1.0 Introduction

Plug-in hybrid electric vehicles (PHEVs or "Plug-in hybrids") and battery electric vehicles (BEVs) are proposed as alternative vehicles to reduce greenhouse gas (GHG) emissions and oil consumption. Greenhouse gas (GHG) emissions attributed to PHEVs and BEVs (and to fuel cell vehicles using hydrogen made by electrolyzing water) will depend on the treatment of emissions from electrical power generation plants. Some analysts calculate GHGs by using the *average* output from all generators in a particular region. For example, if a local utility generated 50% of its electricity from nuclear and 50% from coal, then the GHGs for any new electrical load would be taken as the average of zero (nuclear) and approximately 1,000 grams of CO_2-equivalent/kWh from coal-based generators, or 500 gCO_2/kWh as the average utility grid mix.

However, this does not mimic actual utility operation. To maximize profits, utilities operate their lowest operating cost plants first, and only turn on plants with higher operating costs when they have to meet high demand[1]. In the above example, since nuclear plants have lower operating costs than coal plants, the nuclear plants are run first as baseload. The output from the coal plant would then have to be increased to accommodate any new electrical load. The net impact of adding a new load to the grid would generate 1,000 gCO_2/kWh from the *marginal* coal plant, or twice the average GHG emissions in this example.

2.0 Summary of Results

The average US GHG emissions will ***increase*** by 7.4% substituting a BEV for a gasoline HEV, and by 10% using a PHEV compared to a gasoline HEV. These average US GHG values are calculated by multiplying the GHG emissions produced by the marginal grid mix in each region of the country times the percentage of light duty vehicles (LDVs) in each region. For comparison, using the same methodology, fuel cell electric vehicles running on hydrogen made from natural gas substituting for a gasoline HEV will *reduce* US GHG emissions by 25.3%.

Using BEVs instead of gasoline HEVs will reduce oil consumption by 92.4%, while PHEVs will reduce oil use by only 36.3%, and FCEVs will reduce oil consumption by 99.4%, all based on the LDV-weighted US averages.

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[1] Note that the capital cost of the power plant does not enter this equation. Once the plant is built, the utility runs the lower operating cost plants first. Thus a nuclear plant might have higher initial capital costs, but operating costs are very low, and so nuclear plants are run as close to 100% as much of the time as possible as baseload.

3.0 Recommended GHG Calculations from the GHG Protocol

The GHG Protocol[2] stipulates that analysts should use the *marginal* grid mix and not the *average* grid mix to determine the impact of adding new loads to a utility grid such as EV battery charging. The Protocol states that:

> "An average emission rate is easy to calculate, but it provides only a rough approximation of marginal displaced emissions."

That is, adding a new load such as a BEV or PHEV will require the utility to ramp up the electrical generator that is on the operating margin. For example, the zero-carbon electrical generators such as hydroelectric plants and nuclear also have the lowest operating cost. With economic dispatch, utilities run their lowest cost generators first, and only turn on the generators with higher operating expenses when demand rises. As a result, nuclear and renewable power plants are run at full capacity whenever possible. Adding a new load (such as a BEV or a PHEV) then requires the utility to ramp up other generators, primarily fossil fuel-fired combustion or gas turbines that do generate significant GHGs.

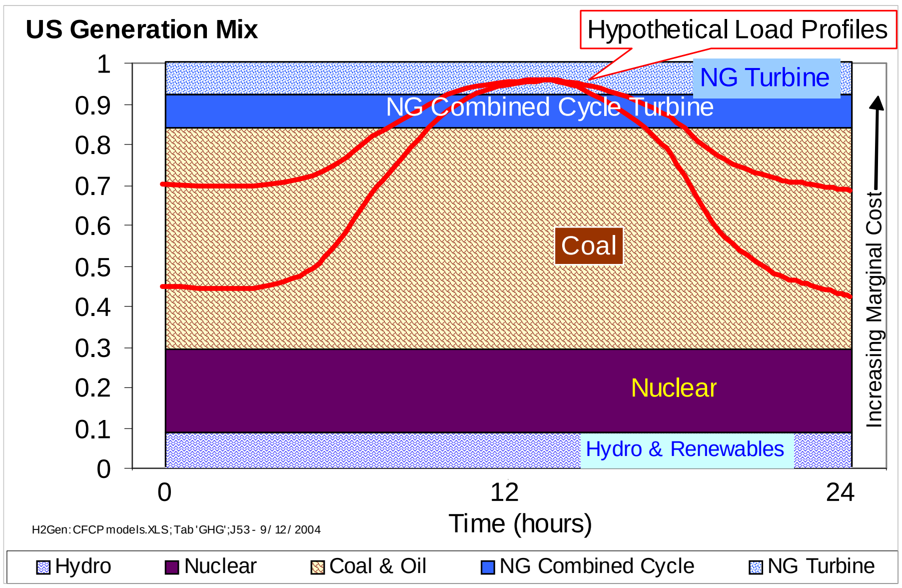


Figure 1. Economic Dispatch Chart for hypothetical utility including two possible load duration curves for a 24-hour period

4.0 Illustration of Marginal Grid Mix Estimation and Economic Dispatch

Figure 1 illustrates economic dispatch ranking for a utility over a 24-hour period, modeled on a hypothetical utility that has approximately the average US utility mix.

Hydro-electric and renewables have very low operating costs, and are turned on first. Nuclear has the next lowest operating cost, followed by coal plants. Natural gas plants are more expensive to operate, so they are turned on last, typically to meet daytime peak load. In some regions of the US, oil is also used to generate electricity, and this

[2] D. Breoekhoff, "The Greenhouse Gas Protocol: Guidelines for quantifying GHG reductions from grid-connected electricity projects," World Resources Council and the World Business Council for Sustainable Development, August 2007. Available at: http://pdf.wri.org/GHGProtocol-Electricity.pdf.

oil-based electricity would typically be at the top of the economic dispatch chart, and will be on the margin and therefore used first to charge EV car batteries.

The solid red lines in Figure 1 illustrate two possible daily load profiles for this hypothetical utility. The marginal electric generator is found at the intersection of the load curve at any time of day with the economic dispatch stack of generators. Consider what happens when a new load, such as a PHEV or a BEV is plugged-in for charging or an electrolyzer is turned on to produce hydrogen. During the night, all of the new electricity to charge the battery or to run the electrolyzer must come from turning up the output from the coal plants in the example of Figure 1. The nuclear and hydro plants are running at full tilt. During the day time, the output from natural gas plants must be increased to meet new demand. Therefore *all* of the electricity to meet the demand for electricity to run a new load will come from some combination of coal plants and natural gas plants in this example utility grid system. The fact that the utility has 20% nuclear power and 10% hydroelectric is *not relevant* to the calculation of marginal greenhouse gases produced when an EV or a new electrolyzer is added to the grid demand.

