GHGs & Gasoline consumption for alternative vehicles[1]

1. Introduction

   The main purpose of this report is to a) determine how many US vehicles could be comfortably and affordably powered by batteries and b) how much these BEVs and also plug-in hybrid electric vehicles (PHEVs) could reduce greenhouse gas (GHG) emissions and oil consumption. We have calculated the greenhouse gas (GHG) emissions and oil consumption for battery electric vehicles (BEVs), plug-in hybrid electric vehicles (PHEVs) and fuel cell electric vehicles (FCEVs) in the US, using the using the DOE's Argonne National Laboratory GREET 1.8_d_0 model that calculates the well-to-wheels total GHGs and oil use for alternative vehicles[2].

2. Conclusions

   On the basis of detailed computer simulations, we conclude that:

   a. Battery EVs (BEVs) could at most replace less than 40% of all US light duty vehicles[3] (LDVs), and these small vehicles account for less than 28% of all US vehicle miles traveled (VMTs), and they produce less than 26% of all LDV GHGs[4]. If we include the GHGs generated at the average US power plant to recharge the BEV batteries, then the net GHG reductions from converting all US small cars[5] and 50% of all US midsize sedans and wagons to BEVs would cut GHGs less than 8%, and they would reduce oil consumption by less than 25%.
   b. PHEVs could in theory replace all larger vehicles. But even with BEVs replacing all small LDVs and PHEVs replacing all other LDVs, GHGs would only be reduced by less than 27%, still far below the goal of cutting GHGs by 80% below 1990 levels, and oil consumption would be reduced by less than 67%. By contrast, hydrogen-powered fuel cell electric vehicles (FCEVs) would immediately cut GHGs by 51% and oil consumption by nearly 100% assuming that all hydrogen is made from natural gas. In the long-term FCEVs could also achieve the desired 80% reduction in GHGs once hydrogen was made from biomass, and other renewable sources, including particularly the anaerobic digester gas from waste water treatment plants or methane from landfill gas.

3. Detailed Results

The reductions in GHGs from the light duty vehicle fleet are shown in Figure 1 and Table 1 for hydrogen-powered FCEVs, BEVs, PHEV, and a combination of BEVs for all small vehicles and PHEVs for all large vehicles. Data are shown for years 2015, 2020 and 2035. The grid emission data for 2015 and 2020 are from the GREET model. The electrical grid generation data for 2035 are taken from the Energy

[1] Available at: http://www.cleancaroptions.com/GHGs___Oil_use_for_AFVs.pdf

[2] Michael 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/

[3] Other vehicles are either too heavy or travel too far to be affordably powered by batteries alone.

[4] For a derivation of these numbers which are based on 30 years of LDV sales in the US, see the report "Distribution of US Car Fleet by Car Class," available at: http://www.cleancaroptions.com/Distribution_of_US_Car_Fleet_by_Car_Class.pdf

[5] By small cars we include all 2-seaters, all minicompacts, subcompact and compact cars, all small pickup trucks, all small vans, and all small SUVs.

Information Administration's Annual Energy Outlook [6](AEO) for 2011. The grid mixture is not expected to change significantly over the next 24 years as shown in Table 2. Total electricity from fossil fuels will decrease only slightly from 70.3% in 2010 to 68.6% in 2035 according to the AEO reference case. Figure 1 shows that FCEVs using hydrogen made exclusively from natural gas will cut GHGs by more than 51%, while BEVs and PHEVs would cut GHGs by at most 27 % due to the preponderance of coal-based electricity, which the AEO predicts will still be at 46.2% of all electrical energy generated in 2035, up slightly from the 2010 coal fraction of 45.8%. Total electricity from fossil fuels is projected to increase from 68.6% in 2010 to 70.3% in 2035.

Table 1. Summary of maximum GHG and oil reductions possible for BEVs and PHEVs replacing all light duty vehicles

	ICV GHG Reductions* (tonnes CO2-eq.)	BEV GHGs (tonnes CO2-eq.)	PHEV GHGs	Net GHGs	Net % GHG Reduction	ICV Oil Reductions **	BEV Oil use**	PHEV Oil use**	Net Oil use**	Net % Oil Reduction
	BEV-Only									
2015	(342,035)	234,667		(107,368)	-7.9%	(25.5)	0.41		(25.1)	-24.5%
2020	(342,035)	236,430		(105,605)	-7.8%	(25.5)	0.44		(25.1)	-24.5%
2035	(342,035)	247,102		(94,933)	-7.0%	(25.5)	0.42		(25.1)	-24.5%
	BEV +PHEV								-	
2015	(1,357,444)	234,667	761,366	(361,411)	-26.6%	(102.5)	0.41	36	(66.3)	-64.7%
2020	(1,357,444)	236,430	774,995	(346,018)	-25.5%	(102.5)	0.44	36	(66.2)	-64.6%
2035	(1,357,444)	247,102	831,384	(278,958)	-20.6%	(102.5)	0.42	34	(68.3)	-66.7%
	PHEV-only									
2015	(1,357,444)		1,017,829	(339,615)	-25.0%	(102.5)		48	(54.8)	-53.5%
2020	(1,357,444)		1,036,048	(321,396)	-23.7%	(102.5)		48	(54.7)	-53.4%
2035	(1,357,444)		1,111,432	(246,012)	-18.1%	(102.5)		45	(57.5)	-56.1%

