Staff's Second Request for Production of Documents Item No. 8 -- Document in support of DSM Plan Adjustment
This page reflects the cumulative energy savings by program that make up the annual exogenous DSM kWh adjustment.

5		Itron Net-Gross Ratio	Selected Ratio	B2011 Exogenous Forecast Energy Reductions (Cumulative Savings kWh at the Meter)									
6	**Residential**			2010	2011 (Was 2010)	2012	2013	2014	2015	2016	2017	2018	2019
7	Walk-Through Audit		0.0%	-	-	-	-	-	-	-	-	-	-
8	Online Audit		0.0%	-	-	-	-	-	-	-	-	-	-
9	Pre-Construction Audit		0.0%	-	-	-	-	-	-	-	-	-	-
10	Customer Usage Comparison (O Power)		100.0%	-	10,000,000	10,000,000	10,000,000	-	-	-	-	-	-
11	Energy Select		0.0%	-	-	-	-	-	-	-	-	-	-
12	Energy Select Lite		0.0%	-	-	-	-	-	-	-	-	-	-
13	Ceiling Insulation		100.0%	-	57,500	258,750	546,250	833,750	1,121,250	1,408,750	1,696,250	1,983,750	2,271,250
14	HPWH	99.5%	100.0%	-	134,800	943,600	2,022,000	3,370,000	4,987,600	6,605,200	8,492,400	10,649,200	13,075,600
15	Reflective Roof	98.4%	100.0%	-	102,900	411,600	823,200	1,337,700	1,955,100	2,675,400	3,395,700	4,116,000	4,836,300
16	Windows -- Low-E	97.8%	100.0%	-	133,800	602,100	1,271,100	2,274,600	3,612,600	5,285,100	7,292,100	9,968,100	13,313,100
17	Windows -- Film	94.6%	95.0%	-	37,430	187,150	336,870	486,590	636,310	786,030	935,750	1,085,470	1,235,190
18	Variable Speed Pool Pump	99.1%	100.0%	-	249,400	872,900	1,745,800	2,743,400	3,741,000	4,738,600	5,736,200	6,733,800	7,731,400
19	Community Energy Saver		100.0%	-	920,000	2,760,000	4,600,000	6,440,000	7,544,000	8,648,000	9,752,000	10,856,000	11,960,000
20	Refrigerator/Freezer Recycling		0.0%	-	-	-	-	-	-	-	-	-	-
21	HVAC Maintenance	85.0%	85.0%	-	1,420,928	5,950,136	13,165,786	24,266,786	34,257,686	42,583,436	49,244,036	55,349,586	61,177,611
22	HVAC Upgrade Tier 1		90.0%	-	383,602	1,606,332	3,563,828	6,570,588	9,214,900	11,859,213	14,503,525	16,884,112	18,999,562
23	HVAC Upgrade Tier 2		100.0%	-	71,858	302,560	673,196	1,240,496	1,807,796	2,375,096	2,942,396	3,462,421	3,935,171
24	HVAC Upgrade Tier 3		0.0%	-	-	-	-	-	-	-	-	-	-
25	HVAC Retirement Tier 1		90.0%	-	1,791,324	7,502,486	16,638,239	30,679,058	44,509,133	58,339,208	71,510,708	83,365,058	93,902,258
26	HVAC Retirement Tier 2		100.0%	-	312,150	1,267,329	2,796,864	5,137,989	7,479,114	9,820,239	12,161,364	14,502,489	16,687,539
27	HVAC Retirement Tier 3		0.0%	-	-	-	-	-	-	-	-	-	-
28	ECM Fan	80.4%	80.0%	-	-	665,400	1,796,580	3,570,980	6,232,580	8,228,780	9,825,740	11,156,540	12,221,180
29	Duct Repair	99.8%	100.0%	-	-	2,764,000	8,568,400	17,551,400	25,843,400	33,306,200	40,216,200	46,849,800	53,068,800
30	Energy Star Appliance (Units)	90.0%	0.0%	-	-	-	-	-	-	-	-	-	-
31	CFL Lighting (units)	74.5%	75.0%	-	4,117,500	12,352,500	12,352,500	12,352,500	12,352,500	12,352,500	12,352,500	12,352,500	12,352,500
32	Residential Custom Incentive		100.0%	-	552,000	1,104,000	1,656,000	2,208,000	2,760,000	3,312,000	3,864,000	4,416,000	4,968,000
33	Solar Thermal		100.0%	-	219,190	438,380	657,570	876,760	876,760	876,760	876,760	876,760	876,760
34	Solar Photovoltaic		100.0%	-	255,520	511,040	766,560	1,022,080	1,022,080	1,022,080	1,022,080	1,022,080	1,022,080
35	**Residential Total**			-	**20,759,902**	**50,500,263**	**83,980,743**	**122,962,677**	**169,953,809**	**214,222,592**	**255,819,709**	**295,629,665**	**333,634,300**
36													
37	**Commercial/Industrial**												
38	Audit		0.0%	-	-	-	-	-	-	-	-	-	-
39	HVAC Upgrade/Replacement	72.6%	75.0%	-	73,350	244,500	440,100	684,600	978,000	1,271,400	1,613,700	1,956,000	2,298,300
40	Geothermal	99.9%	0.0%	-	-	-	-	-	-	-	-	-	-
41	HVAC Retrocommissioning	89.4%	90.0%	-	-	2,117,340	5,646,240	9,880,920	14,821,380	19,761,840	23,996,520	28,231,200	31,760,100
42	Ceiling Insulation	90.0%	90.0%	-	23,274	85,799	164,990	258,034	362,361	475,653	595,849	721,133	849,926
43	Window Film	91.6%	90.0%	-	86,114	328,641	635,983	994,475	1,391,597	1,816,202	2,258,649	2,710,787	3,165,881
44	HPWH	88.5%	90.0%	-	37,117	74,234	111,351	148,468	222,701	296,935	408,286	519,637	630,987
45	Interior Lighting	65.0%	65.0%	-	142,350	427,050	854,100	1,281,150	1,637,025	1,921,725	2,206,425	2,491,125	2,775,825
46	Interior Lighting -- LED	70.0%	70.0%	-	61,320	183,960	337,260	521,220	705,180	889,140	1,073,100	1,257,060	1,441,020
47	Lighting Occupancy Sensor	99.4%	100.0%	-	240,000	720,000	1,280,000	1,880,000	2,480,000	3,080,000	3,680,000	4,240,000	4,720,000
48	HVAC Occupancy Sensor -- Hotel	93.8%	95.0%	-	36,452	133,656	255,161	376,666	498,171	595,375	692,579	789,783	886,987
49	Reflective Roof	93.2%	95.0%	-	232,750	931,000	1,862,000	2,793,000	3,956,750	5,120,500	6,051,500	6,982,500	7,913,500
50	Food Service Equipment		100.0%	-	50,164	136,770	284,617	448,561	615,028	736,351	917,755	1,054,015	1,256,890
51	Energy Efficient Motors	64.0%	65.0%	-	91,764	267,654	443,544	619,434	795,324	971,214	1,147,104	1,322,994	1,498,884
52	RTP		0.0%	-	-	-	-	-	-	-	-	-	-
53	Business Custom Incentive		0.0%	-	-	-	-	-	-	-	-	-	-
54	Solar PV		100.0%	-	38,328	76,656	114,984	153,312	153,312	153,312	153,312	153,312	153,312
55	**C&I Total**			-	**1,112,982**	**5,727,259**	**12,430,330**	**20,039,839**	**28,616,829**	**37,089,646**	**44,794,778**	**52,429,545**	**59,351,612**
56													
57	**RC&I Grand Total**			-	**21,872,883**	**56,227,522**	**96,411,073**	**143,002,515**	**198,570,638**	**251,312,238**	**300,614,487**	**348,059,210**	**392,985,912**
58													

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This page reflects the annual forecast of energy reductions by year for each program after shifting the energy reductions initially planned for 2010 into 2011, with the exception of the Home Energy Reporting program which had energy reductions beginning in 2011 and these savings were assumed in the forecast to occur in 2011.

	Itron Net-Gross Ratio	Selected Ratio	Annual Forecast Energy Reductions										
Residential			2010	2011 (Was 2010)	2012	2013	2014	2015	2016	2017	2018	2019	Total
Walk-Through Audit		0.0%	-	-	-	-	-	-	-	-	-	-	-
Online Audit		0.0%	-	-	-	-	-	-	-	-	-	-	-
Pre-Construction Audit		0.0%	-	-	-	-	-	-	-	-	-	-	-
Customer Usage Comparison (O Power)		100.0%	-	10,000,000	-	-	(10,000,000)	-	-	-	-	-	-
Energy Select		0.0%	-	-	-	-	-	-	-	-	-	-	-
Energy Select Lite		0.0%	-	-	-	-	-	-	-	-	-	-	-
Ceiling Insulation		100.0%	-	57,500	201,250	287,500	287,500	287,500	287,500	287,500	287,500	287,500	2,271,250
HPWH	99.5%	100.0%	-	134,800	808,800	1,078,400	1,348,000	1,617,600	1,617,600	1,887,200	2,156,800	2,426,400	13,075,600
Reflective Roof	98.4%	100.0%	-	102,900	308,700	411,600	514,500	617,400	720,300	720,300	720,300	720,300	4,836,300
Windows -- Low-E	97.8%	100.0%	-	133,800	468,300	669,000	1,003,500	1,338,000	1,672,500	2,007,000	2,676,000	3,345,000	13,313,100
Windows -- Film	94.6%	95.0%	-	37,430	149,720	149,720	149,720	149,720	149,720	149,720	149,720	149,720	1,235,190
Variable Speed Pool Pump	99.1%	100.0%	-	249,400	623,500	872,900	997,600	997,600	997,600	997,600	997,600	997,600	7,731,400
Community Energy Saver		100.0%	-	920,000	1,840,000	1,840,000	1,840,000	1,104,000	1,104,000	1,104,000	1,104,000	1,104,000	11,960,000
Refrigerator/Freezer Recycling		0.0%	-	-	-	-	-	-	-	-	-	-	-
HVAC Maintenance	85.0%	85.0%	-	1,420,928	4,529,208	7,215,650	11,101,000	9,990,900	8,325,750	6,660,600	6,105,550	5,828,025	61,177,611
HVAC Upgrade Tier 1		90.0%	-	383,602	1,222,730	1,957,496	3,006,760	2,644,313	2,644,313	2,644,313	2,380,586	2,115,450	18,999,562
HVAC Upgrade Tier 2		100.0%	-	71,858	230,702	370,636	567,300	567,300	567,300	567,300	520,025	472,750	3,935,171
HVAC Upgrade Tier 3		0.0%	-	-	-	-	-	-	-	-	-	-	-
HVAC Retirement Tier 1		90.0%	-	1,791,324	5,711,162	9,135,752	14,040,819	13,830,075	13,830,075	13,171,500	11,854,350	10,537,200	93,902,258
HVAC Retirement Tier 2		100.0%	-	312,150	955,179	1,529,535	2,341,125	2,341,125	2,341,125	2,341,125	2,341,125	2,185,050	16,687,539
HVAC Retirement Tier 3		0.0%	-	-	-	-	-	-	-	-	-	-	-
ECM Fan	80.4%	80.0%	-	-	665,400	1,131,180	1,774,400	2,661,600	1,996,200	1,596,960	1,330,800	1,064,640	12,221,180
Duct Repair	99.8%	100.0%	-	-	2,764,000	5,804,400	8,983,000	8,292,000	7,462,800	6,910,000	6,633,600	6,219,000	53,068,800
Energy Star Appliance (Units)	90.0%	0.0%	-	-	-	-	-	-	-	-	-	-	-
CFL Lighting (units)	74.5%	75.0%	-	4,117,500	8,235,000	-	-	-	-	-	-	-	12,352,500
Residential Custom Incentive		100.0%	-	552,000	552,000	552,000	552,000	552,000	552,000	552,000	552,000	552,000	4,968,000
Solar Thermal		100.0%	-	219,190	219,190	219,190	219,190	-	-	-	-	-	876,760
Solar Photovoltaic		100.0%	-	255,520	255,520	255,520	255,520	-	-	-	-	-	1,022,080
Residential Total			-	**20,759,902**	**29,740,362**	**33,480,480**	**38,981,934**	**46,991,133**	**44,268,783**	**41,597,118**	**39,809,956**	**38,004,635**	**333,634,300**
Commercial/Industrial													
Audit		0.0%	-	-	-	-	-	-	-	-	-	-	-
HVAC Upgrade/Replacement	72.6%	75.0%	-	73,350	171,150	195,600	244,500	293,400	293,400	342,300	342,300	342,300	2,298,300
Geothermal	99.9%	0.0%	-	-	-	-	-	-	-	-	-	-	-
HVAC Retrocommissioning	89.4%	90.0%	-	-	2,117,340	3,528,900	4,234,680	4,940,460	4,940,460	4,234,680	4,234,680	3,528,900	31,760,100
Ceiling Insulation	90.0%	90.0%	-	23,274	62,525	79,192	93,044	104,326	113,292	120,196	125,285	128,793	849,926
Window Film	91.6%	90.0%	-	86,114	242,527	307,342	358,491	397,122	424,605	442,447	452,137	455,094	3,165,881
HPWH	88.5%	90.0%	-	37,117	37,117	37,117	37,117	74,234	74,234	111,351	111,351	111,351	630,987
Interior Lighting	65.0%	65.0%	-	142,350	284,700	427,050	427,050	355,875	284,700	284,700	284,700	284,700	2,775,825
Interior Lighting -- LED	70.0%	70.0%	-	61,320	122,640	153,300	183,960	183,960	183,960	183,960	183,960	183,960	1,441,020
Lighting Occupancy Sensor	99.4%	100.0%	-	240,000	480,000	560,000	600,000	600,000	600,000	600,000	560,000	480,000	4,720,000
HVAC Occupancy Sensor -- Hotel	93.8%	95.0%	-	36,452	97,204	121,505	121,505	121,505	97,204	97,204	97,204	97,204	886,987
Reflective Roof	93.2%	95.0%	-	232,750	698,250	931,000	931,000	1,163,750	1,163,750	931,000	931,000	931,000	7,913,500
Food Service Equipment		100.0%	-	50,164	86,606	147,847	163,944	166,467	121,323	181,404	136,260	202,875	1,256,890
Energy Efficient Motors	64.0%	65.0%	-	91,764	175,890	175,890	175,890	175,890	175,890	175,890	175,890	175,890	1,498,884
RTP		0.0%	-	-	-	-	-	-	-	-	-	-	-
Business Custom Incentive		0.0%	-	-	-	-	-	-	-	-	-	-	-
Solar PV		100.0%	-	38,328	38,328	38,328	38,328	-	-	-	-	-	153,312
C&I Total			-	1,112,982	4,614,277	6,703,071	7,609,509	8,576,990	8,472,818	7,705,132	7,634,767	6,922,067	59,351,612
Grand Total			-	**21,872,883**	**34,354,639**	**40,183,551**	**46,591,443**	**55,568,122**	**52,741,600**	**49,302,249**	**47,444,723**	**44,926,702**	**392,985,912**