5.0 Oak Ridge National Laboratory Marginal Grid Mix Calculations

Estimating the marginal grid mix for any region is very complex, since the analyst must consider the utility demand load that varies widely on an hourly, daily, weekday/weekend and seasonal basis. Fortunately Hadley and Tsvetkova at the Oak Ridge National Laboratory[3] have made these calculations for each of the 13 continental US electricity regions specified by the North American Electricity Reliability Corporation (NERC), using the Oak Ridge Competitive Electricity Dispatch (ORCED) computer model[4], based on inputs from the EIA's NEMS system that includes operating data on 21,000 electrical generation plants across the US.

The Oak Ridge Model is based on the DOE's Energy Information Administration (EIA)'s 2007 Annual Energy Outlook (AEO) projections for possible electrical generation mixes in each NERC region in 2020 and 2030. For each region of the country, they calculated the electricity grid mix for business-as-usual without any EVs. Then they evaluated six scenarios with PHEVs added to the utility demand curve. These six PHEV scenarios were a mixture of two charging periods ("evening charging" starting at 5PM or 6 PM), and "night-time charging" starting at 10PM and 11PM.) For each of these charging periods, they considered three charging rates:

1.0 1.4 kW (120V/15A)
2.0 2 kW (120V/20A)
3.0 6-kW (220V/30A)

[3] S. Hadley & A. Tsvetkova, "Potential Impact of PHEVs on Regional Power Generation," report # ORCL/Tm-2007/150, January 2008, available at: http://www.ornl.gov/info/ornlreview/v41_1_08/regional_phev_analysis.pdf
[4] Available at: http://www.ornl.gov/sci/ees/etsd/pes/capabilities_ORCED.shtml

For a total of six PHEV scenarios (2 charging times x 3 charging rates) and the base case without any PHEVs. Oak Ridge then subtracted the base-case electricity from each of the six PHEV scenario electricity results to determine which electric plants would have to generate more electricity to charge EV batteries in each of the 13 NERC regions. They assumed that each PHEV traveled 20 miles per day, and they assumed that gasoline hybrid electric vehicles (HEVs) have a fuel economy of 40 miles/gallon of gasoline. They assumed 25% market penetration of PHEVs in 2020 through 2030.

Figure 2. Continental US NERC electricity regions used in the EIA's 2007 annual energy outlook

To simplify our analysis, we averaged the marginal grid results from the six PHEV scenarios in each region, and used only the 2020 results from the Oak Ridge study. The average grid mixes for each region are summarized in Table 1, and the marginal grid mixes are summarized in Table 2.

Oak Ridge did not include Alaska and Hawaii in their analysis, so we used the actual 2009 average grid mixes for these two states as summarized in Table 3. We estimated the marginal grid mixes for each state using a simplified set of load duration curves that were superimposed on the economic dispatch charts for each state. Note the high percentage of oil-based electricity (17.3% in Alaska and 75.3% in Hawaii); since the operating costs for oil plants are high, these plants dominate the marginal grid mix, particularly on Hawaii. The average grid mixes for "Region 14" were then calculated based on the weighted average light duty vehicles (LDVs) in each state to arrive at an LDV-weighted average for both average grid mix and marginal grid mix for "Region 14." The weighted average marginal oil generator mix is 70%, which dominates the GHGs and oil consumption[5] for this region. However, since these two states account for only 0.58% of all US LDVs, the impact on the LDV-weighted average for the US is minimal.

[5] With this high oil-based marginal grid mix, the consumption of oil for BEVs and PHEVs actually increases for Region 14 compared to driving a more conventional (non-plug-in) gasoline HEV!

Table 1. Estimated average utility grid mixes in 2020 for the 13 NERC regions in the continental US from the Oak Ridge study, and actual 2009 average mixes for a "Region 14" for Alaska and Hawaii

	East Central Area Reliability Coordination Agreement - 01	Electric Reliability Council of Texas - 02	Mid-Atlantic Area Council - 03	Mid-America Interconnected Network - 04	Mid-Continent Area Power Pool - 05	Northeast Power Coordinating Council / New York - 06	Northeast Power Coordinating Council / New England - 07	Florida Reliability Coordinating Council - 08	Southeastern Electric Reliability Council - 09	Southwest Power Pool - 10	WECC / Northwest Power Pool Area - 11	WECC / Rocky Mountain, Arizona,New Mexico,S. Nevada Power Area - 12	WECC / California - 13	Alaska & Hawaii- 14
Coal	78.3%	32.1%	49.3%	53.1%	73.3%	13.1%	11.5%	34.7%	51.9%	67.8%	35.0%	66.3%	30.1%	12.2%
Oil	0.0%	0.0%	1.0%	0.0%	0.1%	1.1%	2.1%	3.2%	0.3%	0.3%	0.0%	0.0%	0.0%	56.0%
Gas ST	0.2%	4.2%	0.0%	0.0%	0.0%	1.0%	0.0%	3.5%	2.9%	2.0%	0.3%	0.7%	5.0%	6.4%
Gas CC	10.5%	45.5%	14.2%	12.3%	4.0%	39.7%	55.3%	47.0%	8.4%	20.9%	16.8%	17.3%	27.3%	7.9%
Gas CT	1.1%	4.7%	0.4%	1.9%	2.6%	1.0%	0.4%	4.4%	0.5%	0.7%	0.6%	0.5%	4.4%	3.6%
Total Natural gas	11.8%	54.4%	14.7%	14.2%	6.6%	41.7%	55.8%	54.9%	11.9%	23.7%	17.8%	18.5%	36.7%	17.9%
Renew	1.1%	0.4%	3.4%	1.5%	5.9%	17.5%	10.9%	2.3%	3.9%	2.4%	41.9%	4.6%	18.4%	13.9%
Unserved	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Nuclear	8.8%	11.0%	31.3%	30.9%	11.4%	26.1%	19.7%	4.7%	32.0%	3.9%	2.9%	10.1%	12.0%	0.0%

ST = Natural gas single turbine; CC = NG combined cycle plant; CT = NG combustion (steam) turbine

Table 2. Estimated marginal grid mixes for the 13 NERC regions from the Oak Ridge study for 2020, and estimated "Region 14" marginal grid mixes for Alaska and Hawaii

