Gopstein, Avi (S4)

From: Miner, Laurel (S4)
Sent: Friday, September 23, 2011 6:07 PM
To: Gopstein, Avi (S4)
Subject: FW: QTR inputs
Attachments: GHGs & Oil use for AFVs-final.pdf; Maximum GHG & Oil Reductions.pdf; Key points from McKinsy EU report on electric vehicles.pdf

Follow Up Flag: Follow up
Flag Status: Flagged

From: Cleancaroptions Mail [mailto:ecocargreen@verizon.net]
Sent: Wednesday, July 13, 2011 8:44 PM
To: Miner, Laurel (S4)
Subject: QTR inputs

Dear Laurel,

Thanks for your help coordinating the Capstone workshop today.
As promised, attached are three items: our summary "key points from..."of the McKinsey & Company report on alternative vehicles in the EU, and here is the link to the full report.

Also, I am attaching the results of the recent research that I mentioned; the full information and derivation of the data is presented in the document "GHGs & Oil use for AFVs-final", and a short one-page summary of these data entitled "Maximum GHG & Oil Reductions." (I just noticed that the full 6-page report is listed at only 71.1 K, while the one-page summary is shown as 135 KB...strange!

Bottom line results: if all US LDVs were replaced by BEVs and PHEVs, then, according to the Argonne National Lab GREET model, GHGs would be reduced by only 28%, and oil would be reduced by only 67%. These same two reduction numbers if all cars were replace with fuel cell electric vehicles powered by hydrogen made from natural gas would be 50% GHG reductions and nearly 100% oil consumption reduction.

I would appreciate it if you could insert this information into the QTR process.

Also, I live in Alexandria, so I would be pleased to visit DOE and make a presentation on these and related data.

Thanks again,
Sandy Thomas

C.E. (Sandy) Thomas, Ph.D.
Clean Energy Consultant (former legislative assistant to Senator Tom Harkin and former President of H2Gen Innovations, Inc.)
Mobile: 703-507-8149
thomas@cleancaroptions.com

GHGs & Gasoline consumption for alternative vehicles

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. 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[1] (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[2]. 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[3] and 50% of all US midsize sedans and wagons to BEVs would cut GHGs less than 10%, and they would reduce oil consumption by less than 26%.
   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 28%, 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 50% 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.

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 Information Administration's Annual Energy Outlook (AEO) for 2011. The grid mixture is not expected to change significantly over the next 24 years as shown in Table 2. Figure 1 shows that FCEVs using hydrogen made exclusively from natural gas will cut GHGs by more than 50%, while BEVs and PHEVs

---

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

[2] 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

[3] 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.

would cut GHGs by at most 28% due to the preponderance of coal-based electricity, which the AEO predicts will still be at 46.1% of all electrical energy generated in 2035, down only marginally from the 2010 coal fraction of 46.6% .

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

	ICV GHG Reductions*	BEV GHGs	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	(292,565)	198,332		(94,232)	-8.2%	(26.6)	0.47		(26.1)	-25.1%
2020	(292,565)	185,715		(106,850)	-9.3%	(26.6)	0.46		(26.1)	-25.1%
2035	(292,565)	179,387		(113,177)	-9.9%	(26.6)	0.45		(26.1)	-25.1%
	BEV +PHEV								-	
2015	(1,146,473)	198,332	672,296	(275,844)	-24.1%	(104.2)	0.47	36	(67.4)	-64.7%
2020	(1,146,473)	185,715	654,417	(306,341)	-26.7%	(104.2)	0.46	34	(69.7)	-66.9%
2035	(1,146,473)	179,387	644,438	(322,647)	-28.1%	(104.2)	0.45	34	(69.7)	-66.9%
	PHEV-only									
2015	(1,146,473)		902,637	(243,835)	-21.3%	(104.2)		49	(55.5)	-53.2%
2020	(1,146,473)		878,632	(267,841)	-23.4%	(104.2)		46	(58.5)	-56.1%
2035	(1,146,473)		865,234	(281,238)	-24.5%	(104.2)		46	(58.5)	-56.1%