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This page reflects the annual forecast of energy reductions by year for each program after multiplying by the net-to-gross ratios to account for free-ridership.

	Itron Net-Gross	Selected	Annual Forecast Energy Reductions										
Residential	Ratio	Ratio	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Total
Walk-Through Audit		0.0%	-	-	-	-	-	-	-	-	-	-	-
Online Audit		0.0%	-	-	-	-	-	-	-	-	-	-	-
Pre-Construction Audit		0.0%	-	-	-	-	-	-	-	-	-	-	-
Customer Usage Comparison (O Power)		100.0%	-	10,000,000	-	-	(10,000,000)	-	-	-	-	-	-
Energy Select		0.0%	-	-	-	-	-	-	-	-	-	-	-
Energy Select Lite		0.0%	-	-	-	-	-	-	-	-	-	-	-
Ceiling Insulation		100.0%	57,500	115,000	201,250	287,500	287,500	287,500	287,500	287,500	287,500	287,500	2,386,250
HPWH	99.5%	100.0%	134,800	404,400	808,800	1,078,400	1,348,000	1,617,600	1,617,600	1,887,200	2,156,800	2,426,400	13,480,000
Reflective Roof	98.4%	100.0%	102,900	205,800	308,700	411,600	514,500	617,400	720,300	720,300	720,300	720,300	5,042,100
Windows -- Low-E	97.8%	100.0%	133,800	267,600	468,300	669,000	1,003,500	1,338,000	1,672,500	2,007,000	2,676,000	3,345,000	13,580,700
Windows -- Film	94.6%	95.0%	37,430	74,860	149,720	149,720	149,720	149,720	149,720	149,720	149,720	149,720	1,310,050
Variable Speed Pool Pump	99.1%	100.0%	249,400	374,100	623,500	872,900	997,600	997,600	997,600	997,600	997,600	997,600	8,105,500
Community Energy Saver		100.0%	920,000	1,840,000	1,840,000	1,840,000	1,840,000	1,104,000	1,104,000	1,104,000	1,104,000	1,104,000	13,800,000
Refrigerator/Freezer Recycling		0.0%	-	-	-	-	-	-	-	-	-	-	-
HVAC Maintenance	85.0%	85.0%	1,420,928	2,664,240	4,529,208	7,215,650	11,101,000	9,990,900	8,325,750	6,660,600	6,105,550	5,828,025	63,841,851
HVAC Upgrade Tier 1		90.0%	383,602	719,253	1,222,730	1,957,496	3,006,760	2,644,313	2,644,313	2,644,313	2,380,586	2,115,450	19,718,815
HVAC Upgrade Tier 2		100.0%	71,858	136,152	230,702	370,636	567,300	567,300	567,300	567,300	520,025	472,750	4,071,323
HVAC Upgrade Tier 3		0.0%	-	-	-	-	-	-	-	-	-	-	-
HVAC Retirement Tier 1		90.0%	1,791,324	3,361,367	5,711,162	9,135,752	14,040,819	13,830,075	13,830,075	13,171,500	11,854,350	10,537,200	97,263,625
HVAC Retirement Tier 2		100.0%	312,150	561,870	955,179	1,529,535	2,341,125	2,341,125	2,341,125	2,341,125	2,341,125	2,185,050	17,249,409
HVAC Retirement Tier 3		0.0%	-	-	-	-	-	-	-	-	-	-	-
ECM Fan	80.4%	80.0%	-	354,880	665,400	1,131,180	1,774,400	2,661,600	1,996,200	1,596,960	1,330,800	1,064,640	12,576,060
Duct Repair	99.8%	100.0%	-	1,382,000	2,764,000	5,804,400	8,983,000	8,292,000	7,462,800	6,910,000	6,633,600	6,219,000	54,450,800
Energy Star Appliance (Units)	90.0%	0.0%	-	-	-	-	-	-	-	-	-	-	-
CFL Lighting (units)	74.5%	75.0%	4,117,500	6,176,250	8,235,000	-	-	-	-	-	-	-	18,528,750
Residential Custom Incentive		100.0%	552,000	552,000	552,000	552,000	552,000	552,000	552,000	552,000	552,000	552,000	5,520,000
Solar Thermal		100.0%	219,190	219,190	219,190	219,190	219,190	-	-	-	-	-	1,095,950
Solar Photovoltaic		100.0%	255,520	255,520	255,520	255,520	255,520	-	-	-	-	-	1,277,600
Residential Total			**10,759,902**	**29,664,482**	**29,740,362**	**33,480,480**	**38,981,934**	**46,991,133**	**44,268,783**	**41,597,118**	**39,809,956**	**38,004,635**	**353,298,782**
Commercial/Industrial													
Audit		0.0%	-	-	-	-	-	-	-	-	-	-	-
HVAC Upgrade/Replacement	72.6%	75.0%	73,350	146,700	171,150	195,600	244,500	293,400	293,400	342,300	342,300	342,300	2,445,000
Geothermal	99.9%	0.0%	-	-	-	-	-	-	-	-	-	-	-
HVAC Retrocommissioning	89.4%	90.0%	-	1,411,560	2,117,340	3,528,900	4,234,680	4,940,460	4,940,460	4,234,680	4,234,680	3,528,900	33,171,660
Ceiling Insulation	90.0%	90.0%	23,274	42,819	62,525	79,192	93,044	104,326	113,292	120,196	125,285	128,793	892,746
Window Film	91.6%	90.0%	86,114	163,366	242,527	307,342	358,491	397,122	424,605	442,447	452,137	455,094	3,329,247
HPWH	88.5%	90.0%	37,117	37,117	37,117	37,117	37,117	74,234	74,234	111,351	111,351	111,351	668,104
Interior Lighting	65.0%	65.0%	142,350	213,525	284,700	427,050	427,050	355,875	284,700	284,700	284,700	284,700	2,989,350
Interior Lighting -- LED	70.0%	70.0%	61,320	91,980	122,640	153,300	183,960	183,960	183,960	183,960	183,960	183,960	1,533,000
Lighting Occupancy Sensor	99.4%	100.0%	240,000	400,000	480,000	560,000	600,000	600,000	600,000	600,000	560,000	480,000	5,120,000
HVAC Occupancy Sensor -- Hotel	93.8%	95.0%	36,452	72,903	97,204	121,505	121,505	121,505	97,204	97,204	97,204	97,204	959,890
Reflective Roof	93.2%	95.0%	232,750	465,500	698,250	931,000	931,000	1,163,750	1,163,750	931,000	931,000	931,000	8,379,000
Food Service Equipment		100.0%	50,164	72,378	86,606	147,847	163,944	166,467	121,323	181,404	136,260	202,875	1,329,268
Energy Efficient Motors	64.0%	65.0%	91,764	175,890	175,890	175,890	175,890	175,890	175,890	175,890	175,890	175,890	1,674,774
RTP		0.0%	-	-	-	-	-	-	-	-	-	-	-
Business Custom Incentive		0.0%	-	-	-	-	-	-	-	-	-	-	-
Solar PV		100.0%	38,328	38,328	38,328	38,328	38,328	-	-	-	-	-	191,640
C&I Total			**1,112,982**	**3,332,067**	**4,614,277**	**6,703,071**	**7,609,509**	**8,576,990**	**8,472,818**	**7,705,132**	**7,634,767**	**6,922,067**	**62,683,679**
Grand Total			11,872,883	32,996,549	34,354,639	40,183,551	46,591,443	55,568,122	52,741,600	49,302,249	47,444,723	44,926,702	415,982,461

Staff's Second Request for Production of Documents Item No. 8 -- Document in support of DSM Plan Adjustment
This page reflects the incremental annual energy savings at the meter by year for each program as filed in
Gulf's DSM plan on March 30, 2010 and revised on June 14, 2010 in Docket No. 100154-EG.