* GHGs are in metric tonnes of CO2-eq. per year

Car GHG and criteria pollutants (Rev C).XLS; WS 'Best Fuels' H 156 10/29 /2011

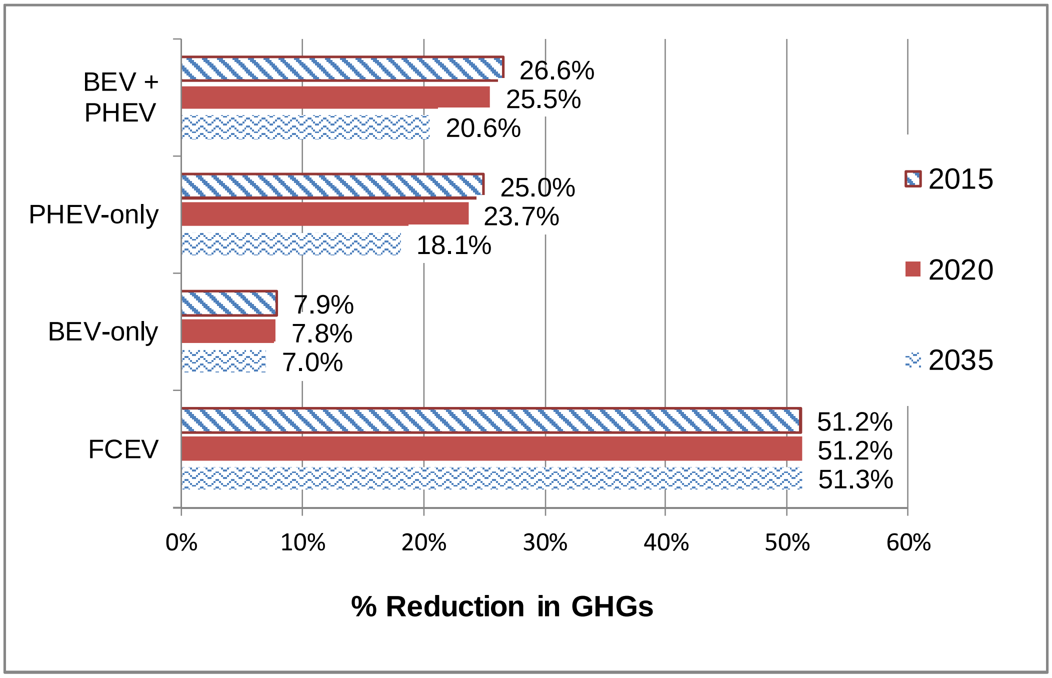
** Oil use is in units of million gallons of gasoline per year

Similarly, FCEVs will cut petroleum consumption much more than BEVs and PHEVs as shown in Figure 2. FCEVs will cut petroleum use by nearly 100%, while the combination of PHEVs and BEVs would at best cut oil consumption by 67%, since PHEVs still use some gasoline, and the GREET model even attributes some petroleum consumption to BEVs, since petroleum is required to mine, clean and transport coal, and petroleum is also used in natural gas recovery and processing. So the two main fuels to generate electricity in the US, coal and natural gas, both consume petroleum in the process of producing electricity to charge the vehicle batteries. Therefore even if BEVs replace all small vehicles and 50% of all midsize sedans and midsize wagons, petroleum use in the LDV sector would only be reduced by 25%, due primarily to the fact that most larger cars would still be consuming gasoline or diesel fuel[7].

The raw data from the GREET model are shown in Tables 3 (GHGs) and 4 (Petroleum use). These are the values per vehicle, and do not reflect the number of IC vehicles that could be displaced by each type of alternative vehicle.

[6] The Annual Energy Outlook 2011, the DOE's Energy Information Administration, available at: http://www.eia.gov/forecasts/aeo/

[7] But BEVs themselves also require petroleum to process and deliver fuel to the electrical generation plant, as shown in the detailed data of Table 4. In fact, each BEV on the road consumes <u>four times</u> the petroleum of each FCEV according to the GREET model as shown in Table 4.



