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Appendix G: Parameters Calculated With The EV and ICEV Energy-Use and Lifexyxle-Cost Model

Author
Delucchi, Mark A.

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An Appendix to the Report, "A Lifecycle Emissions Model (LEM): Lifecycle Emissions From Transportation Fuels, Motor Vehicles, Transportation Modes, Electricity Use, Heating and Cooking Fuels, and Materials"

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by

Mark A. Delucchi
Institute of Transportation Studies
University of California,
Davis, CA 95616, USA
madelucchi@ucdavis.edu

Institute of Transportation Studies
One Shields Avenue
University of California
Davis, California 95616
Tel: 530-752-0247 Fax: 530-752-6572
http://www.its.ucdavis.edu/
email: itspublications@ucdavis.edu

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Mark Delucchi
madelucchi@ucdavis.edu

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Institute of Transportation Studies
One Shields Avenue
University of California
Davis, CA 95616

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THE RELATIONSHIP BETWEEN VEHICLE WEIGHT AND VEHICLE FUEL ECONOMY

Background

In the lifecycle model, the fuel economy of vehicles (in mi/10^6-BTU) is a function of the weight of the vehicle, which is calculated as a function of the weight of the engine and fuel-storage system, which in turn are functions of the desired driving range. The relationship between weight and fuel economy is given by a relational parameter, Wf:

$$\frac{1}{M_i} = \left(1 + EFF_i\right) \cdot \frac{MPG_p}{D_p} \cdot \left(1 - Wf \cdot \frac{W_i}{W_p}\right)$$

where:

M_i = 10^6-BTU/mi efficiency of AFV i

$1+EFF_i$ = the powertrain efficiency of AFV i relative to that of baseline petroleum vehicle p $\left(\frac{mi\ /\ BTU_{powertrain-i}}{mi\ /\ BTU_{powertrain-p}}\right)$

Wf = % decrease in fuel economy (in mi/BTU) per 1% increase in vehicle weight

W_i = the extra weight of AFV i compared to petroleum-fuel vehicle p

W_p = the total driving weight of petroleum-fuel vehicle

MPG_p = the miles-per-gallon fuel economy of petroleum-fuel vehicle p

D_p = the 10^6-BTU/gallon heating value of petroleum fuel p

As explained in the main report, I use an second-by-second drive-cycle simulation model to calculate the value of Wf. This appendix presents the results of that simulation model.

The model of vehicle energy use (Delucchi, 2000) is a second-by-second simulation of all of the forces acting on a vehicle over a specified drive cycle. The purpose of this model is to accurately determine the amount of energy required to move a vehicle of particular characteristics over a specified drivecycle, with the ultimate objective of calculating the size of the battery or fuel-cell system necessary to satisfy the user-specified range and performance requirements. The energy-use simulation is the standard textbook application of the physics of work, with a variety of empirical approximations, to the movement of motor vehicles.

The energy-use model simulates a Ford Taurus and a Ford Escort, in city or highway driving. In order to estimate the weight/fuel economy parameter Wf from as broad a base as possible, I ran the motor-vehicle energy-use model in four configurations: Taurus, city driving; Taurus, highway driving; Escort, city driving; and Escort, highway driving. For each configuration, I had the model estimate the fuel economy of the vehicle (in mi/10^6-BTU) at seven different weights: a baseline weight, three higher weights, and three lower weights. The weight was changed by adding 150, 350, or 650 lbs to the baseline, or subtracting 150, 300, or 500 lbs from the baseline. (The model also added or subtracted extra structural weight as necessary.) For each weight and fuel-economy result, I calculated three measures: the relational parameter described above, a "marginal" relational parameter, and an exponential parameter. The results are shown below. The relational parameter Wf is calculated from the model results as:

$$Wf = \frac{1 - \frac{M_{CH}}{M_{BSL}}}{1 - \frac{W_{CH}}{W_{BSL}}}$$

where:

Wf = Wf = % decrease in fuel economy (in mi/BTU) per 1% increase in vehicle weight

M_{CH} = the fuel economy of the changed (heavier or lighter) vehicle (mi/10^6 BTU) (calculated by the energy-use model)

M_{BSL} = the fuel economy of the baseline vehicle (mi/10^6 BTU) (calculated by the energy-use model)

W_{CH} = the weight of the changed (heavier or lighter) vehicle (lbs)

W_{BSL} = the weight of the baseline vehicle (lbs)

The marginal relational parameter is the same as Wf except that changes are calculated with respect to the previous weight and fuel-economy result rather than with respect to the baseline. The exponential parameter is calculated as:

$$W\ exp = \frac{log\left[\frac{M_{CH}}{M_{BSL}}\right]}{log\left[\frac{W_{BSL}}{W_{CH}}\right]}$$

I calculate this in order to determine which form -- Wexp, or Wf -- varies the least across all of the cases. It turns out (as one would expect) that they are similar.