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

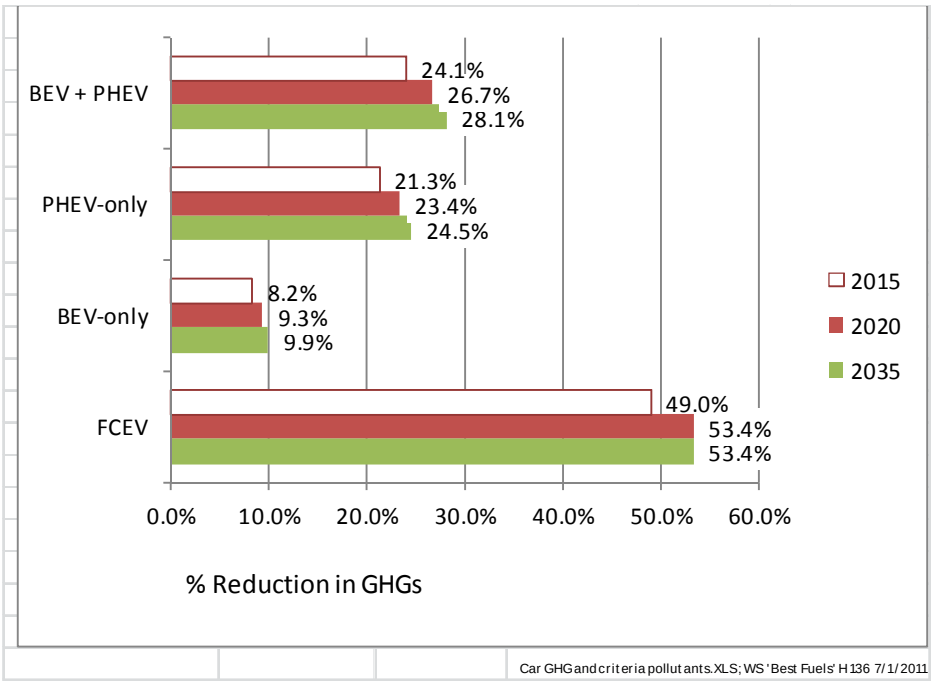
** Oil use is in units of million gallons of gasoline per year

Car GHG and criteria pollutants (Rev B).XLS; WS 'Best Fuels' H153 7/5/2011

Similarly, FCEVs will cut petroleum consumption much more than BEVs and PHEVs as shown in Figure 2 and Table 1. 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 significant 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[4].

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 vehicles that could be displaced by each type of vehicle.

[4] 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.



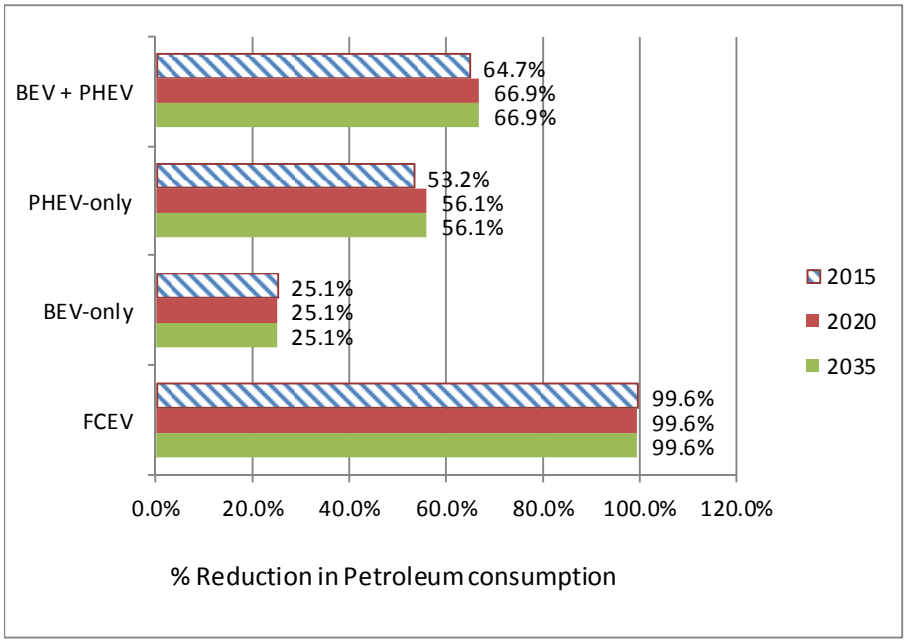
:

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	2020	2035
Petroleum	1.0%	1.0%	0.9%
Natural Gas	23.3%	20.0%	22.1%
Coal	46.6%	45.5%	46.1%
Nuclear	21.4%	21.9%	19.1%
Renewables & other	11.0%	12.1%	11.8%

Car GHG and criteria pollutants.XLS; WS 'Best Fuels' D114 7/1/2011



Car GHG and criteria pollutants.XLS; WS 'Best Fuels' R 136 7/1/2011

Figure 2. Estimated % reduction in petroleum consumption per US vehicle

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)	473	457	447	421	405	405	405
E-85 ICV	442	427	418	395	380	380	380
Gasoline HEV (CG&RFG)	339	327	320	301	290	290	290
NGV	404	370	350	329	316	316	316
NG HEV	274	264	258	242	233	233	233
E-85 HEV	317	306	300	283	273	273	273
BEV	337	316	303	274	257	248	3
FCEV	240	226	218	200	189	189	2
NG PHEV	381	342	314	292	278	274	141
FC PHEV	563	379	296	271	257	252	3
CG & RFG PHEV	473	409	352	326	310	305	173
Grid-connected SI PHEV-40 E-85	103	141	197	187	180	176	43
Grid-connected CIDI PHEV-40 FTD	532	442	369	339	322	317	15
Grid-connected CIDI PHEV-40 DME	482	409	351	324	307	303	4
Grid-Connected CIDI PHEV: BD20	416	363	325	302	288	283	149

(all PHEVs have 40 miles AER)

Car GHG and criteria pollutants.XLS; WS 'Best Fuels' I 54 7/5/2011

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:

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)			5,212	5,002	4,870	4,542	4,343		4,343	4,343
E-85 ICV			4,993	4,809	4,693	4,414	4,246		4,246	4,246
Gasoline HEV (CG&RFG)			3,723	3,573	3,478	3,245	3,102		3,102	3,102
NGV			30	28	26	25	24		24	24
NG HEV			21	20	19	18	18		18	18
E-85 HEV			3,566	3,435	3,352	3,153	3,033		3,033	3,033
BEV			93	89	86	79	74		73	4
FCEV			23	22	21	20	18		18	73
NG PHEV			29	39	55	52	51		50	13
FC PHEV			54	47	56	53	51		50	49
CG & RFG PHEV			5,212	3,815	2,278	2,043	1,905		1,905	1,868
Grid-connected SI PHEV-40 E-85			1,648	1,258	797	714	675		674	637
Grid-connected CIDI PHEV-40 FTD			64	64	69	65	63		62	100
Grid-connected CIDI PHEV-40 DME			85	78	78	73	70		69	100
Grid-Connected CIDI PHEV: BD20			4,405	3,180	1,874	1,687	1,578		1,577	1,540

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' D30 7/5/2011

WWTP ADG = waste water treatment plant anaerobic digester gas

Bob Rose states that the McKinsey and Company report "confirms the value of fuel cell EVs in our national energy portfolio", and lists these key points from that report