	Incremental Annual Energy Savings kWh at the Meter										
Residential	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**Total**
Walk-Through Audit											-
Online Audit											-
Pre-Construction Audit											-
Customer Usage Comparison (O Power)	-	10,000,000	-	-	(10,000,000)	-	-	-	-	-	
Energy Select	762,000	762,000	762,000	762,000	762,000	762,000	762,000	762,000	762,000	762,000	7,620,000
Energy Select Lite	166,800	333,600	333,600	333,600	333,600	333,600	-	-	-	-	1,834,800
Ceiling Insulation	57,500	115,000	201,250	287,500	287,500	287,500	287,500	287,500	287,500	287,500	2,386,250
HPWH	134,800	404,400	808,800	1,078,400	1,348,000	1,617,600	1,617,600	1,887,200	2,156,800	2,426,400	13,480,000
Reflective Roof	102,900	205,800	308,700	411,600	514,500	617,400	720,300	720,300	720,300	720,300	5,042,100
Windows -- Low-E	133,800	267,600	468,300	669,000	1,003,500	1,338,000	1,672,500	2,007,000	2,676,000	3,345,000	13,580,700
Windows -- Film	39,400	78,800	157,600	157,600	157,600	157,600	157,600	157,600	157,600	157,600	1,379,000
Variable Speed Pool Pump	249,400	374,100	623,500	872,900	997,600	997,600	997,600	997,600	997,600	997,600	8,105,500
Community Energy Saver	920,000	1,840,000	1,840,000	1,840,000	1,840,000	1,104,000	1,104,000	1,104,000	1,104,000	1,104,000	13,800,000
Refrigerator/Freezer Recycling	-	1,291,500	2,583,000	2,583,000	2,583,000	2,583,000	1,476,000	1,476,000	1,476,000	1,476,000	17,527,500
HVAC Maintenance	1,671,680	3,134,400	5,328,480	8,489,000	13,060,000	11,754,000	9,795,000	7,836,000	7,183,000	6,856,500	75,108,060
HVAC Upgrade Tier 1	426,224	799,170	1,358,589	2,174,996	3,340,844	2,938,125	2,938,125	2,938,125	2,645,096	2,350,500	21,909,794
HVAC Upgrade Tier 2	71,858	136,152	230,702	370,636	567,300	567,300	567,300	567,300	520,025	472,750	4,071,323
HVAC Upgrade Tier 3	34,560	62,208	107,136	169,344	259,200	259,200	259,200	259,200	207,360	172,800	1,790,208
HVAC Retirement Tier 1	1,990,360	3,734,852	6,345,736	10,150,836	15,600,910	15,366,750	15,366,750	14,635,000	13,171,500	11,708,000	108,070,694
HVAC Retirement Tier 2	312,150	561,870	955,179	1,529,535	2,341,125	2,341,125	2,341,125	2,341,125	2,341,125	2,185,050	17,249,409
HVAC Retirement Tier 3	71,320	142,640	213,960	356,600	534,900	534,900	534,900	534,900	392,260	285,280	3,601,660
ECM Fan	-	443,600	831,750	1,413,975	2,218,000	3,327,000	2,495,250	1,996,200	1,663,500	1,330,800	15,720,075
Duct Repair	-	1,382,000	2,764,000	5,804,400	8,983,000	8,292,000	7,462,800	6,910,000	6,633,600	6,219,000	54,450,800
Energy Star Appliance (Units)	450,700	999,900	1,248,300	1,618,800	1,972,900	2,262,200	2,594,700	2,693,200	2,693,200	2,693,200	19,227,100
CFL Lighting (units)	5,490,000	8,235,000	10,980,000	-	-	-	-	-	-	-	24,705,000
Residential Custom Incentive	552,000	552,000	552,000	552,000	552,000	552,000	552,000	552,000	552,000	552,000	5,520,000
Solar Thermal	219,190	219,190	219,190	219,190	219,190	-	-	-	-	-	1,095,950
Solar Photovoltaic	255,520	255,520	255,520	255,520	255,520	-	-	-	-	-	1,277,600
Residential Total	**14,112,162**	**36,331,302**	**39,477,292**	**42,100,432**	**49,732,189**	**57,992,900**	**53,702,250**	**50,662,250**	**48,340,466**	**46,102,280**	**438,553,523**
Commercial/Industrial											
Audit											-
HVAC Upgrade/Replacement	97,800	195,600	228,200	260,800	326,000	391,200	391,200	456,400	456,400	456,400	3,260,000
Geothermal	102,750	119,875	137,000	171,250	171,250	171,250	171,250	171,250	150,700	150,700	1,517,275
HVAC Retrocommissioning	-	1,568,400	2,352,600	3,921,000	4,705,200	5,489,400	5,489,400	4,705,200	4,705,200	3,921,000	36,857,400
Ceiling Insulation	25,860	47,577	69,472	87,991	103,382	115,918	125,880	133,551	139,205	143,104	991,940
Window Film	95,682	181,518	269,475	341,492	398,324	441,247	471,783	491,608	502,375	505,661	3,699,164
HPWH	41,241	41,241	41,241	41,241	41,241	82,482	82,482	123,723	123,723	123,723	742,338
Interior Lighting	219,000	328,500	438,000	657,000	657,000	547,500	438,000	438,000	438,000	438,000	4,599,000
Interior Lighting -- LED	87,600	131,400	175,200	219,000	262,800	262,800	262,800	262,800	262,800	262,800	2,190,000
Lighting Occupancy Sensor	240,000	400,000	480,000	560,000	600,000	600,000	600,000	600,000	560,000	480,000	5,120,000
HVAC Occupancy Sensor -- Hotel	38,370	76,740	102,320	127,900	127,900	127,900	102,320	102,320	102,320	102,320	1,010,410
Reflective Roof	245,000	490,000	735,000	980,000	980,000	1,225,000	1,225,000	980,000	980,000	980,000	8,820,000
Food Service Equipment	50,164	72,378	86,606	147,847	163,944	166,467	121,323	181,404	136,260	202,875	1,329,268
Energy Efficient Motors	141,175	270,600	270,600	270,600	270,600	270,600	270,600	270,600	270,600	270,600	2,576,575
RTP	-	-	-	-	-	-	-	-	-	-	-
Business Custom Incentive	1,000,000	1,200,000	1,500,000	1,750,000	2,000,000	2,000,000	2,000,000	2,000,000	1,800,000	1,750,000	17,000,000
Solar PV	38,328	38,328	38,328	38,328	38,328	-	-	-	-	-	191,640
C&I Total	**2,422,970**	**5,162,157**	**6,924,042**	**9,574,448**	**10,845,969**	**11,891,764**	**11,752,038**	**10,916,856**	**10,627,583**	**9,787,182**	89,905,010
Grand Total	**16,535,132**	**41,493,459**	**46,401,334**	**51,674,880**	**60,578,158**	**69,884,664**	**65,454,288**	**61,579,106**	**58,968,049**	**55,889,462**	**528,458,533**

Residential	**Itron Net-Gross Ratio**	**Selected Ratio**	
Walk-Through Audit		**0.0%**	In the regression history
Online Audit		**0.0%**	In the regression history
Pre-Construction Audit		**0.0%**	In the regression history
Customer Usage Comparison (O Power)		**100.0%**	
Energy Select		**0.0%**	Already handled separately in the forecast
Energy Select Lite		**0.0%**	Already handled separately in the forecast
Ceiling Insulation		**100.0%**	
HPWH	**99.5%**	**100.0%**	
Reflective Roof	**98.4%**	**100.0%**	
Windows -- Low-E	**97.8%**	**100.0%**	
Windows -- Film	**94.6%**	**95.0%**	
Variable Speed Pool Pump	**99.1%**	**100.0%**	
Community Energy Saver		**100.0%**	
Refrigerator/Freezer Recycling		**0.0%**	In the regression history
HVAC Maintenance	**85.0%**	**85.0%**	
HVAC Upgrade Tier 1		**90.0%**	Based on historical HVAC installations by SEEI
HVAC Upgrade Tier 2		**100.0%**	Based on historical HVAC installations by SEEI
HVAC Upgrade Tier 3		**0.0%**	In the regression history
HVAC Retirement Tier 1		**90.0%**	Based on historical HVAC installations by SEEI
HVAC Retirement Tier 2		**100.0%**	Based on historical HVAC installations by SEEI
HVAC Retirement Tier 3		**0.0%**	In the regression history
ECM Fan	**80.4%**	**80.0%**	
Duct Repair	**99.8%**	**100.0%**	
Energy Star Appliance (Units)	**90.0%**	**0.0%**	In the regression history
CFL Lighting (units)	**74.5%**	**75.0%**	
Residential Custom Incentive		**100.0%**	
Solar Thermal		**100.0%**	
Solar Photovoltaic		**100.0%**	
Residential Total			
Commercial/Industrial			
Audit		**0.0%**	In the regression history
HVAC Upgrade/Replacement	**72.6%**	**75.0%**	
Geothermal	**99.9%**	**0.0%**	In the regression history
HVAC Retrocommissioning	**89.4%**	**90.0%**	
Ceiling Insulation	**90.0%**	**90.0%**	
Window Film	**91.6%**	**90.0%**	
HPWH	**88.5%**	**90.0%**	
Interior Lighting	**65.0%**	**65.0%**	
Interior Lighting -- LED	**70.0%**	**70.0%**	
Lighting Occupancy Sensor	**99.4%**	**100.0%**	
HVAC Occupancy Sensor -- Hotel	**93.8%**	**95.0%**	
Reflective Roof	**93.2%**	**95.0%**	
Food Service Equipment		**100.0%**	
Energy Efficient Motors	**64.0%**	**65.0%**	
RTP		**0.0%**	Already handled separately in the forecast
Business Custom Incentive		**0.0%**	In the regression history
Solar PV		**100.0%**	
C&I Total			
RC&I Grand Total			

Staff's Second Request for Production of Documents Item No. 8 -- Document in support of DSM Plan Adjustment
This worksheet shows the allocation of the annual exogenous DSM kWh adjustments by month.

	kWh		Peak Demand	
	Res	Com	Res	Com
2011 Jan	(2,597,488)	(56,997)	(8,266)	(201)
2011 Feb	(1,897,239)	(40,054)		
2011 Mar	(1,290,046)	(40,392)		
2011 Apr	(786,421)	(57,998)		
2011 May	(1,243,648)	(114,483)		
2011 Jun	(1,962,858)	(153,798)	(6,292)	(356)
2011 Jul	(2,306,711)	(171,527)	(7,398)	(397)
2011 Aug	(2,192,632)	(166,287)	(7,030)	(384)
2011 Sep	(1,643,079)	(135,845)		
2011 Oct	(1,057,977)	(78,759)		
2011 Nov	(1,437,534)	(43,902)		
2011 Dec	(2,344,267)	(52,939)		
2012 Jan	(6,318,616)	(293,300)	(18,629)	(802)
2012 Feb	(4,615,198)	(206,112)		
2012 Mar	(3,138,149)	(207,854)		
2012 Apr	(1,913,038)	(298,450)		
2012 May	(3,025,282)	(589,113)		
2012 Jun	(4,774,824)	(791,424)	(14,319)	(2,003)
2012 Jul	(5,611,274)	(882,658)	(16,836)	(2,233)
2012 Aug	(5,333,769)	(855,689)	(16,001)	(2,165)
2012 Sep	(3,996,932)	(699,039)		
2012 Oct	(2,573,621)	(405,285)		
2012 Nov	(3,496,927)	(225,915)		
2012 Dec	(5,702,634)	(272,418)		
2013 Jan	(10,507,708)	(636,574)	(31,581)	(1,654)
2013 Feb	(7,674,964)	(447,342)		
2013 Mar	(5,218,668)	(451,123)		
2013 Apr	(3,181,337)	(647,749)		
2013 May	(5,030,972)	(1,278,599)		
2013 Jun	(7,940,419)	(1,717,692)	(24,969)	(4,431)
2013 Jul	(9,331,416)	(1,915,703)	(29,359)	(4,942)
2013 Aug	(8,869,931)	(1,857,171)	(27,902)	(4,791)
2013 Sep	(6,646,804)	(1,517,181)		
2013 Oct	(4,279,871)	(879,624)		
2013 Nov	(5,815,307)	(490,321)		
2013 Dec	(9,483,346)	(591,250)		
2014 Jan	(15,385,145)	(1,026,267)	(45,800)	(2,610)
2014 Feb	(11,237,507)	(721,192)		
2014 Mar	(7,641,054)	(727,288)		