In all cases, I include a CNG-fueled ICEV, a battery EV with an advanced NiMH battery and a 100-mile range, and a battery EV with an advanced NiMH battery and a 200-mile range.

Examination of the results

The tables of results, shown below, indicate that Wf is reasonably stable. The results for the Escort are similar to those for the Taurus; the results for CNG are similar to those for gasoline, and for ICEVs results for the highway cycle are similar to those for the city cycle. The parameter Wf is at least as stable as the parameter Wexp. It appears a value of 0.25 for Wf is reasonably accurate for most ICEVs over most drive cycles.

The energy use of EVs is more sensitive to the mass of the vehicle. This makes sense, because the electric drive is much more efficient than the ICE drive, which means that the fraction of the total input energy that goes to mass work is much higher in the EV. The relational parameter also is less stable in the case of EVs, probably for the same fundamental reason: changes in mass have relatively great effect on fuel economy. It appears that Wf is about 0.60 for city driving, and 0.45 for highway driving.

Ford Taurus, city driving

	Gasoline	CNG	EV /100	EV /200
Weight (kg)	1,160	1,299	992	1,321
mi/ million BTU	166.8	178.6	1076.3	912.4
Wf marginal	n.a.	n.a.	n.a.	n.a.
Wf	-0.27	-0.28	-0.69	-0.74
Wexp	0.24	0.25	0.56	0.62
Weight (kg)	1,273	1,416	1,126	1,469
mi/ million BTU	163.4	174.7	999.0	852.0
Wf marginal	-0.21	-0.25	-0.53	-0.59
Wf	-0.28	-0.26	-0.59	-0.66
Wexp	0.26	0.25	0.54	0.61
Weight (kg)	1,341	1,486	1,205	1,556
mi/ million BTU	161.1	172.5	962.5	822.3
Wf marginal	-0.26	-0.25	-0.52	-0.59
Wf	-0.26	-0.25	-0.55	-0.61
Wexp	0.25	0.24	0.53	0.59
Weight (kg) BASELINE	1,409	1,556	1,283	1,640
mi/ million BTU	159.1	170.6	931.3	797.0
Wf marginal	-0.25	-0.23	-0.50	-0.57
Wf	n.a.	n.a.	n.a.	n.a.
Wexp	n.a.	n.a.	n.a.	n.a.
Weight (kg)	1,477	1,625	1,361	1,730
mi/ million BTU	157.3	168.1	899.4	765.7
Wf marginal	-0.23	-0.33	-0.56	-0.72
Wf	-0.23	-0.33	-0.56	-0.72
Wexp	0.23	0.34	0.59	0.76
Weight (kg)	1,568	1,719	1,466	1,842
mi/ million BTU	154.9	166.2	856.7	737.9
Wf marginal	-0.25	-0.20	-0.62	-0.56
Wf	-0.23	-0.25	-0.56	-0.60
Wexp	0.25	0.27	0.63	0.66
Weight (kg)	1,704	1,858	1,623	2,013
mi/ million BTU	150.8	161.6	799.3	693.7
Wf marginal	-0.31	-0.34	-0.63	-0.65
Wf	-0.25	-0.27	-0.54	-0.57
Wexp	0.28	0.31	0.65	0.68

Ford Taurus, highway driving

	Gasoline	CNG	EV /100	EV /200
Weight (kg)	1,160	1,242	989	1,297
mi/ million BTU	267.1	289.4	1086.6	952.0
Wf marginal	n.a.	n.a.	n.a.	n.a.
Wf	-0.25	-0.27	-0.58	-0.57
Wexp	0.23	0.24	0.48	0.49
Weight (kg)	1,273	1,357	1,120	1,437
mi/ million BTU	261.6	283.1	1025.2	898.1
Wf marginal	-0.21	-0.24	-0.43	-0.52
Wf	-0.24	-0.24	-0.55	-0.45
Wexp	0.23	0.23	0.50	0.42
Weight (kg)	1,341	1,426	1,197	1,517
mi/ million BTU	258.5	280.5	995.5	876.5
Wf marginal	-0.22	-0.18	-0.42	-0.43
Wf	-0.23	-0.29	-0.58	-0.40
Wexp	0.23	0.28	0.56	0.39
Weight (kg) BASELINE	1,409	1,495	1,274	1,594
mi/ million BTU	255.6	276.9	961.2	859.9
Wf marginal	-0.22	-0.27	-0.53	-0.37
Wf	n.a.	n.a.	n.a.	n.a.
Wexp	n.a.	n.a.	n.a.	n.a.
Weight (kg)	1,477	1,565	1,350	1,675
mi/ million BTU	252.7	274.0	939.9	839.2
Wf marginal	-0.24	-0.22	-0.38	-0.48
Wf	-0.24	-0.22	-0.38	-0.48
Wexp	0.24	0.23	0.39	0.50
Weight (kg)	1,568	1,657	1,452	1,781
mi/ million BTU	249.2	269.3	903.1	813.5
Wf marginal	-0.23	-0.29	-0.52	-0.48
Wf	-0.22	-0.25	-0.43	-0.46
Wexp	0.24	0.27	0.48	0.50
Weight (kg)	1,704	1,795	1,605	1,943
mi/ million BTU	242.7	263.8	851.4	774.6
Wf marginal	-0.30	-0.24	-0.54	-0.53
Wf	-0.24	-0.23	-0.44	-0.45
Wexp	0.27	0.26	0.53	0.53