- ➔ FCEVs are the best EV option for longer trips and medium size and larger cars, where they are cost-competitive with internal combustion engines.
- ➔ FCEVs have inherent advantages, including better performance and range. FCEV refuelling time is measured in minutes compared to hours for battery EVs.
- ➔ Refuelling infrastructure is affordable and in line with other EV options. ("A dedicated hydrogen infrastructure is therefore justified and doable.")
- ➔ Long lead times make it "a matter of urgency" that governments adopt programs to support vehicle sales and infrastructure in the early years.
- ➔ While the analysis focuses on Europe, the technology and cost assessment is applicable worldwide –and the policy conclusions are relevant to the United States
    - o the U.S. has an even greater percentage of medium and heavy duty vehicles and we drive our cars longer distances

Here are some more details to backup several of Bob's key points:

1. **FCEVs are ready for commercial scale-up**; here's how McKinsey and Company put it: "Given satisfactory testing in a customer environment - with more than 500 cars [FCEVs] covering over 15 million kilometres and 90,000 refuellings - the focus has now shifted from demonstration to planning commercial deployment so that FCEVs, like all technologies, may benefit from mass production and the economies of scale."
2. **FCEVs are the best option for longer trips where they are competitive with ICEVs**. Figure 1 (next page) compares the McKinsey estimated total cost of ownership (TCO) for various vehicles in 2030 and 2050. By 2030, they estimate that the TCO for FCEVs will be less than the TCO for BEVs and PHEVs, although still slightly higher than the TCOs for gasoline or diesel ICVs. By 2050, however, (red bars) they are projecting FCEVs to have the lowest TCO, even lower than gasoline and diesel ICVs. By 2030 they project that a FCEV will cost €32,700 for a large J-segment vehicle, while a large BEV would cost €37,300 and a large PHEV would cost €34,700. For smaller A/B segment cars, the BEV and PHEV would cost less and have slightly lower TCOs. However, they point out that the medium C/D/E-segments & larger J/M-segment cars that travel more than average distances each year account for 50% of all cars in the EU and these medium/large vehicles generate 75% of vehicle CO_2 emissions.

