 0.78	90	50	$ 3.00	$ 5.40	$ 6.18	$ 0.05	63
140	40	$ 0.020	$ 0.78	100	50	$ 3.00	$ 6.00	$ 6.78	$ 0.05	62
150	40	$ 0.020	$ 0.78	110	50	$ 3.00	$ 6.60	$ 7.38	$ 0.05	61
160	40	$ 0.020	$ 0.78	120	50	$ 3.00	$ 7.20	$ 7.98	$ 0.05	60
170	40	$ 0.020	$ 0.78	130	50	$ 3.00	$ 7.80	$ 8.58	$ 0.05	59
180	40	$ 0.020	$ 0.78	140	50	$ 3.00	$ 8.40	$ 9.18	$ 0.05	59
190	40	$ 0.020	$ 0.78	150	50	$ 3.00	$ 9.00	$ 9.78	$ 0.05	58
200	40	$ 0.020	$ 0.78	160	50	$ 3.00	$ 9.60	$ 10.38	$ 0.05	58
210	40	$ 0.020	$ 0.78	170	50	$ 3.00	$ 10.20	$ 10.98	$ 0.05	57
220	40	$ 0.020	$ 0.78	180	50	$ 3.00	$ 10.80	$ 11.58	$ 0.05	57
230	40	$ 0.020	$ 0.78	190	50	$ 3.00	$ 11.40	$ 12.18	$ 0.05	57
240	40	$ 0.020	$ 0.78	200	50	$ 3.00	$ 12.00	$ 12.78	$ 0.05	56
250	40	$ 0.020	$ 0.78	210	50	$ 3.00	$ 12.60	$ 13.38	$ 0.05	56
260	40	$ 0.020	$ 0.78	220	50	$ 3.00	$ 13.20	$ 13.98	$ 0.05	56
270	40	$ 0.020	$ 0.78	230	50	$ 3.00	$ 13.80	$ 14.58	$ 0.05	56
280	40	$ 0.020	$ 0.78	240	50	$ 3.00	$ 14.40	$ 15.18	$ 0.05	55
290	40	$ 0.020	$ 0.78	250	50	$ 3.00	$ 15.00	$ 15.78	$ 0.05	55
300	40	$ 0.020	$ 0.78	260	50	$ 3.00	$ 15.60	$ 16.38	$ 0.05	55
310	40	$ 0.020	$ 0.78	270	50	$ 3.00	$ 16.20	$ 16.98	$ 0.05	55
320	40	$ 0.020	$ 0.78	280	50	$ 3.00	$ 16.80	$ 17.58	$ 0.05	55
330	40	$ 0.020	$ 0.78	290	50	$ 3.00	$ 17.40	$ 18.18	$ 0.06	54
340	40	$ 0.020	$ 0.78	300	50	$ 3.00	$ 18.00	$ 18.78	$ 0.06	54
350	40	$ 0.020	$ 0.78	310	50	$ 3.00	$ 18.60	$ 19.38	$ 0.06	54
360	40	$ 0.020	$ 0.78	320	50	$ 3.00	$ 19.20	$ 19.98	$ 0.06	54
370	40	$ 0.020	$ 0.78	330	50	$ 3.00	$ 19.80	$ 20.58	$ 0.06	54
380	40	$ 0.020	$ 0.78	340	50	$ 3.00	$ 20.40	$ 21.18	$ 0.06	54
390	40	$ 0.020	$ 0.78	350	50	$ 3.00	$ 21.00	$ 21.78	$ 0.06	54
400	40	$ 0.020	$ 0.78	360	50	$ 3.00	$ 21.60	$ 22.38	$ 0.06	54

Table 1 – Hybrid "fuel" cpm and equivalent mpg

The data in the table is summarized in the graph in Figure 1. The flat cost for the first 40 miles results from the use of all-electric mode (~2¢/mile). After that you are burning gas (or ethanol, or hydrogen, etc.) and your average "fuel" cpm increases and approaches that of the hybrid without plug-in capability (~6¢/mile).