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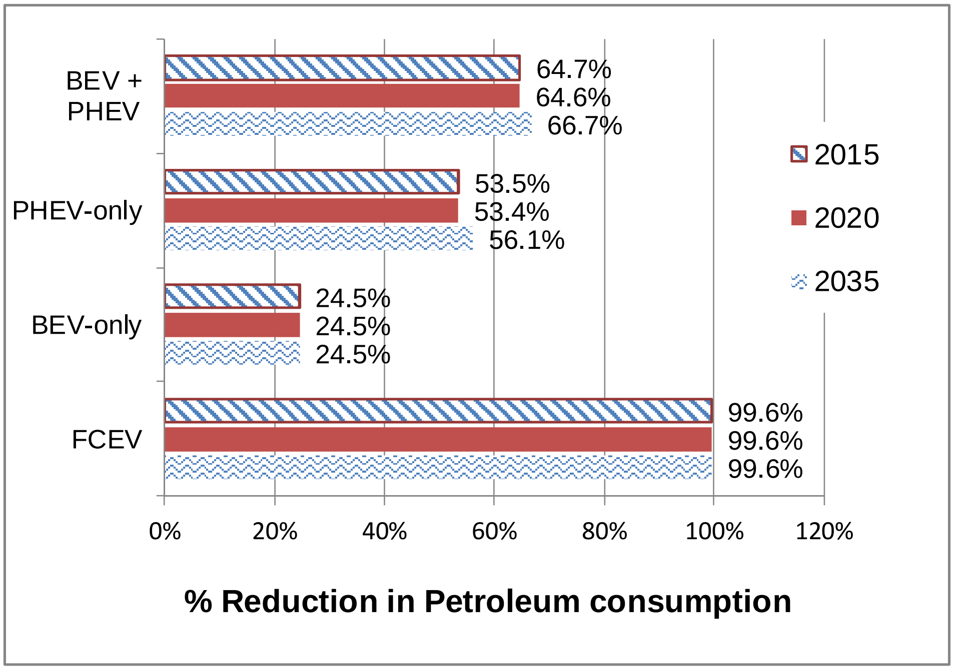
work/emmissions/Car GHG and criteria pollutants (Rev C).XLS; WS 'Best Fuels' H 140 10/29 /2011

Figure 1. Estimated reduction in greenhouse gas (GHG) emissions by US alternative vehicles in three time periods

Table 2. Average US electrical grid mix from the AEO-2011 projections

	2010	2015	2020	2035
Coal	46.2%	44.6%	45.2%	45.8%
Oil	1.0%	0.9%	1.0%	0.9%
Natural Gas	23.1%	20.9%	21.3%	21.9%
Total Fossil Fuels	70.3%	66.4%	67.5%	68.6%
Nuclear	20.3%	21.0%	21.3%	19.0%
Renewables	9.4%	12.5%	12.7%	12.3%

Car GHG and criteria pollutants (Rev C).XLS; WS 'US Grid' E 40 9/30 /2011



Car GHG and criteria pollutants (Rev C).XLS; WS 'Best Fuels' R 140 10/29 /2011

Figure 2. Estimated % reduction in petroleum consumption for four Alternative vehicle scenarios

Table 3. GHGs per vehicle estimated by the GREET model for the time periods shown.

Fuel feedstocks:	NG for H2, FTD & DME; corn for EtOH					NG	Biomass
Electrical grid:	US average electrical grid					AEO2011	all nuclear
Summary of GHGs over time	**grams/mile of CO2-eq.**					US Grid	
Vehicle	2010	2013	2015	2018	2020	2035	2050+
Gasoline ICV (CG&RFG)	532	457	480	421	464	411	405
E-85 ICV	498	427	449	395	434	385	380
Gasoline HEV (CG&RFG)	381	327	344	301	332	294	290
NGV	416	370	376	329	363	322	316
NG HEV	306	264	277	242	268	237	233
E-85 HEV	357	306	322	283	311	276	273
BEV	365	316	312	274	304	279	3
FCEV	260	226	234	200	226	200	2
NG PHEV	345	342	320	292	315	302	141
FC PHEV	325	379	301	271	297	285	3
CG & RFG PHEV	390	409	360	326	354	336	173
Grid-connected SI PHEV-40 E-85	207	141	194	187	194	194	43
Grid-connected CIDI PHEV-40 FT	411	442	379	339	372	353	15
Grid-connected CIDI PHEV-40 DM	389	409	359	324	353	336	4
Grid-Connected CIDI PHEV: BD2	358	363	331	302	326	312	149

(all PHEVs have 40 miles AER)

Car GHG and criteria pollutants (Rev C).XLS; WS 'Best Fuels' J 54 10/29 /2011

ICV = internal combustion engine vehicle; E-85 = mixture of 85% ethanol in gasoline; HEV = hybrid electric vehicle; NG = natural gas; BEV = battery electric vehicle; FCEV = fuel cell electric vehicle; PHEV = plug-in hybrid electric vehicle (with 40 miles all electric range); RFG = reformulated gasoline; SI = spark ignition; CIDI = compression ignition, direct injection (diesel) engine; FTD =Fischer-Tropsch Diesel; DME = dimethyl ether; BD 20 = 20% biodiesel mixture.