	East Central Area Reliability Coordination Agreement - 01	Electric Reliability Council of Texas - 02	Mid-Atlantic Area Council - 03	Mid-America Interconnected Network - 04	Mid-Continent Area Power Pool - 05	Northeast Power Coordinating Council / New York - 06	Northeast Power Coordinating Council / New England - 07	Florida Reliability Coordinating Council - 08	Southeastern Electric Reliability Council - 09	Southwest Power Pool - 10	WECC / Northwest Power Pool Area - 11	WECC / Rocky Mountain, Arizona,New Mexico,S. Nevada Power Area - 12	WECC / California - 13	Alaska & Hawaii- 14
Coal	55.9%	0.0%	25.5%	62.0%	22.7%	4.0%	14.8%	0.3%	33.3%	5.1%	0.0%	7.2%	0.0%	4.2%
Oil	0.3%	0.0%	11.0%	0.0%	2.1%	13.6%	20.7%	16.3%	0.1%	2.3%	0.0%	0.0%	0.1%	70.1%
Gas ST	3.0%	24.5%	0.2%	0.5%	0.2%	12.8%	0.8%	11.0%	0.3%	13.3%	15.9%	1.9%	21.7%	6.1%
Gas CC	20.0%	52.5%	57.4%	9.2%	30.1%	52.5%	49.4%	51.1%	61.9%	75.1%	73.4%	88.2%	60.5%	14.2%
Gas CT	19.9%	22.4%	8.1%	28.2%	36.8%	16.9%	5.4%	18.6%	2.9%	4.1%	10.6%	2.6%	16.9%	6.1%
Total Natural gas	42.9%	99.4%	65.8%	37.9%	67.1%	82.3%	55.6%	80.7%	65.1%	92.5%	100.0%	92.6%	99.2%	26.4%
Renew	0.8%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.6%	1.5%	0.0%	0.0%	0.2%	0.5%	0.0%
Unserved	0.0%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%	0.6%	0.0%	0.0%	0.0%	0.0%	0.2%	0.0%
Nuclear	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.8%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

work/ORNL/Results 2020V4b with NYRL to Gas Hadley's revised Region 6 data.XLS; WS 'Marg & Ave summary' O- 64 1/21/2012

Table 3. Actual 2009 average grid mixes for Alaska and Hawaii, and estimated marginal grid mixes based on a set of generic load duration curves, along with the LDV-weighted marginal and average mixes for "Region 14." (last two columns on the right) (Top row indicates the percentage of US LDVs in each state)

LDV %'s=>	0.193%		0.388%			0.581%	
	Alaska		Hawaii			"Region 14"	
	Marginal	Average	Marginal	Average		Marginal	Average
Coal	8.8%	9.4%	1.9%	13.6%		4.19%	12.22%
Oil	16.4%	17.3%	96.8%	75.3%		70.11%	56.01%
Gas ST	17.8%	19.2%	0.2%	0.1%		6.07%	6.43%
Gas CC	39.3%	23.5%	1.8%	0.1%		14.23%	7.86%
Gas CT	17.8%	10.7%	0.2%	0.0%		6.07%	3.57%
Total Natural gas	74.9%	53.4%	2.3%	0.2%		26.37%	17.87%
Renew		20.0%		10.9%			13.90%
Unserved							
Nuclear		0		0			
	work/ORNL/Results 2020V4b with NYRL to Gas Hadley's revised Region 6 data.XLS; WS 'Marg & Ave summary' H 50 1/20 /2012						

6.0 Argonne National Laboratory GHG and Oil Consumption Calculations

The GHG emissions and oil consumption for a variety of alternative fueled vehicles (AFVs) were calculated using the Argonne GREET Model 1_2001[6]. This GREET model is the "gold standard" of GHG calculations, providing an exhaustive calculation of "well-to-wheels" GHGs and oil consumption for a wide range of alternative fuels and vehicles. The average and marginal grid mixes from the Oak Ridge report were entered into the GREET model to calculate actual GHG emissions (from the marginal grid data) and also to compare the results of using average grid emissions instead of the marginal grid emissions recommended by the GHG Protocol.

The GHG emissions for a range of AFVs are shown in Table 4 using the average utility grid mixes, and in Table 5 using the marginal grid mixes in the GREET model. Most of the GHG values are the same in these two tables, except for the emissions from BEVs and PHEVs that depend heavily on electricity from the grid[7].

[6] M. Q. Wang, "The Greenhouse gas, regulated emissions and energy use in transportation (GREET)," Energy Systems Division, Argonne National Laboratory, available at: http://greet.es.anl.gov

[7] In addition, emissions for FCEVs and NGVs depends slightly on grid electricity to power the compressors needed to compress hydrogen and natural gas, but the differences are too small to show up on this scale.

Table 4. GHG emissions from AFVs in grams of CO_2-equivalent/mile based on the *average* electric utility grid mixes in each region & average US GHGs based on a weighted average of LDVs per region

AFV GHG emissions in Grams/mile of CO2-equivalent based on the average utility grid mixes in each region	East Central Area Reliability Coordination Agreement - 01	Electric Reliability Council of Texas - 02	Mid-Atlantic Area Council - 03	Mid-America Interconnected Network - 04	Mid-Continent Area Power Pool - 05	Northeast Power Coordinating Council / New York - 06	Northeast Power Coordinating Council / New England - 07	Florida Reliability Coordinating Council - 08	Southeastern Electric Reliability Council - 09	Southwest Power Pool - 10	WECC / Northwest Power Pool Area - 11	WECC / Rocky Mountain and Arizona-New Mexico-Southern Nevada Power Area - 12	WECC / California - 13	Alaska & Hawaii - 14	LDV-wgt'd Average US grid Mix
Gasoline ICV (CG&RFG)	409	409	409	409	409	409	409	409	409	409	409	409	409	409	409
E-85 ICV	307	307	307	307	307	307	307	307	307	307	307	307	307	307	307
Gasoline HEV (CG&RFG)	293	293	293	293	293	293	293	293	293	293	293	293	293	293	293
NGV	353	353	353	353	353	353	353	353	353	353	353	353	353	353	354
NG HEV	260	260	260	260	260	260	260	260	260	260	260	260	260	260	261
E-85 HEV	235	235	235	235	235	235	235	235	235	235	235	235	235	235	235
BEV	435	343	254	348	351	221	272	346	311	300	179	313	116	422	292
FCEV	219	219	219	219	219	219	219	219	219	219	219	219	219	219	219
NG PHEV	362	319	277	321	323	261	285	320	304	299	241	305	211	356	295
FC PHEV	342	299	258	302	303	243	267	301	285	280	224	285	195	336	276
CG & RFG PHEV-40	379	336	294	338	340	278	302	337	321	316	258	322	228	373	312
% of US LDVs	13.7%	5.9%	9.1%	8.8%	3.6%	5.5%	5.3%	5.6%	17.2%	3.0%	5.2%	3.1%	13.5%	0.6%	100%

work/emissions/Car GHG & Criteria Pollutants (Rev 1-2011).XLS; WS 'AFV GHG' R-94 1/25/2012

CG = conventional gasoline; RFG = reformulated gasoline; ICV = internal combustion engine vehicle; NGV = natural gas vehicle; E-85 = mixture of 85% ethanol and 15% gasoline;