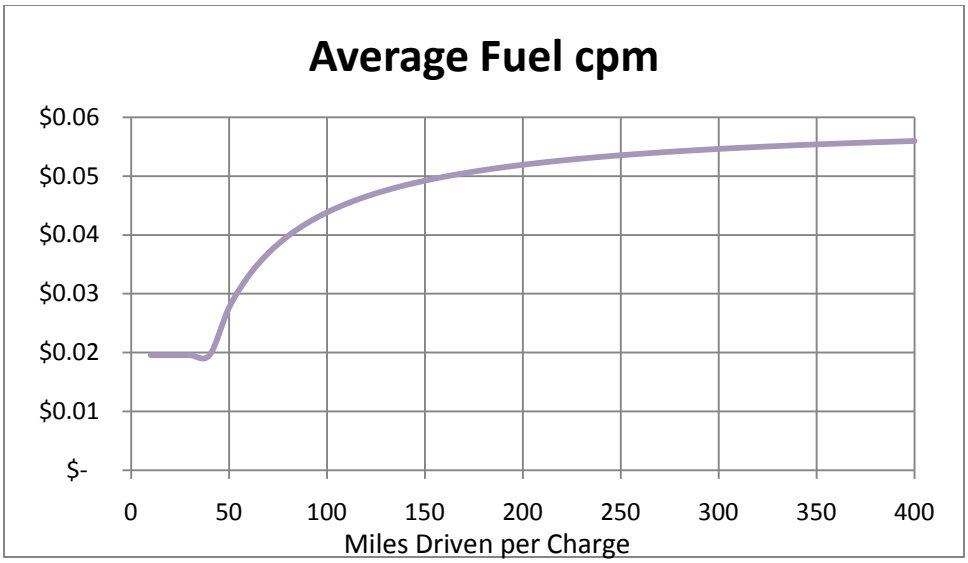

Figure 1 – Avarage "fuel" cpm for the hybrid car assumptions of Table 1

Plug-In Hybrid Equivalent MPG

Americans are used to evaluating efficiency in terms of mpg. But, as shown above, it is more direct to think of plug-in hybrid efficiency in terms of cpm. But, once cpm is determined, obtaining an equivalent mpg for a plug-in hybrid is relatively simple. All that is needed is to divide our price of gas by the cpm. For example, the hybrid operating in hybrid mode costs 6¢ per mile. At $3.00 per gallon, we get the following:

$$\frac{\$3.00}{\$0.06} = 50\ mpg$$

In all-electric mode the "fuel" costs 2¢ per mile. Since gas still costs $3.00 per gallon we get the following:

$$\frac{\$3.00}{\$0.02} = 150\ mpg$$

In other words, the amount of money we are spending on electricity and gasoline combined is equal to the amount of money we would have to spend on gas if we had a car capable of getting 150 mpg.

With our sample vehicle, and our assumed prices of electricity and gasoline, the worst we can do is 50 mpg in hybrid model. The best we can do is 150 mpg in all-electric mode (driving less than 40 miles per charge). The reality would depend on how far we drive on each charge. Figure 2 shows the equivalent mpg for our assumed conditions.