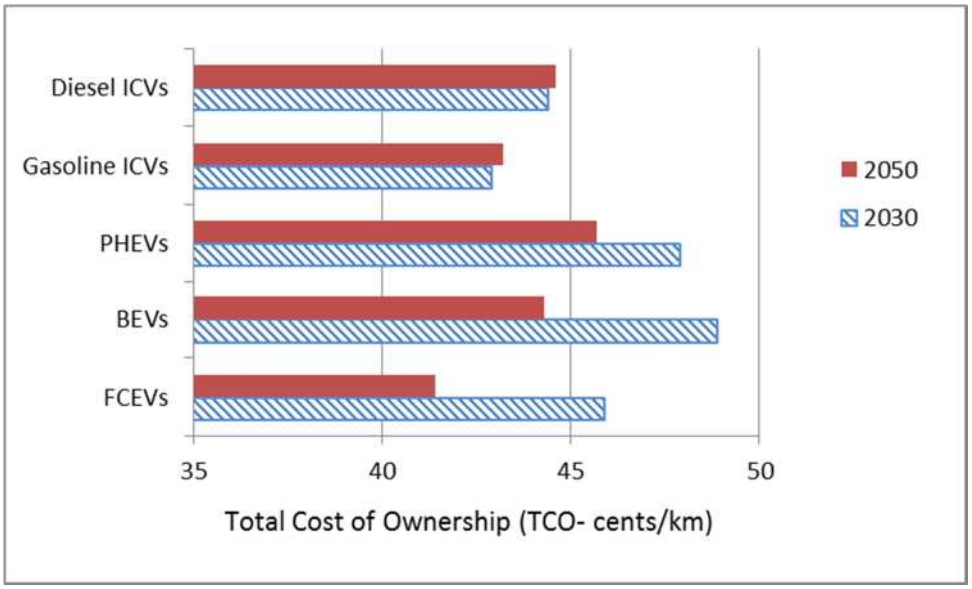


Figure 1. Estimated TCO for large (J-segment) vehicles in 2030 and 2050

3. **FCEVs have inherent advantages** in terms of range and fueling time. As the McKinsey report puts it:
   "Owing to limits in battery capacity and driving range[1] (currently 100-200 km for a medium-sized car[2]) and a current recharging time of several hours, BEVs are ideally suited to smaller cars and shorter trips, i.e. urban driving (including new transportation models such as car sharing). With a driving range and performance comparable to ICEs, FCEVs are the lowest carbon solution for medium/larger cars and longer trips." And:
   " For example, an average, medium-sized BEV with maximum battery loading e.g. 30 kWh, around 220 kg in 2020) will not be able to drive far beyond 150 km at 120 km/hour, if real driving conditions are assumed (taking expected improvements until 2020 into account). Charging times are longer, even at maximum proven battery technology potential: 6-8 hours using normal charging equipment. Using more sophisticated and expensive technologies can reduce charging time. Fast charging may become widespread, but the impact on battery performance degradation over time and power grid stability is unclear. Moreover, it takes 15-30 minutes to (partially) recharge the battery. Battery swapping reduces refueling time; it is expected to be feasible if used once every two months or less and battery standards are adopted by a majority of car manufacturers. FCEVs have a driving performance and range comparable to ICEs: an average driving range of 500-600 km, similar acceleration and a refueling time of less than 5 minutes, similar to ICE fuelling which is a proven business model. The driving range and performance of PHEVs is similar to ICEs when in ICE drive."

[1] The range chosen in the study for BEVs and PHEVs reflects the car manufacturers' current view on the best compromise between range, cost, and load bearing capacity for the vehicle

[2] For C/D segment cars this will increase to 150-250 km in the medium term. With a smaller battery capacity than BEVs, PHEVs have an electric driving range of 40-60 km. Combined with the additional blending of biofuels, they could show emission reductions for longer trips.

See Annex, Exhibit 56, page 61, for a graphical analysis of the impact of cruising speed on range.

4. **Refueling infrastructure is affordable and in line with other EV options.**
For example, they estimate that hydrogen infrastructure will cost between €1,000 and €2,000/FCEV, while the costs for electrical charging infrastructure will cost between €1,500 and €2,500 /BEV. In addition, they estimate that the total cumulative cost for a hydrogen infrastructure for the entire EU will be €100 billion over 40 years, while the cost of an EU electrical charging infrastructure will cost over €500 billion over 40 years (excluding the likely added costs of expanding the electrical distribution system to meet growing demand for BEV and PHEV charging.) [Our own detailed computer simulations for the US showed similar infrastructure costs: we estimated a total hydrogen infrastructure cost over 50 years of $80.9 billion ($29.3 billion government subsidies and $51.6 billion of direct industry investments.) and $276 billion to install electrical charging outlets ($41 billion of government support and $234 billion of industry investments in charging infrastructure.) Thus we estimated that the BEV and PHEV charging infrastructure would cost 3.4 times more than a hydrogen infrastructure, while McKinsey estimated that the electrical charging infrastructure would cost 5 times more; both of these estimates exclude the cost of upgrading the electrical transmission system to handle increased power transfer, particularly during the daytime battery charging which most analysts say would be necessary to attract BEV and PHEV purchasers.)
Note: McKinsey report estimates that the oil & gas, telecommunications, and road infrastructure industries *each* spend €50 billion to €60 billion per year, or a total of €150 billion to €180 billion per year, so the estimated tab of €100 billion over 40 years for building an EU-wide hydrogen infrastructure is reasonable. [note: we estimate that the oil & gas industry has spent more than $100 billion per year over the last three years in the US just to maintain the existing gasoline and diesel fuel infrastructure in the US.]