Table 5. GHG emissions from AFVs in grams/mile based on marginal grid mixes in each region

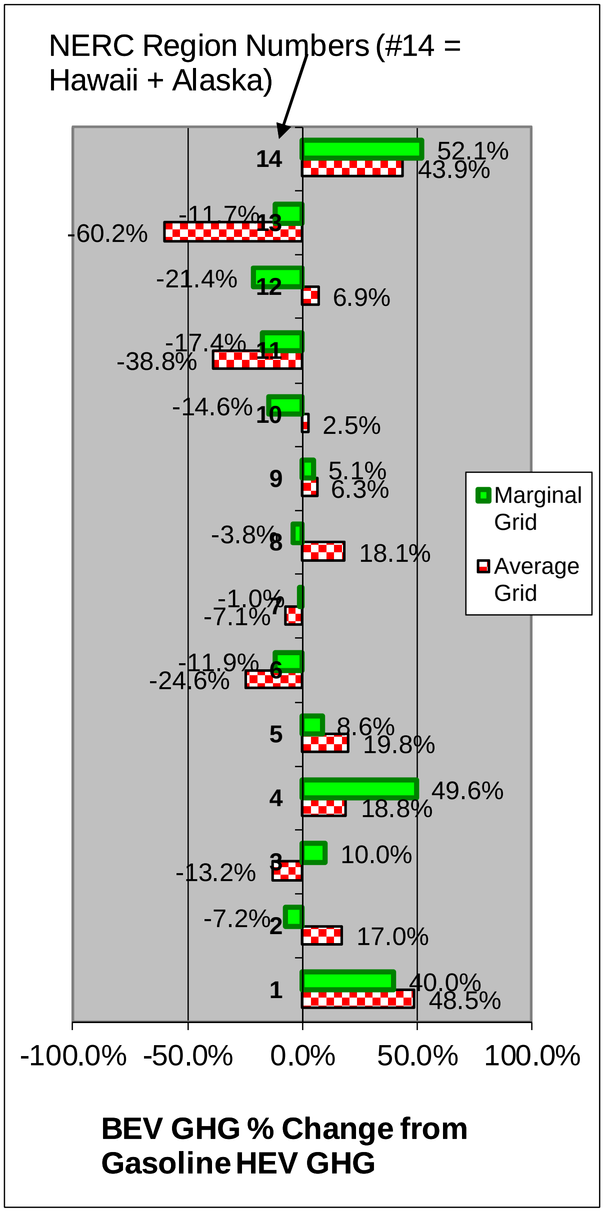
AFV GHG emissions in Grams/mile of CO2-equivalent based on the marginal grid mixes in each region	East Central Area Reliability Coordination Agreement - 01	Electric Reliability Council of Texas - 02	Mid-Atlantic Area Council - 03	Mid-America Interconnected Network - 04	Mid-Continent Area Power Pool - 05	Northeast Power Coordinating Council / New York - 06	Northeast Power Coordinating Council / New England - 07	Florida Reliability Coordinating Council - 08	Southeastern Electric Reliability Council - 09	Southwest Power Pool - 10	WECC / Northwest Power Pool Area - 11	WECC / Rocky Mountain and Arizona-New Mexico-Southern Nevada Power Area - 12	WECC / California - 13	Alaska & Hawaii - 14	LDV-wgt'd average US Marginal Grid Mix
Gasoline ICV (CG&RFG)	409	409	409	409	409	409	409	409	409	409	409	409	409	409	409
E-85 ICV	307	307	307	307	307	307	307	307	307	307	307	307	307	307	307
Gasoline HEV (CG&RFG)	293	293	293	293	293	293	293	293	293	293	293	293	293	293	293
NGV	353	353	353	353	353	353	353	353	353	353	353	353	353	353	354
NG HEV	260	260	260	260	260	260	260	260	260	260	260	260	260	260	261
E-85 HEV	235	235	235	235	235	235	235	235	235	235	235	235	235	235	235
BEV	410	272	322	438	318	258	290	282	308	250	242	230	259	446	315
FCEV	219	219	219	219	219	219	219	219	219	219	219	219	219	219	219
NG PHEV	351	285	309	364	307	278	294	290	302	275	271	265	279	367	305
FC PHEV	330	266	290	343	288	260	275	271	283	256	253	247	260	347	286
CG & RFG PHEV-40	368	302	326	381	324	295	311	307	319	292	288	282	296	384	322
% of US LDVs	13.7%	5.9%	9.1%	8.7%	3.6%	5.5%	5.3%	5.6%	17.2%	3.0%	5.2%	3.1%	13.5%	0.6%	100%
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	0

work/emissions/Car GHG & Criteria Pollutants (Rev 1-2011).XLS; WS 'AFV GHG' R-118 1/25/2012

7.0 GHG Changes due to EVs

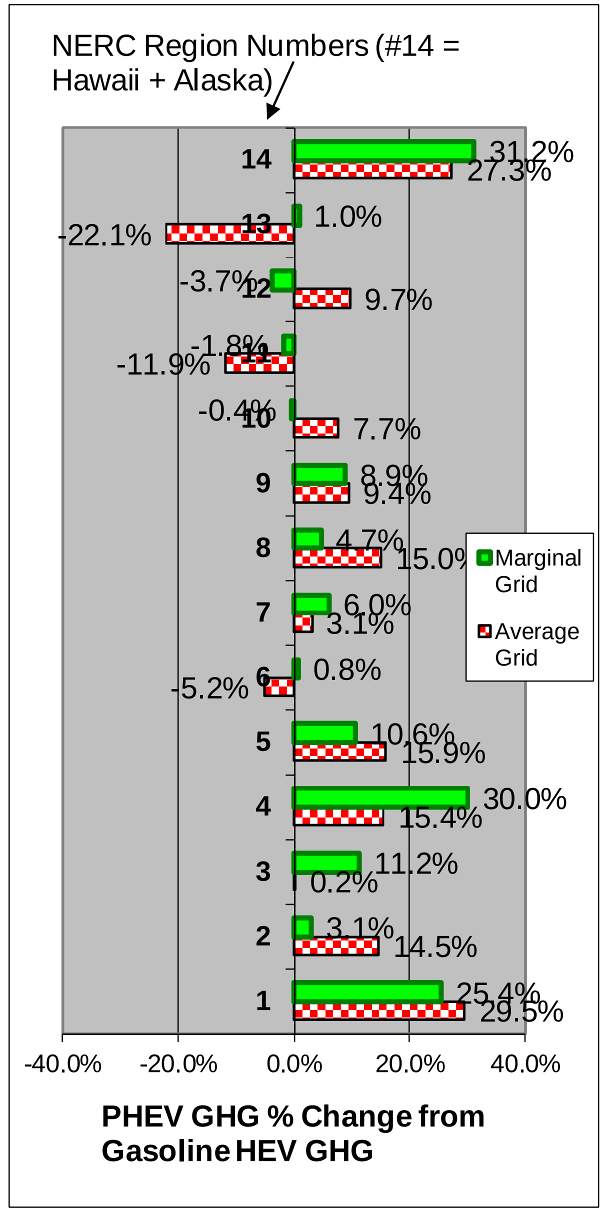
The changes in GHG emissions due to BEVs compared to gasoline-powered HEVs are summarized in Figure 3 for each of the 14 utility regions, and in Figure 4 for PHEVs.