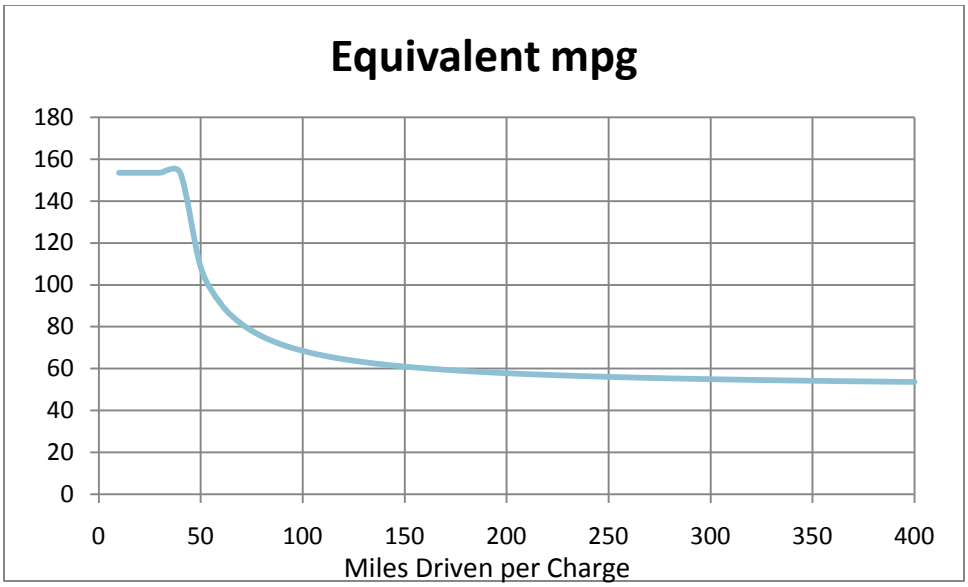

Figure 2 – Plug-In Hybrid Equivalent MPG

Determining Your Equivalent MPG

In order for a consumer to make an intelligent evaluation of their own equivalent miles per gallon for a plug-in hybrid car, vehicle information is required:

- All-Electric Range (miles)
- kWh's per Charge
- Hybrid Mode Mileage (mpg)

And, assumptions need to be made about market prices for energy:

- Price of Electricity ($/kWh)
- Price of Fuel ($/gal)

And, you personal usage must be considered:

- Your miles driven on a charge.

Figure 3 shows the Equivalent MPG for the Chevy Volt based on the company's predicted performance and gasoline prices at $3.00 per gallon. Figure 4 shows the same thing except that a gasoline price of $4.00 per gallon is used.