Ford Escort, city driving

	Gasoline	CNG	EV /100	EV /200
Weight (kg)	773	873	761	1,027
mi/ million BTU	229.4	244.9	1283.9	1101.7
Wf marginal	n.a.	n.a.	n.a.	n.a.
Wf	-0.28	-0.29	-0.64	-0.68
Wexp	0.24	0.25	0.51	0.57
Weight (kg)	864	966	865	1,138
mi/ million BTU	223.1	238.5	1201.3	1040.4
Wf marginal	-0.23	-0.25	-0.47	-0.52
Wf	-0.25	-0.26	-0.57	-0.64
Wexp	0.23	0.24	0.51	0.57
Weight (kg)	932	1,036	941	1,221
mi/ million BTU	219.4	234.9	1159.8	997.3
Wf marginal	-0.21	-0.21	-0.40	-0.56
Wf	-0.24	-0.27	-0.64	-0.58
Wexp	0.23	0.26	0.60	0.55
Weight (kg) BASELINE	1,000	1,106	1,018	1,302
mi/ million BTU	215.8	231.0	1105.9	962.7
Wf marginal	-0.22	-0.25	-0.57	-0.52
Wf	n.a.	n.a.	n.a.	n.a.
Wexp	n.a.	n.a.	n.a.	n.a.
Weight (kg)	1,068	1,176	1,094	1,383
mi/ million BTU	211.9	227.5	1066.4	931.4
Wf marginal	-0.27	-0.24	-0.48	-0.52
Wf	-0.27	-0.24	-0.48	-0.52
Wexp	0.28	0.25	0.51	0.55
Weight (kg)	1,158	1,270	1,195	1,493
mi/ million BTU	207.7	222.8	1012.7	889.3
Wf marginal	-0.23	-0.26	-0.54	-0.57
Wf	-0.24	-0.24	-0.48	-0.52
Wexp	0.26	0.26	0.55	0.58
Weight (kg)	1,295	1,409	1,346	1,660
mi/ million BTU	201.6	215.5	947.2	830.0
Wf marginal	-0.25	-0.30	-0.51	-0.60
Wf	-0.22	-0.24	-0.44	-0.50
Wexp	0.26	0.29	0.55	0.61

Ford Escort, highway driving

	Gasoline	CNG	EV /100	EV /200

Weight (kg)	773	837	761	1,014
mi/ million BTU	339.9	370.9	1284.9	1138.9
Wf marginal	n.a.	n.a.	n.a.	n.a.
Wf	-0.19	-0.24	-0.49	-0.48
Wexp	0.16	0.20	0.40	0.41
Weight (kg)	864	929	861	1,115
mi/ million BTU	335.5	364.3	1227.7	1097.1
Wf marginal	-0.11	-0.16	-0.34	-0.37
Wf	-0.21	-0.25	-0.47	-0.47
Wexp	0.20	0.23	0.42	0.43
Weight (kg)	932	998	937	1,191
mi/ million BTU	330.5	358.0	1180.5	1065.9
Wf marginal	-0.19	-0.23	-0.44	-0.42
Wf	-0.20	-0.22	-0.39	-0.44
Wexp	0.19	0.21	0.37	0.42
Weight (kg) BASELINE	1,000	1,067	1,011	1,267
mi/ million BTU	326.0	353.0	1147.5	1038.6
Wf marginal	-0.18	-0.20	-0.35	-0.40
Wf	n.a.	n.a.	n.a.	n.a.
Wexp	n.a.	n.a.	n.a.	n.a.
Weight (kg)	1,068	1,136	1,085	1,345
mi/ million BTU	320.5	347.0	1109.5	1010.0
Wf marginal	-0.25	-0.26	-0.45	-0.45
Wf	-0.25	-0.26	-0.45	-0.45
Wexp	0.26	0.27	0.47	0.47
Weight (kg)	1,158	1,228	1,183	1,451
mi/ million BTU	314.3	341.1	1071.6	968.5
Wf marginal	-0.23	-0.21	-0.38	-0.52
Wf	-0.23	-0.22	-0.39	-0.46
Wexp	0.25	0.24	0.43	0.51
Weight (kg)	1,295	1,367	1,332	1,610
mi/ million BTU	305.5	330.3	1008.7	914.9
Wf marginal	-0.24	-0.28	-0.47	-0.51
Wf	-0.21	-0.23	-0.38	-0.44
Wexp	0.25	0.27	0.47	0.53

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