For 6 out of the 14 regions in the US, a BEV will generate *more* GHGs than a (now conventional) gasoline HEV such as the Toyota Prius. For example, in Region 1, the East Coast Reliability Agreement or ECAR region, each BEV will generate approximately 48.5% higher GHGs than an HEV (435 g/mile vs. 293 g/mile) using the average grid mix, or 40% higher GHGs (410 vs. 293 g/mile) using the recommended marginal grid mix for Region 1.



work/emissions/Car GHG & Criteria Pollutants (Rev 1-2011).XLS; 'AFV GHG' BX-75 1/25/2012

Figure 3. Percentage change in GHGs due to substituting a BEV for a gasoline HEV in each region



work/emissions/Car GHG & Criteria Pollutants (Rev 1-2011).XLS; 'AFV GHG' CC-75 1/25/2012

Figure 4. Changes in GHG emissions for PHEVs relative to gasoline HEVs in each region

A BEV would reduce GHGs in eight US regions according to the recommended marginal grid measure:

1.0 Region 2-Texas (-7.2%)
2.0 Region 6-New York (-11.9%)
3.0 Region 7 –New England (-1%)
4.0 Region 8-Florida (-3.8%)
5.0 Region 10-Southwest Power Pool (-14.6%)

6.0 Region-11-WECC[8]-Northwest (-17.4%)
7.0 Region 12-WECC-Rocky Mountain Power Pool, Arizona, New Mexico & Southern Nevada (--21.4%)
8.0 Region13 WECC-California (-11.7%)

While some regions of the US will have lower GHG emissions if BEVs are substituted for gasoline HEVs, it turns out that those regions with lower BEV GHGs also have statistically fewer total vehicles as shown in Figure 5; conversely, those regions with larger BEV GHGs tend to be in regions with more total vehicles (indicated by the trend line in Figure 5 that slopes slightly upward as the density of vehicles increases.) So the vehicle weighted average GHG emissions actually increase if BEVs are substituted for gasoline HEVs! Figure 6 shows the same trend for GHG emissions from PHEVs; PHEV GHG emissions also tend to be higher in regions with a higher density of vehicles.

Averaged over the entire US, a BEV will, based on the weighted average of LDVs in each region, *increase* GHGs by 7.4% compared to gasoline HEVs (315 g/m vs. 293 g/m) as shown in the last column of Table 5.
For comparison, a FCEV using hydrogen made from natural gas will *reduce* GHG emissions by 25.3% relative to a gasoline HEV (219 vs. 293 g/m).

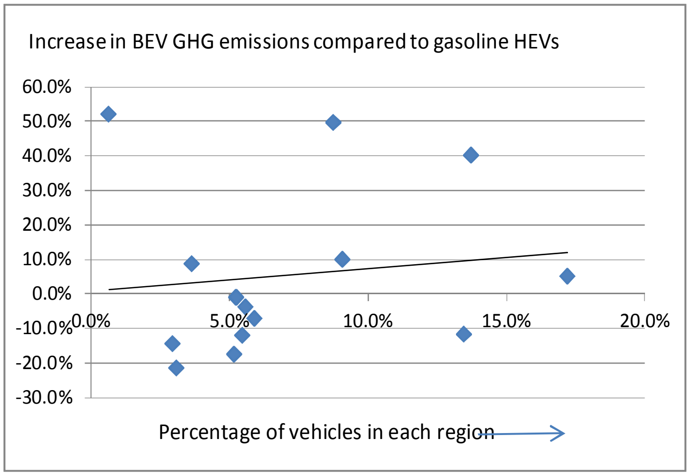
The GHG reductions for a PHEV are even worse, since the PHEV generates GHGs from burning gasoline in addition to the GHGs from electricity generation.

As shown in Figure 4, PHEVs will increase GHGs in all but three regions of the US (#'s 10, 11, & 12) using the recommended marginal grid mix calculation.

Note also the wide divergence between average and marginal grid mix calculations in some regions. Using the average grid mix in California (Region 13) would predict a 22.1% reduction in GHGs, but the recommended marginal grid mix calculation shows a 1% increase for PHEVs in California.

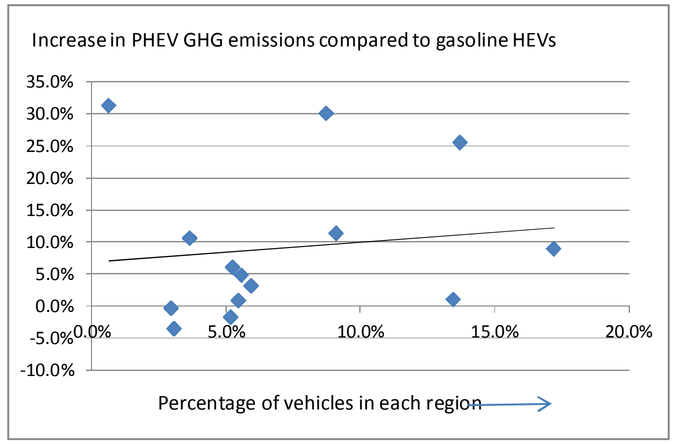
The LDV-weighted averages over the entire US show a 6.3% *increase* in PHEV GHGs with the average grid mix and a 10% *increase* using marginal grid mixes as summarized in Figure 7. For comparison, a FCEV reduces GHGs by 25.3% relative to an HEV.

