MEMORANDUM

To: Greg Dana, Alliance of Automobile Manufacturers

From: Jeremy G. Heiken

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Subject: Greenhouse gas emissions from light-duty vehicles in Connecticut

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Executive Summary

The memorandum summarizes an evaluation of the total lifecycle greenhouse gas (GHG) emissions from light-duty on-highway vehicles operating in Connecticut.

The evaluation of lifecycle GHG emissions covers two regulatory scenarios, the Federal Tier II program and the California LEV II program for light-duty vehicles. Currently, vehicles sold in Connecticut are subject to Federal standards. In the emission inventory results presented, the two regulatory paths are 1) a continuation of Federal standards, including Tier II and 2) a change from Federal to California standards beginning with the 2007 model year. Connecticut light-duty vehicle GHG emission inventories are estimated for the years 2010, 2015, 2020 and 2025.

The estimated difference in GHG emissions under the two regulatory programs results from a subset of vehicles needed to fulfill the ZEV Mandate portion of California's LEV II regulation. The ZEV Mandate includes requirements for two categories of vehicles, "zero emission vehicles" (ZEVs) and "advanced-technology partial zero emission vehicles" (AT-PZEVs). At this time, the current consensus of industry and government stakeholders is that automobile manufacturers will use fuel-cell electric vehicles (FCEVs) and hybrid electric vehicles (HEVs) to meet ZEV and AT-PZEV requirements, respectively.[1] Estimated lifecycle GHG emissions for FCEVs and HEVs, which make up a small fraction of the light-duty fleet under California's LEV II, differ from the remaining "conventional" vehicles.

Before presenting the results, two key assumptions of this evaluation need to be stated up front. This analysis assumes compliance to the letter of the each regulation, and the regulations are mutually exclusive. Therefore, this analysis assumes that HEVs and FCEV would only be present in Connecticut under the California LEV II program. Conversely, this means that the analysis assumes that there would be no HEVs and FCEVs under the

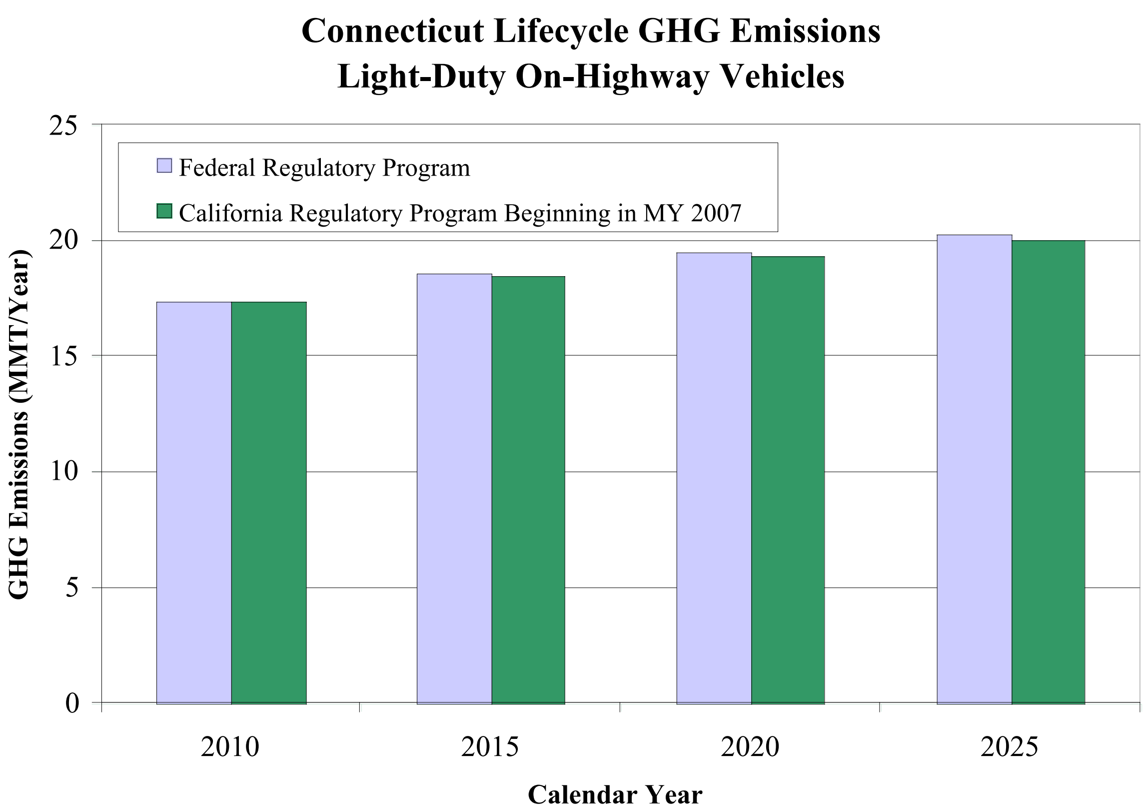
[1] California ARB rulemaking and regulatory models assume the sale of FCEVs and HEVs to meet the ZEV Mandate requirements.