Table 4. Petroleum consumption estimated by GREET for time periods shown

Fuel feedstocks:	NG for H2, FTD & DME; corn for EtOH						NG	Biomass
Electrical grid:	US average electrical grid						AEO2011	all nuclear
Summary of GHGs over time	**btu/mile**						US Grid	
Vehicle	2010	2013	2015	2018	2020		2035	2050+
Gasoline ICV (CG&RFG)	5,808	5,002	5,239	4,542	5,059		4,343	4,343
E-85 ICV	5,597	4,809	5,049	4,414	4,875		4,246	4,246
Gasoline HEV (CG&RFG)	4,149	3,573	3,742	3,245	3,614		3,102	3,102
NGV	32	28	28	25	27		24	24
NG HEV	23	20	21	18	20		18	18
E-85 HEV	3,998	3,435	3,606	3,153	3,482		3,033	3,033
BEV	102	89	85	79	83		73	4
FCEV	25	22	22	20	22		18	73
NG PHEV	57	39	52	52	52		50	13
FC PHEV	58	47	53	53	53		50	49
CG & RFG PHEV	2,689	3,815	2,436	2,043	2,358		1,905	1,868
Grid-connected SI PHEV-40 E-85	936	1,258	849	714	822		674	637
Grid-connected CIDI PHEV-40 FT	74	64	68	65	67		62	100
Grid-connected CIDI PHEV-40 DM	84	78	77	73	76		69	100
Grid-Connected CIDI PHEV: BD2	2,211	3,180	2,003	1,687	1,939		1,577	1,540

(all PHEVs have 40 miles AER)

Car GHG and criteria pollutants (Rev C).XLS; WS 'Best Fuels' S 54 10/29 /2011

BEV Reductions per vehicle displaced

For the future GHGs and oil use can be reduced further by replacing electrical generation with zero-carbon sources such as renewables or nuclear power, and by replacing fossil fuels with biofuels for other vehicles. Several possibilities are summarized in Table 5 for future GHG and oil reductions. The best options (lowest GHGs or petroleum use) are highlighted for each fuel. I have added one option for hydrogen generation that is not currently in the GREET model: utilizing the anaerobic digester gas from waste water treatment plants, such as the molten carbonate fuel cell system installed at the Orange County Sanitation District in Fountain Valley California. This option should have negative net GHGs, since the stationary fuel cell displaces grid electricity for the treatment plant, and its waste heat displaces the use of natural gas to heat the digester vessel, eliminating two sources of GHGs from the existing WWTP operation. This option can produce totally green, renewable hydrogen at very low cost, since the electricity and natural gas fuel savings pay for the stationary fuel cell system in a few years. This is not some future option, but has been implemented in California, supplying renewable hydrogen to FCEVs near a major interchange in Fountain Valley.

As shown in Table 5, the FCEV option with woody biomass gasification produces the lowest GHG source at only 2 grams of CO2-eq. per mile. The next best option is dimethyl ether (DME) in a diesel enginePHEV-40 at 4 grams/mile.

Table 5. Estimated future per vehicle GHGs and oil use with zero-carbon (Nuclear) grid and biofuels or biomass feedstocks

Vehicle	Fuel	GHGs grams/mile	Oil btu/mile
SI PHEV-40	gasoline	173	1868
E-85 SI PHEV-40	Corn	148	629
	Farmed Trees	43	654
	Herb. Biomass	60	636
	Forest residue	70	678
	Corn stover	43	637
FTD CIDI PHEV-40	NG	182	25
	Landfill Gas	7	14
	Farmed Trees	15	100
	Herb. Biomass	36	95
	Forest residue	20	178
	Corn stover	18	101
DME CIDI PHEV-40	NG	168	32
	Landfill Gas	8	22
	Farmed Trees	4	100
	Herb. Biomass	24	96
	Forest residue	9	171
	Corn stover	7	101
G. H2 FCEV	NG	189	18
	Landfill Gas	2	73
	100% woody trees*	2	73
	50/50 woody/H.bio*	12	71
	PV	29	8
	WWTP ADG	(negative?)	0?

*H2 from biomass with electricity cogeneration

Car GHG and criteria pollutants.XLS; WS 'Best Fuels' D 30 7/5/2011

WWTP ADG = waste water treatment plant anaerobic digester gas