[8] WECC = western electricity coordinating council



work/emissions/Car GHG & Criteria Pollutants (Rev 1-2011).XLS; WS 'AFV GHG' T-143 2/11/2012

Figure 5. Scatter diagram showing the relation between the % increase in GHG emissions for BEVs relative to gasoline HEVs as a function of the total number of vehicles in each region, showing that regions with more total vehicles tend to have higher BEV GHG emissions



work/emissions/Car GHG & Criteria Pollutants (Rev 1-2011).XLS; WS 'AFV GHG' T-163 2/11/2012

Figure 6. Scatter diagram showing the relation between the % increase in GHG emissions for PHEVs relative to gasoline HEVs as a function of the total number of vehicles in each region, showing that regions with more total vehicles tend to have higher PHEV GHG emissions

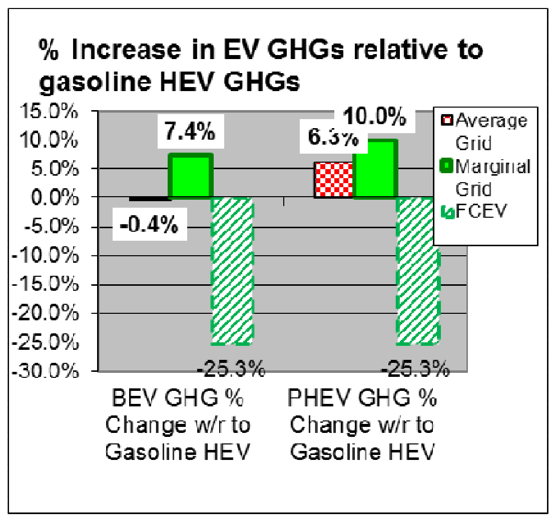


Figure 7, Summary of LDV-weighted average GHG changes for EVs replacing gasoline HEVs

9.0 Petroleum Consumption Reductions due to EVs

Most observers assume that BEVs will eliminate all oil consumption since these vehicles run exclusively on electricity. However, petroleum is used to prospect for, mine, process and deliver the fossil fuels used at most US electrical power generation plants. This is particularly true of coal-based plants, but even natural gas requires some petroleum to find and deliver natural gas to the power station. And, as noted above, oil is still used in some regions to produce some of the electricity that will be used to charge EV batteries[9] .

In fact, at least some oil-generated electricity is on the margin in 10 of the 14 regions in this study according to the Oak Ridge study. As a result, the reduction of oil consumption is less than 90% in six regions, and net oil consumption will actually *increase* by 7.3% in Region 14 (Alaska & Hawaii) as a result of replacing gasoline HEVs with BEVs as shown in Figure 8.

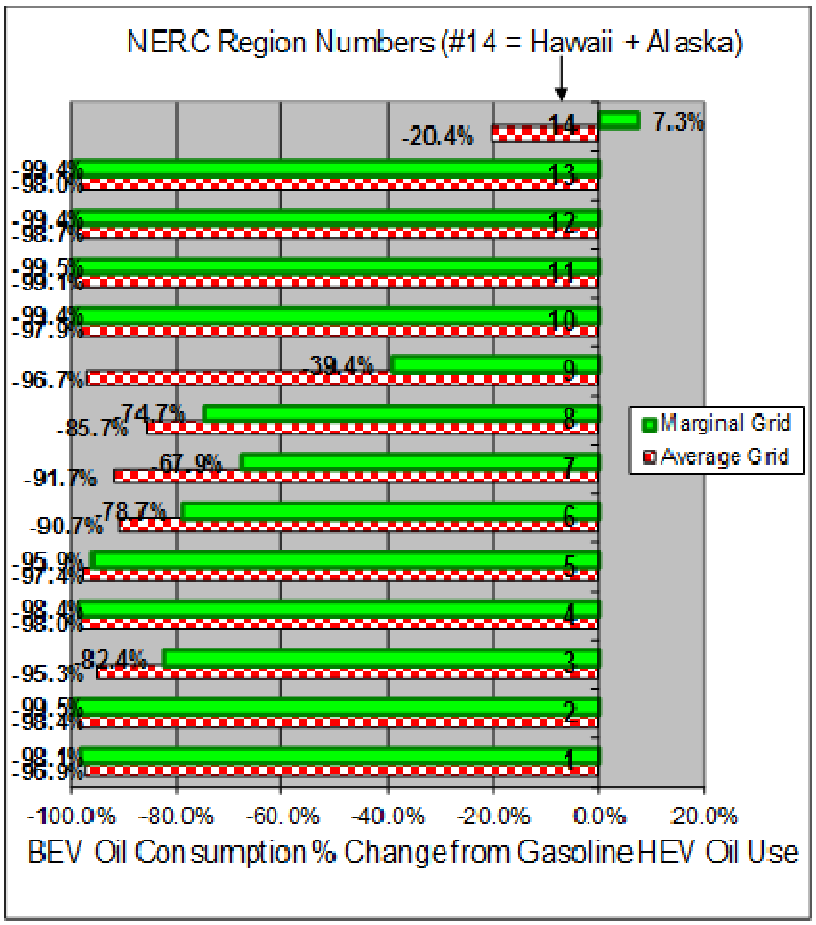
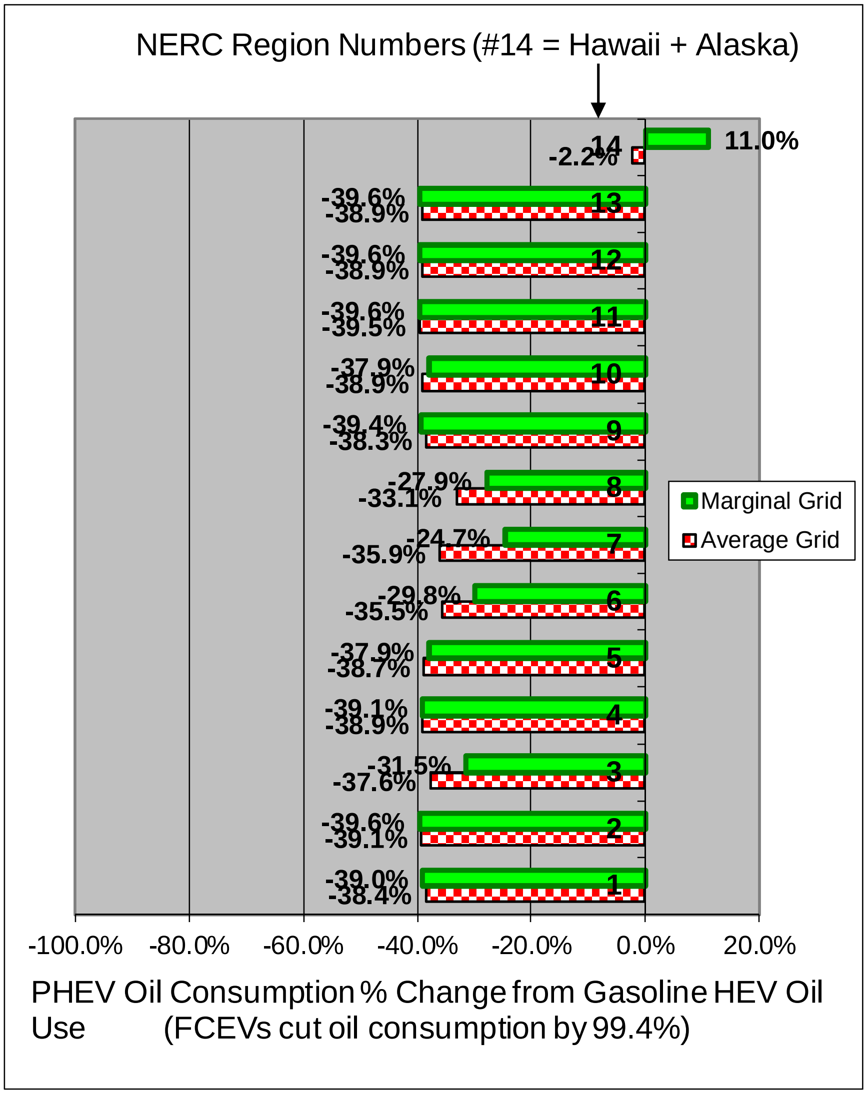