2014 Apr	(4,658,041)	(1,044,283)		
2014 May	(7,366,233)	(2,061,322)		
2014 Jun	(11,626,179)	(2,769,216)	(37,129)	(7,200)
2014 Jul	(13,662,846)	(3,088,445)	(43,655)	(8,029)
2014 Aug	(12,987,149)	(2,994,081)	(41,489)	(7,784)
2014 Sep	(9,732,097)	(2,445,958)		
2014 Oct	(6,266,489)	(1,418,105)		
2014 Nov	(8,514,639)	(790,483)		
2014 Dec	(13,885,297)	(953,197)		
2015 Jan	(21,264,697)	(1,465,505)	(62,312)	(3,625)
2015 Feb	(15,532,006)	(1,029,861)		
2015 Mar	(10,561,141)	(1,038,566)		
2015 Apr	(6,438,147)	(1,491,233)		
2015 May	(10,181,296)	(2,943,562)		
2015 Jun	(16,069,213)	(3,954,432)	(51,171)	(10,351)
2015 Jul	(18,884,207)	(4,410,290)	(60,167)	(11,544)
2015 Aug	(17,950,288)	(4,275,539)	(57,181)	(11,191)
2015 Sep	(13,451,293)	(3,492,821)		
2015 Oct	(8,661,276)	(2,025,050)		
2015 Nov	(11,768,574)	(1,128,807)		
2015 Dec	(19,191,670)	(1,361,163)		
2016 Jan	(26,803,627)	(1,899,410)	(77,409)	(4,606)
2016 Feb	(19,577,712)	(1,334,780)		
2016 Mar	(13,312,058)	(1,346,062)		
2016 Apr	(8,115,126)	(1,932,755)		
2016 May	(12,833,273)	(3,815,086)		
2016 Jun	(20,254,847)	(5,125,253)	(63,822)	(13,484)
2016 Jul	(23,803,078)	(5,716,080)	(75,041)	(15,039)
2016 Aug	(22,625,897)	(5,541,432)	(71,317)	(14,579)
2016 Sep	(16,955,024)	(4,526,969)		
2016 Oct	(10,917,325)	(2,624,623)		
2016 Nov	(14,833,997)	(1,463,022)		
2016 Dec	(24,190,628)	(1,764,174)		
2017 Jan	(32,008,277)	(2,294,000)	(91,985)	(5,544)
2017 Feb	(23,379,255)	(1,612,072)		
2017 Mar	(15,896,955)	(1,625,698)		
2017 Apr	(9,690,898)	(2,334,272)		
2017 May	(15,325,200)	(4,607,646)		
2017 Jun	(24,187,874)	(6,189,991)	(75,702)	(16,291)
2017 Jul	(28,425,091)	(6,903,558)	(89,009)	(18,169)
2017 Aug	(27,019,327)	(6,692,629)	(84,592)	(17,614)
2017 Sep	(20,247,301)	(5,467,417)		
2017 Oct	(13,037,219)	(3,169,871)		
2017 Nov	(17,714,420)	(1,766,956)		

2017 Dec	(28,887,893)	(2,130,669)		
2018 Jan	(36,989,317)	(2,684,986)	(106,288)	(6,455)
2018 Feb	(27,017,470)	(1,886,831)		
2018 Mar	(18,370,795)	(1,902,780)		
2018 Apr	(11,198,968)	(2,732,123)		
2018 May	(17,710,066)	(5,392,967)		
2018 Jun	(27,951,924)	(7,245,005)	(87,042)	(19,081)
2018 Jul	(32,848,525)	(8,080,192)	(102,343)	(21,280)
2018 Aug	(31,224,000)	(7,833,312)	(97,264)	(20,630)
2018 Sep	(23,398,130)	(6,399,277)		
2018 Oct	(15,066,035)	(3,710,140)		
2018 Nov	(20,471,089)	(2,068,113)		
2018 Dec	(33,383,348)	(2,493,818)		
2019 Jan	(41,744,474)	(3,039,474)	(120,323)	(7,285)
2019 Feb	(30,490,697)	(2,135,942)		
2019 Mar	(20,732,450)	(2,153,997)		
2019 Apr	(12,638,650)	(3,092,834)		
2019 May	(19,986,781)	(6,104,979)		
2019 Jun	(31,545,280)	(8,201,535)	(97,842)	(21,592)
2019 Jul	(37,071,363)	(9,146,989)	(115,042)	(24,081)
2019 Aug	(35,237,998)	(8,867,514)	(109,333)	(23,346)
2019 Sep	(26,406,074)	(7,244,148)		
2019 Oct	(17,002,847)	(4,199,975)		
2019 Nov	(23,102,747)	(2,341,158)		
2019 Dec	(37,674,940)	(2,823,067)		

Staff's Second Request for Production of Documents Item No. 8 -- Document in support of DSM Plan Adjustment
This worksheet shows the ratios used to allocate the annual exogenous DSM kWh adjustments by month.

"Exogenous" Forecast Adjustments due to Conservation

	kWh Reduction	
	Residential	Commercial
2011	(20,759,902)	(1,112,982)
2012	(50,500,263)	(5,727,259)
2013	(83,980,743)	(12,430,330)
2014	(122,962,677)	(20,039,839)
2015	(169,953,809)	(28,616,829)
2016	(214,222,592)	(37,089,646)
2017	(255,819,709)	(44,794,778)
2018	(295,629,665)	(52,429,545)
2019	(333,634,300)	(59,351,612)

	Winter Peak Reduction	
	Residential	Commercial
2011	(8,266)	(201)
2012	(18,629)	(802)
2013	(31,581)	(1,654)
2014	(45,800)	(2,610)
2015	(62,312)	(3,625)
2016	(77,409)	(4,606)
2017	(91,985)	(5,544)
2018	(106,288)	(6,455)
2019	(120,323)	(7,285)

	Summer Peak Reduction	
	Residential	Commercial
2011	(7,398)	(397)
2012	(16,836)	(2,233)
2013	(29,359)	(4,942)
2014	(43,655)	(8,029)
2015	(60,167)	(11,544)
2016	(75,041)	(15,039)
2017	(89,009)	(18,169)
2018	(102,343)	(21,280)
2019	(115,042)	(24,081)

	kWh Reduction	
	Residential	Commercial
Jan	13%	5%
Feb	9%	4%
Mar	6%	4%
Apr	4%	5%
May	6%	10%
Jun	9%	14%
Jul	11%	15%
Aug	11%	15%
Sep	8%	12%
Oct	5%	7%
Nov	7%	4%
Dec	11%	5%

	Winter Peak Multiplier	
	Residential	Commercial
Jan	100%	100%
Feb	73%	61%
Mar	46%	
Apr		
May		
Jun		
Jul		
Aug		
Sep		
Oct		
Nov	50%	
Dec	89%	83%

	Summer Peak Multiplier	
	Residential	Commercial
Jan		
Feb		
Mar		16%
Apr	15%	32%
May	51%	67%
Jun	85%	90%
Jul	100%	100%
Aug	95%	97%
Sep	70%	79%
Oct	29%	45%
Nov		16%
Dec		

Staff's Second Request for Production of Documents Item No. 8 -- Document in support of DSM Plan Adjustment This worksheet shows the monthly normal cooling and heating degree hours used as the basis for calculating the ratios used to allocate the annual exogenous DSM kWh adjustments by month.

CUBE: forecasting:Weather
forecasting B2011
forecasting 2011

	Cal Res HDH	Cal Res CDH	Cal Com HDH	Cal Com CDH
Jan	9,914	45	4,218	698
Feb	7,196	78	2,558	897
Mar	4,531	416	1,169	2,315
Apr	1,706	1,310	221	4,781
May	230	4,538	5	9,868
Jun	4	7,522	-	13,265
Jul	-	8,844	-	14,794
Aug	2	8,406	-	14,342
Sep	96	6,204	2	11,715
Oct	1,494	2,563	202	6,591
Nov	4,954	558	1,362	2,425
Dec	8,872	116	3,490	1,076

Measure Number	Measure	% Incentive	Max	Mid	Fit	Net Energy	Gross Energy	1st Yr Net to Gross Ratio
101	14 SEER Split-System Air Conditioner	90.78%	0.8	2	1.7	9,895	9,936	99.6%
102	15 SEER Split-System Air Conditioner	0.00%	0.8	2	1.7	0	0	N/A
103	17 SEER Split-System Air Conditioner	0.00%	0.8	2	1.7	0	0	N/A
104	19 SEER Split-System Air Conditioner	0.00%	0.8	2	1.7	0	0	N/A
105	14 SEER Split-System Heat Pump	0.00%	0.8	2	1.7	0	0	N/A
106	15 SEER Split-System Heat Pump	0.00%	0.8	2	1.7	0	0	N/A
107	17 SEER Split-System Heat Pump	0.00%	0.8	2	1.7	0	0	N/A
108	13 EER Geothermal Heat Pump	0.00%	0.8	2	1.7	0	0	N/A
109	HVAC Proper Sizing	0.00%	0.8	0.2	1.7	0	0	N/A
110	Attic Venting	0.00%	0.5	0.2	1.7	0	0	N/A
111	Sealed Attic w/Sprayed Foam Insulated Roof Deck	0.00%	0.8	0.1	1.7	0	0	N/A
112	AC Maintenance (Outdoor Coil Cleaning)	18.67%	0.8	0.1	1.7	7,176	8,280	86.7%
113	AC Maintenance (Indoor Coil Cleaning)	39.99%	0.8	0.1	1.7	33,175	35,628	93.1%
114	Proper Refrigerant Charging and Air Flow	27.32%	0.8	0.1	1.7	41,921	50,984	82.2%
115	Electronically Commutated Motors (ECM) on an Air Handler Unit	20.46%	0.8	0.2	1.7	36,577	56,947	64.2%
116	Duct Repair	85.25%	0.8	0.2	1.7	187,104	187,953	99.5%
117	Reflective Roof	52.46%	0.8	0.1	1.7	19,769	21,130	93.6%
118	Radient Barrier	0.00%	0.8	0.1	1.7	0	0	N/A
119	Window Film	54.47%	0.8	0.2	1.7	76,246	82,866	92.0%
120	Window Tinting	62.83%	0.8	0.2	1.7	1,284	1,357	94.6%
121	Default Window With Sunscreen	55.56%	0.3	0.1	1.7	14,724	15,360	95.9%
122	Single Pane Clear Windows to Double Pane Low-E Windows	55.56%	0.8	2	1.7	0	0	N/A
123	Double Pane Clear Windows to Double Pane Low-E Windows	66.64%	0.8	2	1.7	26,941	30,380	88.7%
124	Ceiling R-0 to R-19 Insulation	0.00%	0.3	0.1	1.7	0	0	N/A
125	Ceiling R-19 to R-38 Insulation	0.00%	0.3	0.1	1.7	0	0	N/A
126	Wall 2x4 R-0 to Blow-In R-13 Insulation	0.00%	0.8	0.2	1.7	0	0	N/A
127	Weather Strip/Caulk w/Blower Door	70.01%	0.8	0.1	1.7	1,407	1,419	99.1%
131	14 SEER Split-System Heat Pump	0.00%	0.8	2	1.7	0	0	N/A
132	15 SEER Split-System Heat Pump	0.00%	0.8	2	1.7	0	0	N/A
133	17 SEER Split-System Heat Pump	0.00%	0.8	2	1.7	0	0	N/A
134	13 EER Geothermal Heat Pump	0.00%	0.8	2	1.7	0	0	N/A
135	HVAC Proper Sizing	0.00%	0.8	0.2	1.7	0	0	N/A
136	Attic Venting	0.00%	0.5	0.2	1.7	0	0	N/A
137	Sealed Attics	0.00%	0.8	0.1	1.7	0	0	N/A
138	AC Maintenance (Outdoor Coil Cleaning)	34.20%	0.8	0.1	1.7	1,442	1,544	93.4%
139	AC Maintenance (Indoor Coil Cleaning)	51.23%	0.8	0.1	1.7	24,155	25,115	96.2%
140	Proper Refrigerant Charging and Air Flow	26.10%	0.8	0.1	1.7	168,879	220,675	76.5%
141	Electronically Commutated Motors (ECM) on an Air Handler Unit	0.00%	0.8	0.2	1.7	0	0	N/A
142	Duct Repair	87.16%	0.8	0.2	1.7	74,299	74,493	99.7%
143	Reflective Roof	61.77%	0.8	0.1	1.7	10,083	10,427	96.7%
144	Radient Barrier	0.00%	0.8	0.1	1.7	0	0	N/A
145	Window Film	59.63%	0.8	0.2	1.7	20,709	21,990	94.2%
146	Window Tinting	48.24%	0.8	0.2	1.7	1,612	1,992	80.9%
147	Default Window With Sunscreen	47.73%	0.3	0.1	1.7	15,629	17,583	88.9%
148	Single Pane Clear Windows to Double Pane Low-E Windows	47.73%	0.8	2	1.7	0	0	N/A
149	Double Pane Clear Windows to Double Pane Low-E Windows	75.20%	0.8	2	1.7	14,398	15,065	95.6%
150	Ceiling R-0 to R-19 Insulation	0.00%	0.3	0.1	1.7	0	0	N/A
151	Ceiling R-19 to R-38 Insulation	0.00%	0.3	0.1	1.7	0	0	N/A
152	Wall 2x4 R-0 to Blow-In R-13 Insulation	0.00%	0.8	0.2	1.7	0	0	N/A
153	Weather Strip/Caulk w/Blower Door	0.00%	0.8	0.1	1.7	0	0	N/A
161	14 SEER Split-System Air Conditioner	0.00%	0.8	2	1.7	0	0	N/A
162	15 SEER Split-System Air Conditioner	0.00%	0.8	2	1.7	0	0	N/A
163	17 SEER Split-System Air Conditioner	0.00%	0.8	2	1.7	0	0	N/A
164	19 SEER Split-System Air Conditioner	0.00%	0.8	2	1.7	0	0	N/A
165	HVAC Proper Sizing	0.00%	0.8	0.2	1.7	0	0	N/A
166	Attic Venting	0.00%	0.5	0.2	1.7	0	0	N/A
167	Sealed Attic w/Sprayed Foam Insulated Roof Deck	0.00%	0.8	0.1	1.7	0	0	N/A
168	AC Maintenance (Outdoor Coil Cleaning)	37.97%	0.8	0.1	1.7	917	980	93.5%
169	AC Maintenance (Indoor Coil Cleaning)	54.99%	0.8	0.1	1.7	10,907	11,248	97.0%
170	Proper Refrigerant Charging and Air Flow	31.91%	0.8	0.1	1.7	83,377	102,761	81.1%
171	Electronically Commutated Motors (ECM) on an Air Handler Unit	40.09%	0.8	0.2	1.7	15,865	19,735	80.4%
172	Duct Repair	89.55%	0.8	0.2	1.7	21,660	21,695	99.8%
173	Reflective Roof	64.77%	0.8	0.1	1.7	4,703	4,836	97.3%
174	Radient Barrier	0.00%	0.8	0.1	1.7	0	0	N/A
175	Window Film	58.83%	0.8	0.2	1.7	4,826	5,100	94.6%
176	Window Tinting	45.70%	0.8	0.2	1.7	536	639	83.9%
177	Default Window With Sunscreen	52.14%	0.3	0.1	1.7	3,686	3,962	93.0%
178	Single Pane Clear Windows to Double Pane Low-E Windows	52.14%	0.8	2	1.7	0	0	N/A
179	Double Pane Clear Windows to Double Pane Low-E Windows	79.42%	0.8	2	1.7	4,877	4,987	97.8%
180	Ceiling R-0 to R-19 Insulation	0.00%	0.3	0.1	1.7	0	0	N/A
181	Ceiling R-19 to R-38 Insulation	0.00%	0.3	0.1	1.7	0	0	N/A
182	Wall 2x4 R-0 to Blow-In R-13 Insulation	0.00%	0.8	0.2	1.7	0	0	N/A
183	Weather Strip/Caulk w/Blower Door	75.95%	0.8	0.1	1.7	488	491	99.5%
191	HE Room Air Conditioner - EER 11	75.02%	0.8	2	1.7	14,430	15,197	95.0%
192	HE Room Air Conditioner - EER 12	0.00%	0.8	2	1.7	0	0	N/A
196	Reflective Roof	72.82%	0.8	0.1	1.7	601	610	98.4%
197	Window Film	69.91%	0.8	0.2	1.7	2,857	2,934	97.4%
198	Window Tinting	52.59%	0.8	0.2	1.7	193	221	87.6%
199	Default Window With Sunscreen	56.50%	0.3	0.1	1.7	2,145	2,326	92.2%
200	Single Pane Clear Windows to Double Pane Low-E Windows	56.50%	0.8	2	1.7	0	0	N/A
201	Double Pane Clear Windows to Double Pane Low-E Windows	78.35%	0.8	2	1.7	1,079	1,142	94.4%
202	Ceiling R-0 to R-19 Insulation	90.63%	0.3	0.1	1.7	40	41	99.9%
203	Ceiling R-19 to R-38 Insulation	0.00%	0.3	0.1	1.7	0	0	N/A
204	Wall 2x4 R-0 to Blow-In R-13 Insulation	0.00%	0.8	0.2	1.7	0	0	N/A
205	Weather Strip/Caulk w/Blower Door	0.00%	0.8	0.1	1.7	0	0	N/A
221	CFL (18-Watt integral ballast), 0.5 hr/day	24.65%	0.5	0.1	1.7	73,095	98,058	74.5%
231	CFL (18-Watt integral ballast), 2.5 hr/day	0.00%	0.5	0.1	1.7	0	0	N/A
241	CFL (18-Watt integral ballast), 6.0 hr/day	0.00%	0.5	0.1	1.7	0	0	N/A