Federal Tier II regulation. Practically speaking, HEVs and FCEVs will be present in Connecticut under both the California and Federal programs. Indeed, the first two vehicles currently certified as AT-PZEVs under the California regulations are also available for sale in Connecticut without any regulatory requirement to do so.[2] For this reason, the GHG analysis of this memo represents an upper bound estimate of the differences between Tier II and LEV II.

With these assumptions understood, the estimated lifecycle light-duty GHG inventories in Connecticut are summarized in Figure 1. The difference between the Federal and California programs does not reach 1 percent until 13 years after implementation, in calendar year 2020. In this year, lifecycle GHG inventories under Federal and California programs are estimated to equal 19.5 and 19.3 million metric tons (MMT) per year, respectively. Thereby, the estimated GHG benefit of the California program in 2020 is 0.2 MMT per year.

The remainder of this memorandum presents additional documentation of the evaluation of lifecycle GHG emissions in Connecticut from light-duty vehicles.

Figure 1.



[2] In automotive manufacturing, it is common that economics of scale and distribution result in a 50-state product line with no difference between California and Federally certified vehicles.

Analytical Method

The latest available data were compiled for this evaluation of lifecycle GHG emissions. The inventory evaluation includes all light-duty on-highway vehicles under 8,500 lb gross vehicle weight rating (GVRW). GHG emissions reported in this evaluation include the species carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) which are expressed in summation as total CO_2 equivalents.[3] And lifecycle emissions include all components from fuel extraction to vehicle tailpipe exhaust. Note that "lifecycle" emissions are also commonly referred to as "well-to-wheel" emissions.

The following summarizes both assumptions and data sources used.

1. Vehicle Miles Traveled (VMT) - Total statewide VMT data are those provided by Connecticut Department of Transportation. Data were provided for calendar years 2000, 2002, 2007, 2010, 2015 and 2020. Linear interpolation or extrapolation was used to estimate VMT for years not provided. The VMT data used are shown in Table 1.

2. Lifecycle Emission Factors - The lifecycle emission factors are those currently being developed for the next release of the GREET model and are summarized in Table 2.[4] These data are based on a General Motors Study *Well-to-Wheels Analysis of Advanced Fuel/Vehicle Systems* being completed with Argonne National Laboratory.

3. Fuel Economy - Fuel economy data by vehicle class are those developed by the US EPA for MOBILE6.2, which include in-use adjustments for typical on-highway operation. These data are shown in Table 3.

4. FCEVs & HEVs Implementation - The proportions of FCEVs and HEVs under the California LEV II program are those from the latest California Air Resources Board (ARB) ZEV Mandate rulemaking completed in April 2003. The model year sales percentages estimated by the ARB are shown in Table 4 and taking into account the complicated credits scheme developed in the latest rulemaking

5. Fleet Characteristics – MOBILE6.2 was used for age distribution data and for the fleet mix (proportions of model year VMT by vehicle class).

The lifecycle GHG inventory was estimated combining all these data sources into a spreadsheet model. Under the Federal program, it is assumed that there would be only conventional vehicles operating. For this regulatory case, the VMT data were converted to in-use gasoline consumption (in gallons) using MOBILE6.2 fleet characteristics and EPA's in-use fuel economy. The in-use GHG inventory was then estimated by multiplying the gram-per-gallon GHG emission factor (shown in Table 2 for conventional vehicles) times the total gasoline consumption.

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[3] Expressing emissions in terms of CO_2 equivalents also takes into consideration the warming potential of each species relative to that of CO_2.

[4] The GREET model is the current state of the science for modeling lifecycle emissions in the U.S. This model is maintained by the Department of Energy's Argonne National Laboratory.

Table 1. Connecticut On-Highway VMT Estimates, Connecticut Department of Transportation	
Calendar Year	Vehicle Miles Traveled (Million Miles per Year)
2002	31,058
2003	31,384
2004	31,709
2005	32,035
2006	32,361
2007	32,686
2008	33,061
2009	33,436
2010	33,812
2011	34,153
2012	34,494
2013	34,835
2014	35,176
2015	35,516
2016	35,806
2017	36,095
2018	36,385
2019	36,674
2020	36,963
2021	37,253
2022	37,542
2023	37,831
2024	38,121
2025	38,410

Table 2. MOBILE6.2 In-Use Fuel Economy (Miles per Gallon).					
Model Year	Automobile	LDT1	LDT2	LDT3	LDT4
1985	22.9	18.7	18.7	14.4	14.4
1986	23.7	19.6	19.6	15.0	15.0
1987	23.8	19.7	19.7	15.2	15.2
1988	24.3	19.3	19.3	14.8	14.8
1989	23.9	19.1	19.1	14.7	14.7
1990	23.6	18.9	18.9	14.6	14.6
1991	23.8	19.4	19.4	14.9	14.9
1992	23.5	19.0	19.0	14.6	14.6
1993	24.0	19.1	19.1	14.7	14.7
1994	23.9	18.9	18.9	14.6	14.6
1995	24.1	18.7	18.7	14.4	14.4
1996	24.1	19.0	19.0	14.6	14.6
1997	24.2	18.8	18.8	14.5	14.5
1998	24.3	19.0	19.0	14.6	14.6
1999	24.0	18.7	18.7	14.4	14.4
2000-2020	24.1	18.7	18.7	14.4	14.4