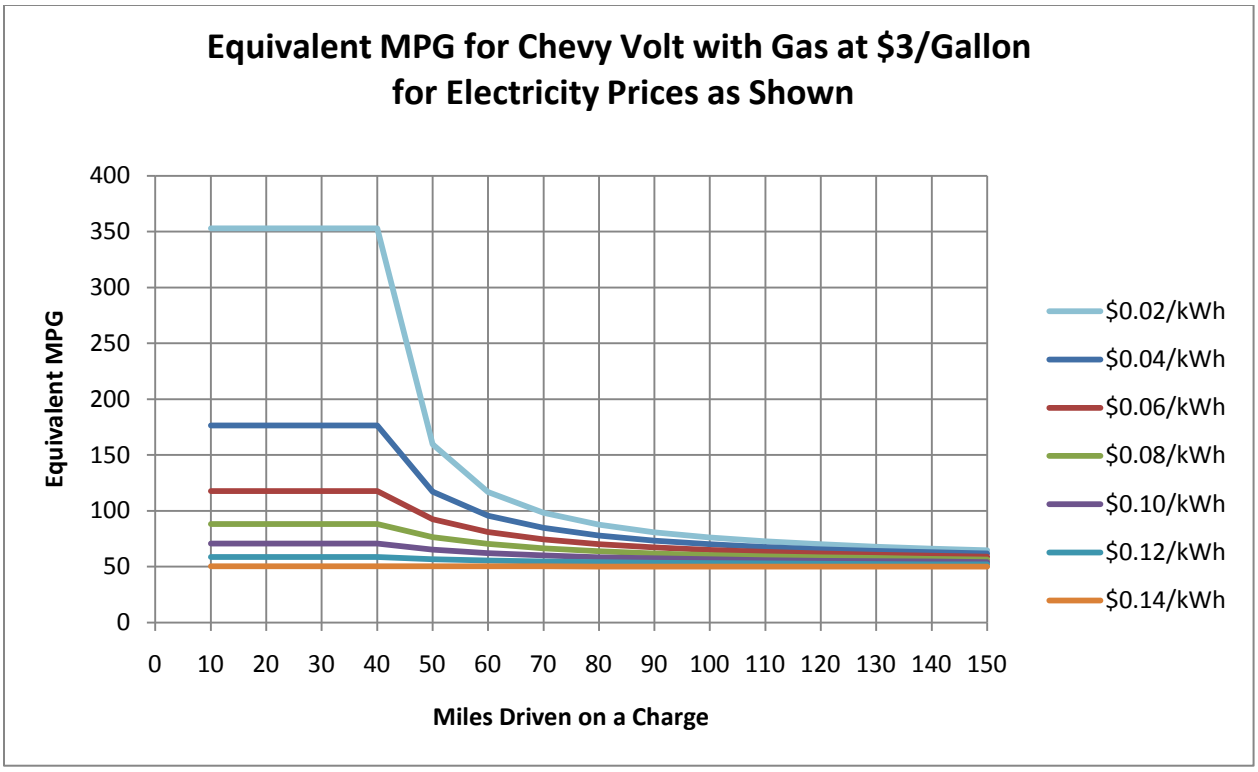

Figure 3 – Equivalent MPG with $3.00 per Gallon Gas

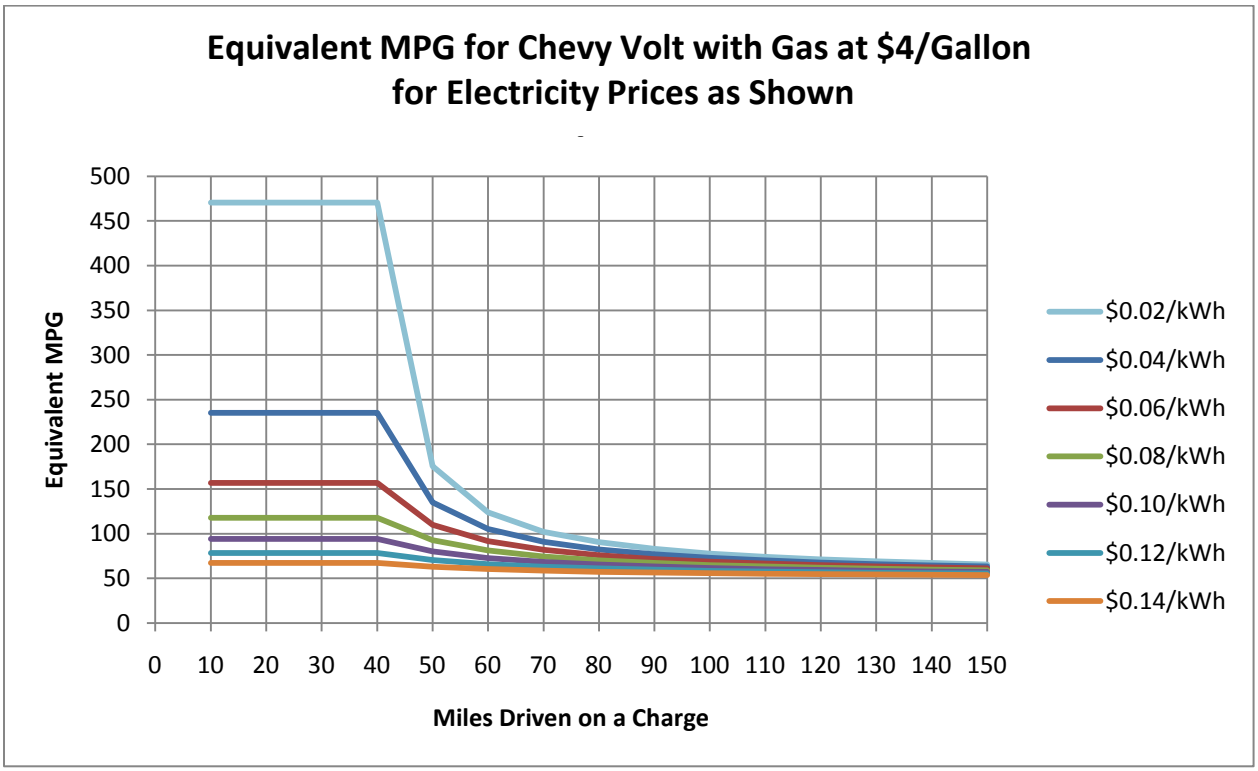

Figure 4 – Equivalent MPG with $4.00 per Gallon Gas

From these graphs it is clear that high Equivalent mpg is extremely dependent on doing most of your driving in all-electric mode, and charging your vehicle with low-cost off-peak electricity.

But, do not despair at the apparent "low" Equivalent MPG if you drive into hybrid mode. The very worst you can get is the 50 mpg that hybrid operation provides (for these cars) – still excellent by today's standards. And, you can start striving for that elusive 200 mpg with your very next charge.

Conclusion

While each person's use will affect their choice, some common targets can be identified presuming you want to reduce both CO_2 emissions and our dependence on foreign oil:

- Get a plug-in hybrid
- that can use E85 ethanol, hydrogen, or other home-grown fuel
- and, has enough range in all electric mode to provide for a significant amount of your driving.

In any case, you now know how to calculate your personal equivalent MPG.