5. **Authenticity**
McKinsey and Company report was based on proprietary data from the auto companies: "This study represents the most accurate to date[3], as conclusions are based not on informed speculation, but on confidential, granular and proprietary data, provided by key industry players. This has allowed a true comparison of the power-trains, with all underlying assumptions clearly stated

The full Mckinsey report can be downloaded from:
http://www.europeanclimate.org/documents/Power_trains_for_Europe.pdf

[3] Other studies taken into consideration include "Hydrogen Highway": www.hydrogenhighway.com; Roads2HyCom project www.roads2hy.com; "On the road in 2035", published 2008; "The Hydrogen Economy", published 2009; "Hydrogen Production Roadmap: Technology Pathways to the Future", published 2010

Maximum Greenhouse Gas and Oil use Reductions

Recent analysis of the US vehicle fleet revealed that even if **all** US small cars, vans, pickup trucks and SUVs and 50% of all midsize sedans and midsize wagons were replaced by BEVs, and **all other US vehicles** were replaced with PHEVs with 40 miles all-electric range such as the Chevy Volt, then the GHGs and Oil use could only be reduced by at most 28% and 67% respectively, while hydrogen-powered FCEVs[1] could reduce these two factors by 50% and nearly 100%, as shown in Figures 1 & 2.

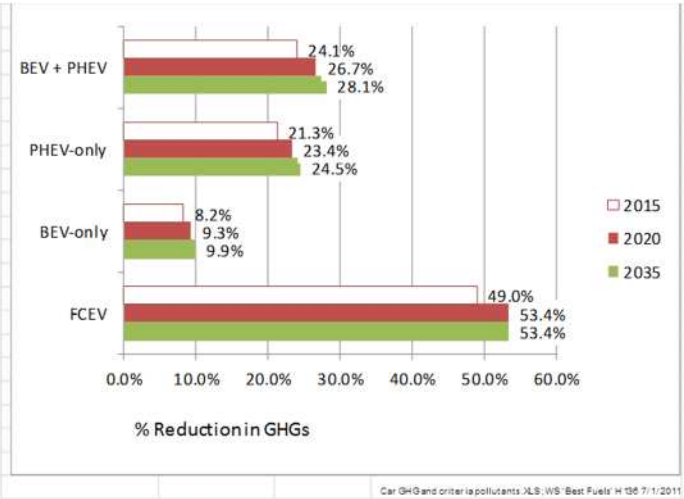


Figure 1. Maximum reductions in greenhouse gases (GHGs) possible with 100% replacement of all US vehicles with the alternative vehicles shown on the graph

These results will be valid until at least 2035 according to the EIA projections for grid electricity, after which time both hydrogen and electricity may be generated from renewable sources, with subsequently larger decreases in GHGs and oil use.

Therefore limiting alternative vehicle choices to only BEVs and PHEVs as proposed by Secretary Chu and the Obama administration will severely limit our nation's ability to substantially cut GHGs or oil consumption until mid-century or later. The ill-advised decision by the administration to terminate the DOE's hydrogen and FCEV program is dangerous and very short-sighted and dangerous, robbing future generations their best tool for fighting our addiction to oil and climate change gases.

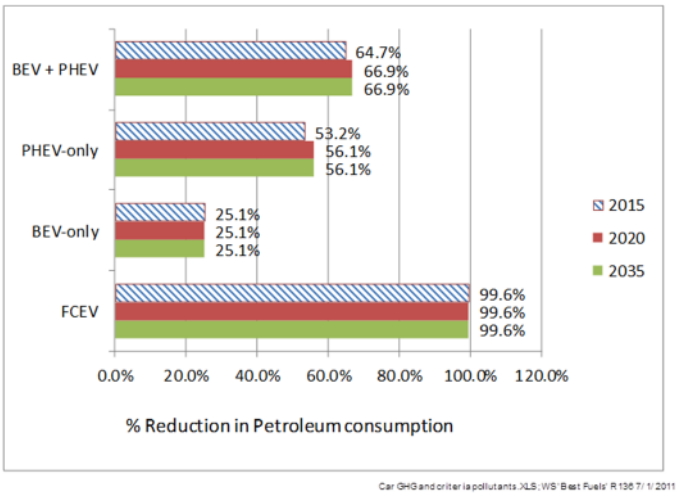


Figure 2.Maximum reductions in oil consumption possible with 100% replacement of all US vehicles with the alternative vehicles shown on this graph

[1] Assuming that all hydrogen is made from natural gas.