Table 3. Lifecycle GHG Emission Factors Under the Light-Duty FTP Driving Cycle.			
Vehicle Type	Technology Assumption	GHG Emission Factor (g/mi)	GHG Emission Factor (g/gal)
Conventional	Conventional drive spark-ignited engine operating on Federal reformulated gasoline	540	11,600
AT-PZEV	Spark-ignited hybrid electric vehicle (parallel hybrid) operating on Federal reformulated gasoline	440	11,600
ZEV	Fuel cell electric vehicle operating on hydrogen produced by a centralized reformer using natural gas as feed fuel.[5]	252	n/a

Table 4. California ARB Estimated Percent Sales of AT-PZEVs and ZEVs Under the April 2003 ZEV Mandate.[6]				
Model Year	Automobiles, LDT1		LDT2, LDT3, LDT4	
	AT-PZEVs	ZEVs	AT-PZEVs	ZEVs
2007	4.61%	0.01%	0.00%	0.00%
2008	6.66%	0.01%	0.00%	0.00%
2009	9.39%	0.07%	0.00%	0.00%
2010	9.99%	0.06%	0.00%	0.00%
2011	10.91%	0.06%	0.00%	0.00%
2012	11.66%	0.65%	0.00%	0.00%
2013	11.56%	0.64%	0.00%	0.00%
2014	11.42%	0.63%	0.00%	0.00%
2015	15.01%	1.25%	0.00%	0.00%
2016	15.07%	1.26%	0.00%	0.00%
2017	14.78%	1.23%	0.00%	0.00%
2018	14.52%	2.15%	0.00%	0.00%
2019	14.30%	2.12%	0.00%	0.00%
2020-2025	14.06%	2.08%	0.00%	0.00%

Under the California regulatory case, the AT-PZEV and ZEV sales percentages are assumed to occur in Connecticut beginning with the 2007 model year, and for these two vehicle technologies, the lifecycle GHG reductions assumed (over a comparable conventional vehicle) are 19 and 53 percent for AT-PZEVs and ZEVs, respectively. These reductions in GHG emissions, derived from the data shown in Table 3, were applied to the GHG inventory estimated under the Federal program to calculate the GHG inventory under the California program.

[5] There is uncertainty as to the future source of hydrogen needed to power FCEVs, and the source of hydrogen has a significant impact on the lifecycle GHG emission factor. Hydrogen from electrolysis, for instance, has an estimated GHG emission factor of 653 g/mi. The selected hydrogen source, a centrally located hydrogen refueling station which derives the hydrogen from a natural gas reformer, was selected as the most probably source of hydrogen.

[6] The ZEV Mandate applies to all vehicle classes shown (autos, LDT1 through LDT4); however, the ARB makes the assumption that manufacturers will derive all the required AT-PZEVs and ZEVs credits by implementing these technologies in the lightest vehicle classes (autos and LDT1 only).

The resulting lifecycle GHG inventories under both regulatory paths are shown in Table 5. The estimated difference between programs is small, less than a one percent difference in GHG emissions until 2020. By 2025, the difference is 1.3 percent.

Table 5. Estimated Lifecycle GHG Inventory, Connecticut Light-Duty, On-Highway Vehicles (MMT per Year).

Year	Federal Regulatory Program	California Regulatory Program Beginning in MY 2007	Benefit of California Regulation
2010	17.40	17.36	0.04
2015	18.60	18.48	0.11
2020	19.51	19.31	0.20
2025	20.28	20.03	0.26

The assumptions used in this study were biased towards overestimating the differences between the two programs. Therefore, the differences recorded in Table 5 should be considered an upper bound. Assumptions that support this assertion are as follows.

1. The analysis assumes that there will be no HEVs or FCEVs sold under the Federal program. This is already demonstrated as a poor assumption. The only HEVs currently being sold in the U.S. are being distributed to all 50 states independent of the regulatory context. Upcoming releases of HEVs (e.g., the Ford Escape) will also be a 50-state product line.

2. The percent reduction in GHG emissions for HEVs, shown in Table 3, is based on the light-duty FTP. The improvement in efficiency of the HEV (resulting in lower GHG emissions) is amplified in this stop-and-go type driving cycle. The percent benefit of HEVs on highway type driving will be less.

3. The analysis assumes that FCEVs will be driven exactly like a conventional gasoline vehicle. For the foreseeable future, this is an optimistic assumption. Range limitations of FCEVs will limit the ability of these vehicles to fully replace gasoline vehicle VMT resulting in a reduced GHG emissions benefit.

4. The source of hydrogen needed to power FCEVs is an uncertainty. The source selected in this study (centralized natural gas reformer) also corresponds to the source with the lowest lifecycle GHG emissions. Hydrogen from on-board reformers and hydrogen from electrolysis have significantly higher lifecycle GHG emissions. Under some fuel pathways, lifecycle GHG emissions from FCEVs can be higher than conventional vehicles.