251	ROB 2L4'T8, 1EB	0.00%	0.8	0.1	1.7	0	0	N/A
252	RET 2L4'T8, 1EB	0.00%	0.8	0.1	1.7	0	0	N/A
261	CFL - medium screw based <30 Watts	0.00%	0.5	0.1	1.7	0	0	N/A
262	Photocell/timeclock	0.00%	0.8	0.2	1.7	0	0	N/A
301	HE Refrigerator - Energy Star version of above	40.41%	0.8	0.2	1.7	82,442	96,435	85.5%
351	HE Freezer	63.96%	0.8	0.2	1.7	3,593	3,698	97.2%
401	Heat Pump Water Heater (EF=2.9)	82.53%	0.8	0.2	1.7	38,811	38,986	99.5%
402	HE Water Heater (EF=0.93)	82.53%	0.8	0.2	1.7	0	0	N/A
403	Solar Water Heat	0.00%	0.8	0.2	1.7	0	0	N/A
404	AC Heat Recovery Units	0.00%	0.5	0.1	1.7	0	0	N/A
405	Low Flow Showerhead	18.85%	0.5	0.1	1.7	15,331	20,280	75.6%
406	Pipe Wrap	0.00%	0.5	0.1	1.7	0	0	N/A
407	Faucet Aerators	6.09%	0.5	0.1	1.7	6,088	9,849	61.8%
408	Water Heater Blanket	0.00%	0.5	0.1	1.7	0	0	N/A
409	Water Heater Temperature Check and Adjustment	0.00%	0.5	0.1	1.7	0	0	N/A
410	Water Heater Timeclock	68.57%	0.5	0.1	1.7	18,666	19,024	98.1%
411	Heat Trap	0.00%	0.5	0.1	1.7	0	0	N/A
501	Energy Star CW CEE Tier 1 (MEF=1.8)	0.00%	0.8	2	1.7	0	0	N/A
502	Energy Star CW CEE Tier 2 (MEF=2.0)	69.10%	0.8	2	1.7	136,344	144,486	94.4%
503	Energy Star CW CEE Tier 3 (MEF=2.2)	0.00%	0.8	2	1.7	0	0	N/A
610	High Efficiency CD (EF=3.01 w/moisture sensor)	84.07%	0.8	2	1.7	46,188	46,961	98.4%
701	Energy Star DW (EF=0.68)	0.00%	0.8	2	1.7	0	0	N/A
801	Two Speed Pool Pump (1.5 hp)	0.00%	0.8	0.2	1.7	0	0	N/A
802	High Efficiency One Speed Pool Pump (1.5 hp)	0.00%	0.8	0.2	1.7	0	0	N/A
803	Variable-Speed Pool Pump (<1 hp)	75.92%	0.8	0.2	1.7	19,439	19,616	99.1%
804	PV-Powered Pool Pumps	0.00%	0.8	0.2	1.7	0	0	N/A
901	Energy Star TV	0.00%	0.8	0.2	1.7	0	0	N/A
911	Energy Star TV	0.00%	0.8	0.2	1.7	0	0	N/A
921	Energy Star Set-Top Box	0.00%	0.8	0.2	1.7	0	0	N/A
931	Energy Star DVD Player	0	0.8	0.2	1.7	0	0	N/A
941	Energy Star VCR	0	0.8	0.2	1.7	0	0	N/A
951	Energy Star Desktop PC	0	0.8	0.2	1.7	0	0	N/A
961	Energy Star Laptop PC	0	0.8	0.2	1.7	0	0	N/A
						1,400,610	1,587,424	88.2%