Figure 8. Changes in petroleum consumption due to BEVs replacing gasoline HEVs in each region

PHEVs will reduce oil even less, of course, since they will consume some gasoline directly in addition to using electricity. Figure 9 shows the percent reductions for PHEVs relative to gasoline HEVs. Note that petroleum consumption would increase 11% in Region 14 (Alaska & Hawaii) due to their use of oil-fired boilers to generate electricity. The LDV-weighted average reduction for PHEVs is 32.8% using the average grid mixes and 36.3% using the recommended marginal grid mix calculations.

[9] More than 75% of the *average* electricity generated in Hawaii comes from burning oil, and 17% of Alaskan electricity comes from petroleum.

Figure 10 is a summary of average LDV-weighted petroleum reductions for the various electric vehicles.



work/emissions/Car GHG & Criteria Pollutants (Rev 1- 2011).XLS; 'AFV GHG' BE-74 1/25 /2012

Figure 9. Percentage change in petroleum consumption for PHEVs relative to gasoline HEVs for the 14 electricity regions

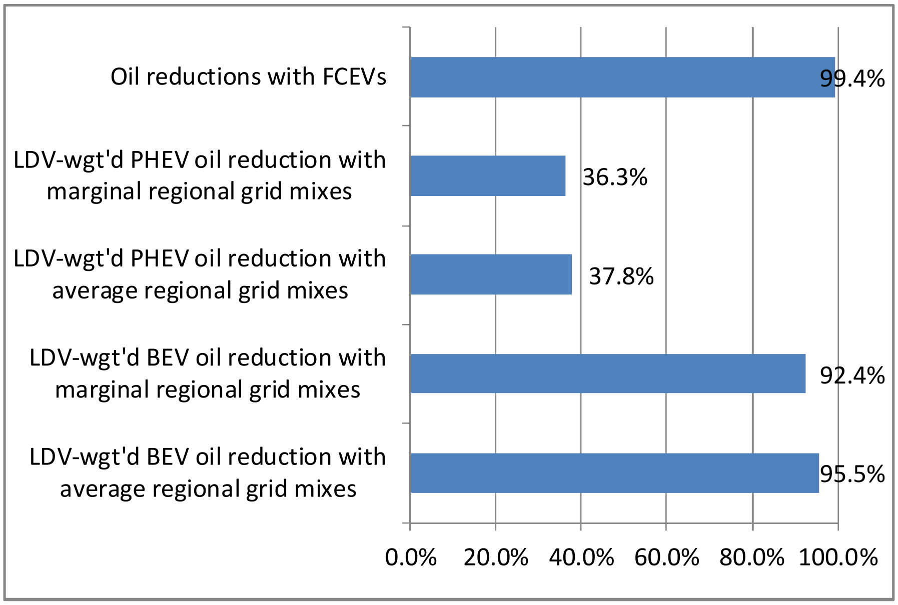


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Figure 10. the LDV-weighted average reductions in total US vehicle petroleum consumption (large is good!) for various EVs relative to gasoline HEVs; the FCEV value assumes that all hydrogen is made from natural gas.

9.0 Comparison with Scientific American article

The July 2010 issue of Scientific American included an article[10] originally titled "the Dirty Truth about Plug-in hybrids," although the web version was later changed to "how green is that electric car?" This article includes estimates of the percentage GHG reductions and percentage oil consumption reductions for various US regions that are similar to the NERC regions used by the Oak Ridge report. These Scientific American percentage reduction numbers were subsequently incorporated into an interactive web page that is still accessible online[11].

Since Scientific American is not a peer-reviewed magazine, it does not include any description of the origin of or methodology used to generate the percent reduction numbers, and the author refers only to unnamed "DOE researchers," as the source of the data.

As shown in Figure 11, the Scientific American GHG data are generally much lower than the estimates using the recommended marginal grid mix in each region (the Scientific American article did not consider "Region 14" of Alaska and Hawaii.) On the

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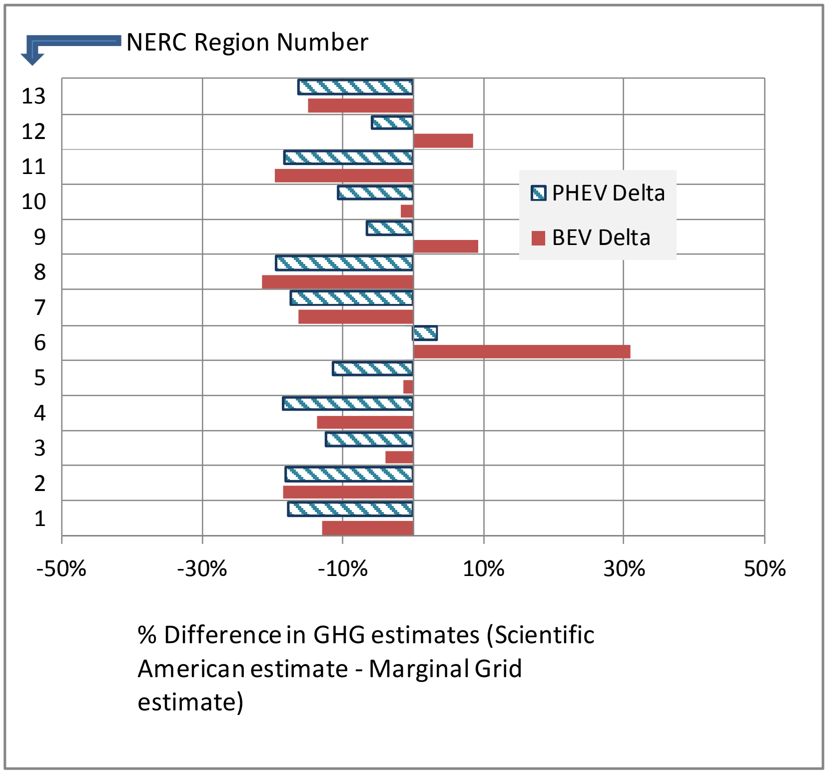
[10] M. Mayer, "The Dirty Truth about Plug-in Hybrids," Scientific American, Vol 303, Issue 1, July, 2010, pages 54-55.