Measure #	Measure	% Incentive	Max	Mid	Fit	Net Energy	Gross Energy	1st Yr Net to Gross Ratio
111	Premium T8, Elecctronic Ballast	0.00%	0.7	2	1.7	0	0	N/A
112	Premium T8, EB, Reflector	21.23%	0.7	0	1.7	3,598	5,701	63.1%
113	Occupancy Sensor	79.89%	0.7	0.2	1.7	67,838	68,258	99.4%
114	Continuous Dimming	86.14%	0.7	0.2	1.7	2,180	2,183	99.9%
115	Lighting Control Tuneup	11.44%	0.7	0.1	1.7	44	74	59.3%
121	ROB Premium T8, 1EB	10.01%	0.7	2	1.7	9,218	27,337	33.7%
122	ROB Premium T8, EB, Reflector	15.34%	0.7	0	1.7	31	57	53.9%
123	Occupancy Sensor	80.55%	0.7	0.2	1.7	28,246	28,386	99.5%
124	Lighting Control Tuneup	25.25%	0.7	0.1	1.7	60	81	74.2%
131	CFL Screw-in 18W	0.00%	0.7	0.1	1.7	0	0	N/A
141	CFL Hardwired, Modular 18W	20.27%	0.7	0.1	1.7	2,697	3,962	68.1%
151	PSMH, 250W, magnetic ballast	0.00%	0.7	0.5	1.7	0	0	N/A
152	PSMH, 250 W, electronic ballast	0.00%	0.7	0.5	1.7	0	0	N/A
153	High Bay T5	0.00%	0.7	0.5	1.7	0	0	N/A
161	LED Exit Sign	7.29%	0.7	0.2	1.7	10,526	28,662	36.7%
201	High Pressure Sodium 250W Lamp	71.11%	0.5	0.1	1.7	10,450	10,530	99.2%
202	Outdoor Lighting Controls (Photocell/Timeclock)	27.40%	0.5	0.1	1.7	1,153	1,433	80.5%
211	Outdoor Lighting Controls (Photocell/Timeclock)	60.26%	0.5	0.1	1.7	1,512	1,549	97.6%
301	Centrifugal Chiller, 0.51 kW/ton, 500 tons	34.67%	0.7	1	1.7	29,836	108,614	27.5%
302	High Efficiency Chiller Motors	42.25%	0.7	0.1	1.7	34,218	42,876	79.8%
304	EMS - Chiller	37.05%	0.7	1	1.7	17,591	26,731	65.8%
305	Chiller Tune Up/Diagnostics	48.44%	0.7	0.2	1.7	23,789	27,144	87.6%
306	VSD for Chiller Pumps and Towers	24.61%	0.7	0.5	1.7	78,086	144,028	54.2%
307	EMS Optimization	23.55%	0.7	0.1	1.7	274	361	75.9%
308	Aerosole Duct Sealing	0.00%	0.7	0.1	1.7	0	0	N/A
309	Duct/Pipe Insulation	0.00%	0.7	0.1	1.7	0	0	N/A
311	Window Film (Standard)	60.52%	0.7	0.1	1.7	15,090	16,476	91.6%
313	Ceiling Insulation	67.11%	0.3	0.1	1.7	8,368	8,767	95.4%
314	Roof Insulation	70.44%	0.4	0.1	1.7	8,246	8,639	95.5%
315	Cool Roof - Chiller	81.33%	0.7	0.2	1.7	103,559	105,246	98.4%
317	Thermal Energy Storage (TES)	0.00%	0.7	0.1	1.7	0	0	N/A
321	DX Packaged System, EER=10.9, 10 tons	74.10%	0.7	1	1.7	74,027	101,995	72.6%
322	Hybrid Dessicant-DX System (Trane CDQ)	46.26%	0.5	0.1	1.7	7,354	8,417	87.4%
323	Geothermal Heat Pump, EER=13, 10 tons	88.23%	0.5	0.1	1.7	145	145	99.9%
326	DX Tune Up/ Advanced Diagnostics	47.85%	0.7	0.1	1.7	12,466	13,942	89.4%
327	DX Coil Cleaning	0.00%	0.7	0.1	1.7	0	0	N/A
328	Optimize Controls	8.75%	0.7	0.1	1.7	160	281	56.9%
329	Aerosole Duct Sealing	0.00%	0.7	0.1	1.7	0	0	N/A
330	Duct/Pipe Insulation	0.00%	0.7	0.1	1.7	0	0	N/A
332	Window Film (Standard)	52.06%	0.7	0.1	1.7	15,673	17,108	91.6%
334	Ceiling Insulation	51.04%	0.3	0.1	1.7	16,107	18,222	88.4%
335	Roof Insulation	45.57%	0.4	0.1	1.7	26,762	33,523	79.8%
336	Cool Roof - DX	67.51%	0.7	0.2	1.7	380,949	408,813	93.2%
341	Packaged HP System, EER=10.9, 10 tons	0.00%	0.7	1	1.7	0	0	N/A
342	Geothermal Heat Pump, EER=13, 10 tons	90.90%	0.5	0.1	1.7	39	39	99.9%
344	Aerosole Duct Sealing	0.00%	0.7	0.1	1.7	0	0	N/A
345	Duct/Pipe Insulation	0.00%	0.7	0.1	1.7	0	0	N/A
347	Window Film (Standard)	51.47%	0.7	0.1	1.7	1,168	1,269	92.0%
349	Ceiling Insulation	57.86%	0.3	0.1	1.7	1,402	1,506	93.1%
350	Roof Insulation	54.73%	0.4	0.1	1.7	2,626	3,048	86.2%
351	Cool Roof - DX	71.64%	0.7	0.2	1.7	33,421	35,215	94.9%
361	HE PTAC, EER=9.6, 1 ton	36.36%	0.7	1	1.7	11,925	19,198	62.1%
362	Occupancy Sensor (hotels)	60.03%	0.7	0.1	1.7	65,987	70,356	93.8%
401	High Efficiency Fan Motor, 15hp, 1800rpm, 92.4%	51.97%	0.7	1	1.7	16,223	35,793	45.3%
402	Variable Speed Drive Control	52.00%	0.7	0.5	1.7	309,439	375,404	82.4%
403	Air Handler Optimization	30.34%	0.7	0.1	1.7	7,297	9,437	77.3%
404	Electronically Commutated Motors (ECM) on an Air Handler Unit	31.67%	0.7	0.1	1.7	13,053	17,902	72.9%
405	Demand Control Ventilation (DCV)	0.00%	0.7	0.1	1.7	0	0	N/A
406	Energy Recovery Ventilation (ERV)	90.84%	0.7	1	1.7	28,278	28,383	99.6%
407	Separate Makeup Air / Exhaust Hoods AC	90.84%	0.7	0.1	1.7	0	0	N/A
501	High-efficiency fan motors	90.84%	0.5	0.1	1.7	291,203	293,020	99.4%
502	Strip curtains for walk-ins	90.84%	0.5	0.1	1.7	0	0	N/A
503	Night covers for display cases	90.84%	0.5	0.1	1.7	0	0	N/A
504	Evaporator fan controller for MT walk-ins	90.84%	0.5	0.1	1.7	2,119	2,123	99.8%
505	Efficient compressor motor	90.84%	0.5	0.1	1.7	0	0	N/A
506	Compressor VSD retrofit	90.84%	0.5	0.1	1.7	89,179	90,074	99.0%
507	Floating head pressure controls	90.84%	0.5	0.1	1.7	0	0	N/A
508	Refrigeration Commissioning	90.84%	0.5	0.1	1.7	0	0	N/A
509	Demand Hot Gas Defrost	90.84%	0.5	0.1	1.7	0	0	N/A
510	Demand Defrost Electric	90.84%	0.3	0	1.7	0	0	N/A
511	Anti-sweat (humidistat) controls	90.84%	0.5	0.1	1.7	0	0	N/A
513	High R-Value Glass Doors	90.84%	0.5	0.1	1.7	23,994	24,095	99.6%
514	Multiplex Compressor System	90.84%	0.5	0.1	1.7	23,826	23,863	99.8%
515	Oversized Air Cooled Condenser	90.84%	0.5	0.1	1.7	214,881	219,297	98.0%
516	Freezer-Cooler Replacement Gaskets	90.84%	0.5	0.1	1.7	0	0	N/A
517	LED Display Lighting	90.84%	0.5	0.1	1.7	1,485	1,487	99.9%
601	High Efficiency Water Heater (electric)	53.74%	0.7	0.1	1.7	120	134	89.5%
603	Heat Pump Water Heater (air source)	49.10%	0.5	0.1	1.7	1,764	1,993	88.5%
604	Solar Water Heater	0.00%	0.5	0.1	1.7	0	0	N/A
606	Demand controlled circulating systems	40.54%	0.7	0.1	1.7	787	994	79.2%
608	Heat Recovery Unit	46.14%	0.7	0.1	1.7	22,987	26,019	88.3%
609	Heat Trap	0.00%	0.7	0.1	1.7	0	0	N/A
610	Hot Water Pipe Insulation	60.63%	0.7	0.1	1.7	7	8	95.3%
701	PC Manual Power Management Enabling	0.00%	0.5	0.1	1.7	0	0	N/A
702	PC Network Power Management Enabling	0.00%	0.5	0.1	1.7	0	0	N/A
711	Energy Star or Better Monitor	0.00%	0.5	0.1	1.7	0	0	N/A
712	Monitor Power Management Enabling	0.00%	0.5	0.1	1.7	0	0	N/A
721	Energy Star or Better Monitor	0.00%	0.5	0.1	1.7	0	0	N/A
722	Monitor Power Management Enabling	0.00%	0.5	0.1	1.7	0	0	N/A
731	Energy Star or Better Copier	0.00%	0.5	0.1	1.7	0	0	N/A
732	Copier Power Management Enabling	8.93%	0.5	0.1	1.7	1,639	2,948	55.6%
741	Printer Power Management Enabling	0.00%	0.5	0.1	1.7	0	0	N/A
801	Convection Oven	0.00%	0.7	0.2	1.7	0	0	N/A
811	Efficient Fryer	0.00%	0.7	0.2	1.7	0	0	N/A
901	Vending Misers (cooled machines only)	0.00%	0.5	0.1	1.7	0	0	N/A
						2,155,102	2,553,145	84.4%

Measure #	Measure	% Incentive	Max	Mid	Fit	Net Energy	Gross Energy	1st Yr Net to Gross Ratio
101	Compressed Air-O&M	0.00%	0.7	0	1.7	0	0	N/A
102	Compressed Air - Controls	17.56%	0.7	0.2	1.7	7,553	13,571	55.7%
103	Compressed Air - System Optimization	0.00%	0.7	0.1	1.7	0	0	N/A
104	Compressed Air- Sizing	0.00%	0.7	0.1	1.7	0	0	N/A
105	Comp Air - Replace 1-5 HP motor	0.00%	0.7	0.2	1.7	0	0	N/A
106	Comp Air - ASD (1-5 hp)	0.00%	0.7	0.2	1.7	0	0	N/A
107	Comp Air - Motor practices-1 (1-5 HP)	76.74%	0.7	0.2	1.7	1,054	1,062	99.3%
108	Comp Air - Replace 6-100 HP motor	87.92%	0.7	0.2	1.7	100	100	100.0%
109	Comp Air - ASD (6-100 hp)	0.00%	0.7	0.2	1.7	0	0	N/A
110	Comp Air - Motor practices-1 (6-100 HP)	53.08%	0.7	0.2	1.7	2,669	2,877	92.7%
111	Comp Air - Replace 100+ HP motor	63.71%	0.7	0.2	1.7	167	171	98.1%
112	Comp Air - ASD (100+ hp)	0.00%	0.7	0.2	1.7	0	0	N/A
113	Comp Air - Motor practices-1 (100+ HP)	26.68%	0.7	0.2	1.7	1,138	1,510	75.4%
114	Power recovery	26.68%	0.7	0.2	1.7	0	0	N/A
115	Refinery Controls	26.68%	0.7	0.2	1.7	26	37	69.8%
201	Fans - O&M	0.00%	0.7	0	1.7	0	0	N/A
202	Fans - Controls	44.17%	0.7	0.2	1.7	71,224	82,115	86.7%
203	Fans - System Optimization	40.39%	0.7	0.1	1.7	13,864	15,974	86.8%
204	Fans- Improve components	0.00%	0.7	0.1	1.7	0	0	N/A
205	Fans - Replace 1-5 HP motor	0.00%	0.7	0.2	1.7	0	0	N/A
206	Fans - ASD (1-5 hp)	0.00%	0.7	0.2	1.7	0	0	N/A
207	Fans - Motor practices-1 (1-5 HP)	72.57%	0.7	0.2	1.7	2,358	2,390	98.7%
208	Fans - Replace 6-100 HP motor	85.76%	0.7	0.2	1.7	497	497	99.9%
209	Fans - ASD (6-100 hp)	0.00%	0.7	0.2	1.7	0	0	N/A
210	Fans - Motor practices-1 (6-100 HP)	35.91%	0.7	0.2	1.7	6,310	7,968	79.2%
211	Fans - Replace 100+ HP motor	57.21%	0.7	0.2	1.7	373	386	96.5%
212	Fans - ASD (100+ hp)	0.00%	0.7	0.2	1.7	0	0	N/A
213	Fans - Motor practices-1 (100+ HP)	0.00%	0.7	0.2	1.7	4	12	34.8%
214	Optimize drying process	0.00%	0.7	0.2	1.7	723	1,806	40.0%
215	Power recovery	0.00%	0.7	0.2	1.7	0	0	54.6%
216	Refinery Controls	0.00%	0.7	0.2	1.7	9	34	27.5%
301	Pumps - O&M	0.00%	0.7	0	1.7	0	0	N/A
302	Pumps - Controls	0.00%	0.7	0.2	1.7	0	0	N/A
303	Pumps - System Optimization	25.47%	0.7	0.1	1.7	69,828	97,991	71.3%
304	Pumps - Sizing	0.00%	0.7	0.1	1.7	0	0	N/A
305	Pumps - Replace 1-5 HP motor	0.00%	0.7	0.2	1.7	0	0	N/A
306	Pumps - ASD (1-5 hp)	0.00%	0.7	0.2	1.7	0	0	N/A
307	Pumps - Motor practices-1 (1-5 HP)	77.62%	0.7	0.2	1.7	3,952	3,976	99.4%
308	Pumps - Replace 6-100 HP motor	0.00%	0.7	0.2	1.7	0	0	88.3%
309	Pumps - ASD (6-100 hp)	0.00%	0.7	0.2	1.7	0	0	N/A
310	Pumps - Motor practices-1 (6-100 HP)	54.85%	0.7	0.2	1.7	10,050	10,729	93.7%
311	Pumps - Replace 100+ HP motor	65.08%	0.7	0.2	1.7	628	638	98.4%
312	Pumps - ASD (100+ hp)	0.00%	0.7	0.2	1.7	0	0	N/A
313	Pumps - Motor practices-1 (100+ HP)	29.44%	0.7	0.2	1.7	4,401	5,615	78.4%
314	Power recovery	29.44%	0.7	0.2	1.7	0	0	N/A
315	Refinery Controls	29.44%	0.7	0.2	1.7	160	229	69.8%
317	Low Pressure Nozzle	29.44%	0.7	0.2	1.7	0	0	N/A
318	Micro Watering System	29.44%	0.7	0.2	1.7	0	0	N/A
319	Pump Retrofit - Irrigation	29.44%	0.7	0.2	1.7	0	0	N/A
401	Bakery - Process (Mixing) - O&M	0.00%	0.7	0	1.7	0	0	N/A
402	O&M/drives spinning machines	0.00%	0.7	0	1.7	6	19	30.5%
403	Air conveying systems	0.00%	0.7	0.2	1.7	0	0	N/A
404	Replace V-Belts	0.00%	0.7	0.2	1.7	0	0	N/A
405	Drives - EE motor	0.00%	0.7	0.2	1.7	524	1,716	30.5%
406	Gap Forming papermachine	0.00%	0.7	0.2	1.7	0	0	N/A
407	High Consistency forming	0.00%	0.7	0.2	1.7	0	0	N/A
408	Optimization control PM	0.00%	0.7	0.2	1.7	3,329	8,200	40.6%
409	Efficient practices printing press	0.00%	0.7	0.2	1.7	0	0	N/A
410	Efficient Printing press (fewer cylinders)	0.00%	0.7	0.2	1.7	23	54	42.9%
411	Light cylinders	0.00%	0.7	0.2	1.7	1	1	75.6%
412	Efficient drives	0.00%	0.7	0.2	1.7	14	49	28.2%
413	Clean Room - Controls	0.00%	0.7	0.2	1.7	199	569	35.0%
414	Clean Room - New Designs	0.00%	0.7	0.2	1.7	84	160	52.4%
415	Drives - Process Controls (batch + site)	0.00%	0.7	0.2	1.7	206	450	45.8%
416	Process Drives - ASD	0.00%	0.7	0.2	1.7	0	0	N/A
417	O&M - Extruders/Injection Moulding	0.00%	0.7	0	1.7	0	0	N/A
418	Extruders/injection Moulding-multipump	0.00%	0.7	0.2	1.7	23	60	38.4%
419	Direct drive Extruders	0.00%	0.7	0.2	1.7	5	9	52.7%
420	Injection Moulding - Impulse Cooling	0.00%	0.7	0.2	1.7	6	13	44.6%
421	Injection Moulding - Direct drive	0.00%	0.7	0.2	1.7	2	3	61.1%
422	Efficient grinding	0.00%	0.7	0.2	1.7	3	3	77.1%
423	Process control	0.00%	0.7	0.2	1.7	0	0	N/A
424	Process optimization	0.00%	0.7	0.2	1.7	61	137	44.6%
425	Drives - Process Control	0.00%	0.7	0.2	1.7	52	130	39.6%
426	Efficient drives - rolling	0.00%	0.7	0.2	1.7	15	56	26.4%
427	Drives - Optimization process (M&T)	0.00%	0.7	0.2	1.7	0	0	N/A
428	Drives - Scheduling	0.00%	0.7	0	1.7	4	14	30.7%
429	Machinery	0.00%	0.7	0.2	1.7	60	207	29.2%
430	Efficient Machinery	0.00%	0.7	0.2	1.7	2	6	29.5%

501	Bakery - Process	0.00%	0.7	0.2	1.7	0	0	N/A
502	Drying (UV/IR)	0.00%	0.7	0.2	1.7	15	38	40.9%
503	Heat Pumps - Drying	0.00%	0.7	0.2	1.7	2	3	66.6%
504	Top-heating (glass)	0.00%	0.7	0.2	1.7	0	0	N/A
505	Efficient electric melting	0.00%	0.7	0.2	1.7	7	18	38.5%
506	Intelligent extruder (DOE)	0.00%	0.7	0.2	1.7	0	0	79.3%
507	Near Net Shape Casting	0.00%	0.7	0.2	1.7	0	0	N/A
508	Heating - Process Control	0.00%	0.7	0.2	1.7	129	326	39.6%
509	Efficient Curing ovens	0.00%	0.7	0.2	1.7	44	98	44.4%
510	Heating - Optimization process (M&T)	0.00%	0.7	0.2	1.7	0	0	N/A
511	Heating - Scheduling	0.00%	0.7	0	1.7	2	7	30.2%
551	Efficient Refrigeration - Operations	0.00%	0.7	0.2	1.7	0	0	N/A
552	Optimization Refrigeration	54.60%	0.7	0.2	1.7	4,139	4,527	91.4%
601	Other Process Controls (batch + site)	0.00%	0.7	0.2	1.7	1,764	3,902	45.2%
602	Efficient desalter	0.00%	0.7	0.2	1.7	0	1	30.7%
603	New transformers welding	0.00%	0.7	0.2	1.7	48	197	24.3%
604	Efficient processes (welding, etc.)	0.00%	0.7	0.2	1.7	42	172	24.3%
605	Process control	0.00%	0.7	0.2	1.7	0	1	48.2%
606	Power recovery	0.00%	0.7	0.2	1.7	0	0	50.4%
607	Refinery Controls	0.00%	0.7	0.2	1.7	0	0	N/A
701	Centrifugal Chiller, 0.51 kW/ton, 500 tons	83.60%	0.7	1	1.7	11,280	12,628	89.3%
702	High Efficiency Chiller Motors	52.87%	0.7	0.1	1.7	3,089	3,330	92.8%
703	EMS - Chiller	49.26%	0.7	1	1.7	1,110	1,400	79.3%
704	Chiller Tune Up/Diagnostics	56.97%	0.7	0.2	1.7	3,247	3,429	94.7%
705	VSD for Chiller Pumps and Towers	24.58%	0.7	0.5	1.7	8,505	16,612	51.2%
706	EMS Optimization - Chiller	9.43%	0.7	0.1	1.7	171	303	56.6%
707	Aerosole Duct Sealing - Chiller	0.00%	0.7	0.1	1.7	0	0	N/A
708	Duct/Pipe Insulation - Chiller	0.00%	0.7	0.1	1.7	0	0	N/A
709	Window Film (Standard) - Chiller	78.64%	0.7	0.1	1.7	1,016	1,019	99.8%
710	Roof Insulation - Chiller	84.39%	0.4	0.1	1.7	633	633	99.9%
711	Cool Roof - Chiller	0.00%	0.7	0.2	1.7	8	9	88.3%
712	Thermal Energy Storage (TES) - Chiller	0.00%	0.7	0.1	1.7	0	0	N/A
721	DX Packaged System, EER=10.9, 10 tons	0.00%	0.7	1	1.7	27	1,042	2.6%
722	Hybrid Dessicant-DX System (Trane CDQ)	42.94%	0.5	0.1	1.7	724	819	88.4%
723	Geothermal Heat Pump, EER=13, 10 tons	0.00%	0.5	0.1	1.7	0	0	N/A
724	DX Tune Up/ Advanced Diagnostics	64.78%	0.7	0.1	1.7	1,182	1,203	98.2%
725	DX Coil Cleaning	0.00%	0.7	0.1	1.7	0	0	N/A
726	Optimize Controls	0.00%	0.7	0.1	1.7	0	0	N/A
727	Aerosole Duct Sealing	0.00%	0.7	0.1	1.7	0	0	N/A
728	Duct/Pipe Insulation	0.00%	0.7	0.1	1.7	0	0	N/A
729	Window Film (Standard)	67.49%	0.7	0.1	1.7	1,466	1,485	98.7%
730	Roof Insulation	72.66%	0.4	0.1	1.7	1,009	1,019	99.1%
731	Cool Roof - DX	83.93%	0.7	0.2	1.7	19,249	19,282	99.8%
801	Premium T8, Elecctronic Ballast	0.00%	0.7	2	1.7	0	0	N/A
802	CFL Hardwired, Modular 18W	1.74%	0.7	0.1	1.7	883	2,089	42.3%
803	CFL Screw-in 18W	0.00%	0.7	0.1	1.7	0	0	N/A
804	High Bay T5	0.00%	0.7	0.5	1.7	0	0	N/A
805	Occupancy Sensor	38.33%	0.7	0.2	1.7	12,926	15,674	82.5%
901	Replace V-belts	0.00%	0.7	0.2	1.7	0	0	N/A
902	Membranes for wastewater	0.00%	0.7	0.2	1.7	1	1	41.7%
						274,423	352,810	77.8%

FPOPQ.FL
FPOPQ
Population: Total, (Ths.)
BOC; Moody's Analytics
STFOR.db
QUARTERLY
Florida
05/19/2010 updated
06/30/09 historic end

Total Population
Thousands
DFPOP_SC0410.GULF
May Macro

FREGCAR.FL
New Vehicle Registrations: Cars, (#, SAAR)
The Polk Company; Moody's Analytics
QUARTERLY
Florida
May vintage

From EPRI/NRDC study
Electric Power Research Institute
Natural Resources Defense Council

Service Life assumption (yrs)
10

kWh per day assumption
10

	Florida Population	Gulf Population	Ratio of Gulf/Florida Population	Florida New Car Registrations	Estimated Gulf New Car Registrations	PHEV/EV Penetration Assumption	Estimated Annual Registrations of PHEV/EV in Gulf Service Area	Estimated Cumulative no. of PHEV/EV in Gulf Service Area	Estimated Energy consumed by PHEV/EV in Gulf Service Area (kWh)	MWH	GWH
1980	10,029	501	4.994%								
1981	10,336	513	4.967%								
1982	10,609	524	4.943%								
1983	10,893	539	4.953%								
1984	11,194	550	4.911%								
1985	11,508	564	4.900%								
1986	11,833	579	4.893%								
1987	12,154	593	4.883%								
1988	12,464	598	4.795%								
1989	12,835	610	4.749%								
1990	13,212	617	4.674%	790,600							
1991	13,514	631	4.670%	821,186							
1992	13,785	648	4.702%	824,156							
1993	14,082	662	4.701%	871,800							
1994	14,390	674	4.683%	904,258							
1995	14,692	685	4.664%	811,827							
1996	15,021	698	4.650%	793,375							
1997	15,342	714	4.651%	777,154							
1998	15,623	724	4.634%	738,506							
1999	15,902	727	4.573%	759,482							
2000	16,197	732	4.522%	754,442							
2001	16,520	742	4.492%	810,866							
2002	16,826	756	4.493%	729,782							
2003	17,167	767	4.467%	751,028							
2004	17,588	780	4.435%	739,331							
2005	17,953	790	4.399%	707,880							
2006	18,191	796	4.375%	711,375							
2007	18,356	795	4.329%	647,435							
2008	18,485	796	4.309%	556,547							
2009	18,589	798	4.295%	415,641	17,851	0.00%	-	-			
2010	18,742	802	4.280%	436,366	18,677	1.67%	311	311	1,135,150	1,135	1.1
2011	19,005	805	4.237%	507,129	21,485	3.33%	716	1,027	3,748,550	3,749	3.7
2012	19,361	814	4.202%	596,919	25,082	5.00%	1,254	2,281	8,325,650	8,326	8.3
2013	19,793	827	4.177%	636,717	26,597	6.67%	1,773	4,054	14,797,100	14,797	14.8
2014	20,237	842	4.163%	650,652	27,084	8.33%	2,257	6,311	23,035,150	23,035	23.0
2015	20,692	857	4.142%	639,052	26,469	10.00%	2,647	8,958	32,696,700	32,697	32.7
2016	21,170	872	4.121%	632,306	26,059	10.00%	2,606	11,564	42,208,600	42,209	42.2
2017	21,666	888	4.100%	640,574	26,265	10.00%	2,627	14,191	51,797,150	51,797	51.8
2018	22,172	904	4.079%	657,958	26,836	10.00%	2,684	16,875	61,593,750	61,594	61.6
2019	22,687	920	4.057%	674,832	27,380	10.00%	2,738	19,613	71,587,450	71,587	71.6
2020	23,198	937	4.037%	690,703	27,886	10.00%	2,789	22,091	80,632,150	80,632	80.6
2021	23,699	952	4.015%	706,487	28,365	10.00%	2,837	24,212	88,373,800	88,374	88.4
2022	24,194	965	3.991%	721,021	28,773	10.00%	2,877	25,835	94,297,750	94,298	94.3
2023	24,688	979	3.965%	733,224	29,076	10.00%	2,908	26,970	98,440,500	98,441	98.4
2024	25,181	992	3.940%	748,923	29,509	10.00%	2,951	27,664	100,973,600	100,974	101.0
2025	25,671	1,005	3.915%	760,719	29,780	10.00%	2,978	27,995	102,181,750	102,182	102.2
2026	26,160	1,017	3.889%	774,417	30,114	10.00%	3,011	28,400	103,660,000	103,660	103.7
2027	26,653	1,030	3.863%	787,908	30,438	10.00%	3,044	28,817	105,182,050	105,182	105.2
2028	27,147	1,042	3.838%	798,369	30,642	10.00%	3,064	29,197	106,569,050	106,569	106.6
2029	27,648	1,055	3.815%	812,763	31,005	10.00%	3,101	29,560	107,894,000	107,894	107.9
2030	28,147	1,068	3.793%	825,826	31,321	10.00%	3,132	29,903	109,145,950	109,146	109.1
2031	28,636	1,080	3.773%	835,468	31,520	10.00%	3,152	30,218	110,295,700	110,296	110.3
2032	29,118	1,092	3.752%	848,223	31,825	10.00%	3,183	30,524	111,412,600	111,413	111.4
2033	29,584	1,105	3.734%	860,609	32,132	10.00%	3,213	30,829	112,525,850	112,526	112.5
2034	30,019	1,116	3.716%	871,914	32,400	10.00%	3,240	31,118	113,580,700	113,581	113.6
2035	30,423	1,126	3.700%	888,941	32,887	10.00%	3,289	31,429	114,715,850	114,716	114.7

Gulf Power Company
B2011
Exogenous Energy Adjustments Related to Electric Vehicles