[11] The interactive map can be accessed at: http://www.scientificamerican.com/article.cfm?id=interactive-plug-in-hybrids

average over the 13 continental US NERC regions, the LDV-weighted Scientific American GHG estimates are 13.9% lower than the marginal grid estimates for BEVs, and 14.8% lower for PHEV GHG estimates.

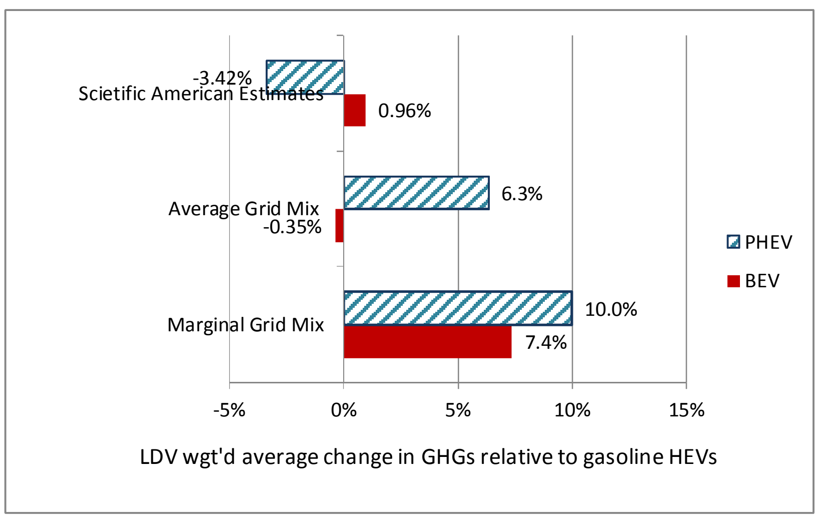
The average LDV-weighted changes in GHGs for BEVs and PHEVs relative to gasoline HEVs is summarized in Figure 12 using the average grid mixes and marginal grid mixes in each region, along with the LDV-weighted results using the Scientific American data. The greatest difference is in the PHEV projections, with the Scientific American data showing an LDV-weighted average *reduction* of 3.42% in GHG emissions compared to HEVs, versus an estimated 10% *increase* in GHG emissions from PHEVs averaged over the entire US using the recommended marginal grid mix.

The Scientific American data on BEVs are closer to the marginal grid mix estimates, with the Scientific American data showing a net increase of 0.96% averaged according to the vehicle density in each region, versus an



work/emissions/Car GHG & Criteria Pollutants (Rev 1-2011).XLS; WS 'AFV GHG' AP-86 1/25/2012

Figure 11. Difference between of GHG emissions estimated in this article using the marginal grid mix data recommended by the GHG Protocol and the Scientific American estimates.



work/emissions/Car GHG & Criteria Pollutants (Rev 1-2011).XLS; WS 'AFV GHG' AF-66 1/26/2012

Figure 12. Changes in GHG emissions for BEVs and PHEVs relative to gasoline HEVs, averaged over all regions of the continental US based on the density of light duty vehicles in each region.

estimated 7.4% increase in GHG emissions using the weighted average marginal grid mixes around the country.

Since the Scientific American article was glaringly unscientific by not reporting how these data were calculated or what sources were used, we cannot explain these differences.

10.0 Conclusions

We conclude the following:

1. According to the GHG Protocol, GHG emissions from new utility loads such as charging the batteries of PHEVs and BEVs should utilize the *marginal* grid mix, not the *average* grid mix for any utility region.
2. The marginal grid mix will usually (but not always) generate more GHG emissions than the average grid mix, since the low-carbon electrical generators such as nuclear and hydroelectric generally have the lowest operating cost and will therefore be run first as baseload and will rarely be on the margin[12] for satisfying demand from new loads such as battery charging.
3. Greenhouse Gas Emissions.
    a. The greenhouse gas emissions from battery EVs will be larger than the GHG emissions from gasoline hybrid electric vehicles in 6 of the 14 continental utility regions[13] in the US.
    b. Averaged over the entire US according to the number of light duty vehicles in each region, the average US LDV GHG emissions will increase by 7.4% due to replacing BEVs with gasoline HEVs.
    c. Plug-in hybrid electric vehicles (PHEVs) will generate more GHG emissions in 11 out of 14 regions of the US compared to gasoline HEVs.
    d. Averaged over the entire US according to the number of LDV in each region, the average GHG emissions from PHEVs will *increase* by 10% compared to gasoline HEVs. This implies that drivers purchasing PHEVs would actually reduce GHGs by running their PHEVs on gasoline all the time, and never recharging the batteries[14]!
    e. For comparison, a fuel cell electric vehicle (FCEV) running on hydrogen made from natural gas will *reduce* GHG emissions by 25.3% compared to gasoline HEVs.
4. Petroleum Consumption
    a. EVs do "consume" some petroleum, since oil is needed to find, process and deliver the fossil fuels used to generate most marginal grid electricity,

[12] Nuclear power is never on the margin for any of the 13 NERC regions according to the Oak Ridge study.
[13] 13 North American Electric Reliability Corporation (NERC) regions in the continental US plus a "14th region" consisting of Hawaii and Alaska.
[14] In fact, the GHG emissions will still be higher than estimated here for the PHEV running on gasoline all the time than for a conventional HEV, due to the added weight of the extra battery bank for the PHEV compared to the HEV, which will decrease the fuel economy of the PHEV and increase GHGs compared to a lighter HEV.

and, in the case of the PHEVs, for partial use of gasoline or diesel fuel to power the vehicle.

b. Averaged over the entire US according to the density of LDVs in each region, each BEV would reduce oil consumption by 92.4% compared to gasoline HEVs, and each PHEV would reduce oil use by only 36.3% compared to HEVs.
c. For comparison, each FCEV reduces oil consumption by 99.4%, assuming that the hydrogen is made from natural gas.

5. Scientific American article and interactive web page on EV GHGs.
    a. The July 2010 Scientific American article "The Dirty Truth about Plug-in hybrids" and subsequent interactive web page map exaggerate the ability of PHEVs and BEVs to cut GHGs.
    b. Even so, the Scientific American GHG estimates, averaged over the entire continental US according to vehicle density in each region results in a net increase in GHG emissions of+0.96% compared to gasoline HEVs. (vs. a 7.4% GHG increase based on the weighted average marginal grid mix.)
    c. The Scientific American PHEV GHG data leads to a net *decrease* in LDV-weighted average US GHGs of 3.42% for PHEVs relative to gasoline HEVs, compared to an *increase* of 10% based on the weighted average using the marginal grid mixes recommended by the GHG protocol.
    d. Since the Scientific American article contains no references or description of the methodology used to generate their data, we cannot determine the reason(s) for these discrepancies.