		Cumulative Monthly Energy Adjustments MWH	Incremental Monthly Energy Adjustments MWH
2011	JAN	312	312
2011	FEB	625	312
2011	MAR	937	312
2011	APR	1,250	312
2011	MAY	1,562	312
2011	JUN	1,874	312
2011	JUL	2,187	312
2011	AUG	2,499	312
2011	SEP	2,811	312
2011	OCT	3,124	312
2011	NOV	3,436	312
2011	DEC	3,749	312
2012	JAN	4,130	694
2012	FEB	4,511	694
2012	MAR	4,893	694
2012	APR	5,274	694
2012	MAY	5,656	694
2012	JUN	6,037	694
2012	JUL	6,419	694
2012	AUG	6,800	694
2012	SEP	7,181	694
2012	OCT	7,563	694
2012	NOV	7,944	694
2012	DEC	8,326	694
2013	JAN	8,865	1,233
2013	FEB	9,404	1,233
2013	MAR	9,944	1,233
2013	APR	10,483	1,233
2013	MAY	11,022	1,233
2013	JUN	11,561	1,233
2013	JUL	12,101	1,233
2013	AUG	12,640	1,233
2013	SEP	13,179	1,233
2013	OCT	13,719	1,233
2013	NOV	14,258	1,233
2013	DEC	14,797	1,233
2014	JAN	15,484	1,920
2014	FEB	16,170	1,920
2014	MAR	16,857	1,920
2014	APR	17,543	1,920
2014	MAY	18,230	1,920
2014	JUN	18,916	1,920
2014	JUL	19,603	1,920
2014	AUG	20,289	1,920
2014	SEP	20,976	1,920
2014	OCT	21,662	1,920
2014	NOV	22,349	1,920
2014	DEC	23,035	1,920
2015	JAN	23,840	2,725
2015	FEB	24,645	2,725
2015	MAR	25,451	2,725
2015	APR	26,256	2,725
2015	MAY	27,061	2,725
2015	JUN	27,866	2,725
2015	JUL	28,671	2,725
2015	AUG	29,476	2,725
2015	SEP	30,281	2,725
2015	OCT	31,086	2,725
2015	NOV	31,892	2,725
2015	DEC	32,697	2,725
2016	JAN	33,489	3,517
2016	FEB	34,282	3,517
2016	MAR	35,075	3,517
2016	APR	35,867	3,517
2016	MAY	36,660	3,517
2016	JUN	37,453	3,517
2016	JUL	38,245	3,517
2016	AUG	39,038	3,517
2016	SEP	39,831	3,517
2016	OCT	40,623	3,517
2016	NOV	41,416	3,517
2016	DEC	42,209	3,517

	Cumulative Residential MWH	Residential GWH
2010	-	-
2011	3,749	3.7
2012	8,326	8.3
2013	14,797	14.8
2014	23,035	23.0
2015	32,697	32.7
2016	42,209	42.2
2017	51,797	51.8
2018	61,594	61.6
2019	71,587	71.6
2020	80,632	80.6
2021	88,374	88.4
2022	94,298	94.3
2023	98,441	98.4
2024	100,974	101.0
2025	102,182	102.2
2026	103,660	103.7
2027	105,182	105.2
2028	106,569	106.6
2029	107,894	107.9
2030	109,146	109.1
2031	110,296	110.3
2032	111,413	111.4
2033	112,526	112.5
2034	113,581	113.6
2035	114,716	114.7

Check	
3,749	-
8,326	-
14,797	-
23,035	-
32,697	-
42,209	-
51,797	-
61,594	-
71,587	-
80,632	-
88,374	-
94,298	-
98,441	-
100,974	-
102,182	-
103,660	-
105,182	-
106,569	-
107,894	-
109,146	-
110,296	-
111,413	-
112,526	-
113,581	-
114,716	-

2017	JAN	43,008	4,316
2017	FEB	43,807	4,316
2017	MAR	44,606	4,316
2017	APR	45,405	4,316
2017	MAY	46,204	4,316
2017	JUN	47,003	4,316
2017	JUL	47,802	4,316
2017	AUG	48,601	4,316
2017	SEP	49,400	4,316
2017	OCT	50,199	4,316
2017	NOV	50,998	4,316
2017	DEC	51,797	4,316
2018	JAN	52,614	5,133
2018	FEB	53,430	5,133
2018	MAR	54,246	5,133
2018	APR	55,063	5,133
2018	MAY	55,879	5,133
2018	JUN	56,695	5,133
2018	JUL	57,512	5,133
2018	AUG	58,328	5,133
2018	SEP	59,145	5,133
2018	OCT	59,961	5,133
2018	NOV	60,777	5,133
2018	DEC	61,594	5,133
2019	JAN	62,427	5,966
2019	FEB	63,259	5,966
2019	MAR	64,092	5,966
2019	APR	64,925	5,966
2019	MAY	65,758	5,966
2019	JUN	66,591	5,966
2019	JUL	67,423	5,966
2019	AUG	68,256	5,966
2019	SEP	69,089	5,966
2019	OCT	69,922	5,966
2019	NOV	70,755	5,966
2019	DEC	71,587	5,966
2020	JAN	72,341	6,719
2020	FEB	73,095	6,719
2020	MAR	73,849	6,719
2020	APR	74,602	6,719
2020	MAY	75,356	6,719
2020	JUN	76,110	6,719
2020	JUL	76,864	6,719
2020	AUG	77,617	6,719
2020	SEP	78,371	6,719
2020	OCT	79,125	6,719
2020	NOV	79,878	6,719
2020	DEC	80,632	6,719
2021	JAN	81,277	7,364
2021	FEB	81,922	7,364
2021	MAR	82,568	7,364
2021	APR	83,213	7,364
2021	MAY	83,858	7,364
2021	JUN	84,503	7,364
2021	JUL	85,148	7,364
2021	AUG	85,793	7,364
2021	SEP	86,438	7,364
2021	OCT	87,084	7,364
2021	NOV	87,729	7,364
2021	DEC	88,374	7,364
2022	JAN	88,867	7,858
2022	FEB	89,361	7,858
2022	MAR	89,855	7,858
2022	APR	90,348	7,858
2022	MAY	90,842	7,858
2022	JUN	91,336	7,858
2022	JUL	91,829	7,858
2022	AUG	92,323	7,858
2022	SEP	92,817	7,858
2022	OCT	93,310	7,858
2022	NOV	93,804	7,858
2022	DEC	94,298	7,858
2023	JAN	94,643	8,203
2023	FEB	94,988	8,203
2023	MAR	95,333	8,203
2023	APR	95,679	8,203
2023	MAY	96,024	8,203
2023	JUN	96,369	8,203
2023	JUL	96,714	8,203
2023	AUG	97,060	8,203

2023	SEP	97,405	8,203
2023	OCT	97,750	8,203
2023	NOV	98,095	8,203
2023	DEC	98,441	8,203
2024	JAN	98,652	8,414
2024	FEB	98,863	8,414
2024	MAR	99,074	8,414
2024	APR	99,285	8,414
2024	MAY	99,496	8,414
2024	JUN	99,707	8,414
2024	JUL	99,918	8,414
2024	AUG	100,129	8,414
2024	SEP	100,340	8,414
2024	OCT	100,551	8,414
2024	NOV	100,763	8,414
2024	DEC	100,974	8,414
2025	JAN	101,074	8,515
2025	FEB	101,175	8,515
2025	MAR	101,276	8,515
2025	APR	101,376	8,515
2025	MAY	101,477	8,515
2025	JUN	101,578	8,515
2025	JUL	101,678	8,515
2025	AUG	101,779	8,515
2025	SEP	101,880	8,515
2025	OCT	101,980	8,515
2025	NOV	102,081	8,515
2025	DEC	102,182	8,515
2026	JAN	102,305	8,638
2026	FEB	102,428	8,638
2026	MAR	102,551	8,638
2026	APR	102,675	8,638
2026	MAY	102,798	8,638
2026	JUN	102,921	8,638
2026	JUL	103,044	8,638
2026	AUG	103,167	8,638
2026	SEP	103,290	8,638
2026	OCT	103,414	8,638
2026	NOV	103,537	8,638
2026	DEC	103,660	8,638
2027	JAN	103,787	8,765
2027	FEB	103,914	8,765
2027	MAR	104,041	8,765
2027	APR	104,167	8,765
2027	MAY	104,294	8,765
2027	JUN	104,421	8,765
2027	JUL	104,548	8,765
2027	AUG	104,675	8,765
2027	SEP	104,802	8,765
2027	OCT	104,928	8,765
2027	NOV	105,055	8,765
2027	DEC	105,182	8,765
2028	JAN	105,298	8,881
2028	FEB	105,413	8,881
2028	MAR	105,529	8,881
2028	APR	105,644	8,881
2028	MAY	105,760	8,881
2028	JUN	105,876	8,881
2028	JUL	105,991	8,881
2028	AUG	106,107	8,881
2028	SEP	106,222	8,881
2028	OCT	106,338	8,881
2028	NOV	106,453	8,881
2028	DEC	106,569	8,881
2029	JAN	106,679	8,991
2029	FEB	106,790	8,991
2029	MAR	106,900	8,991
2029	APR	107,011	8,991
2029	MAY	107,121	8,991
2029	JUN	107,232	8,991
2029	JUL	107,342	8,991
2029	AUG	107,452	8,991
2029	SEP	107,563	8,991
2029	OCT	107,673	8,991
2029	NOV	107,784	8,991
2029	DEC	107,894	8,991
2030	JAN	107,998	9,095
2030	FEB	108,103	9,095
2030	MAR	108,207	9,095
2030	APR	108,311	9,095

2030	MAY	108,416	9,095
2030	JUN	108,520	9,095
2030	JUL	108,624	9,095
2030	AUG	108,729	9,095
2030	SEP	108,833	9,095
2030	OCT	108,937	9,095
2030	NOV	109,042	9,095
2030	DEC	109,146	9,095
2031	JAN	109,242	9,191
2031	FEB	109,338	9,191
2031	MAR	109,433	9,191
2031	APR	109,529	9,191
2031	MAY	109,625	9,191
2031	JUN	109,721	9,191
2031	JUL	109,817	9,191
2031	AUG	109,912	9,191
2031	SEP	110,008	9,191
2031	OCT	110,104	9,191
2031	NOV	110,200	9,191
2031	DEC	110,296	9,191
2032	JAN	110,389	9,284
2032	FEB	110,482	9,284
2032	MAR	110,575	9,284
2032	APR	110,668	9,284
2032	MAY	110,761	9,284
2032	JUN	110,854	9,284
2032	JUL	110,947	9,284
2032	AUG	111,040	9,284
2032	SEP	111,133	9,284
2032	OCT	111,226	9,284
2032	NOV	111,320	9,284
2032	DEC	111,413	9,284
2033	JAN	111,505	9,377
2033	FEB	111,598	9,377
2033	MAR	111,691	9,377
2033	APR	111,784	9,377
2033	MAY	111,876	9,377
2033	JUN	111,969	9,377
2033	JUL	112,062	9,377
2033	AUG	112,155	9,377
2033	SEP	112,248	9,377
2033	OCT	112,340	9,377
2033	NOV	112,433	9,377
2033	DEC	112,526	9,377
2034	JAN	112,614	9,465
2034	FEB	112,702	9,465
2034	MAR	112,790	9,465
2034	APR	112,877	9,465
2034	MAY	112,965	9,465
2034	JUN	113,053	9,465
2034	JUL	113,141	9,465
2034	AUG	113,229	9,465
2034	SEP	113,317	9,465
2034	OCT	113,405	9,465
2034	NOV	113,493	9,465
2034	DEC	113,581	9,465
2035	JAN	113,675	9,560
2035	FEB	113,770	9,560
2035	MAR	113,864	9,560
2035	APR	113,959	9,560
2035	MAY	114,054	9,560
2035	JUN	114,148	9,560
2035	JUL	114,243	9,560
2035	AUG	114,337	9,560
2035	SEP	114,432	9,560
2035	OCT	114,527	9,560
2035	NOV	114,621	9,560
2035	DEC	114,716	9,560

	Useful Battery capacity kWh	rating	max	min	useable
Chevy Volt	8.8	16	13.6	4.8	8.8
Prius conversion	5	5			5
Nissan Leaf	24	24			24
Average	12.6				

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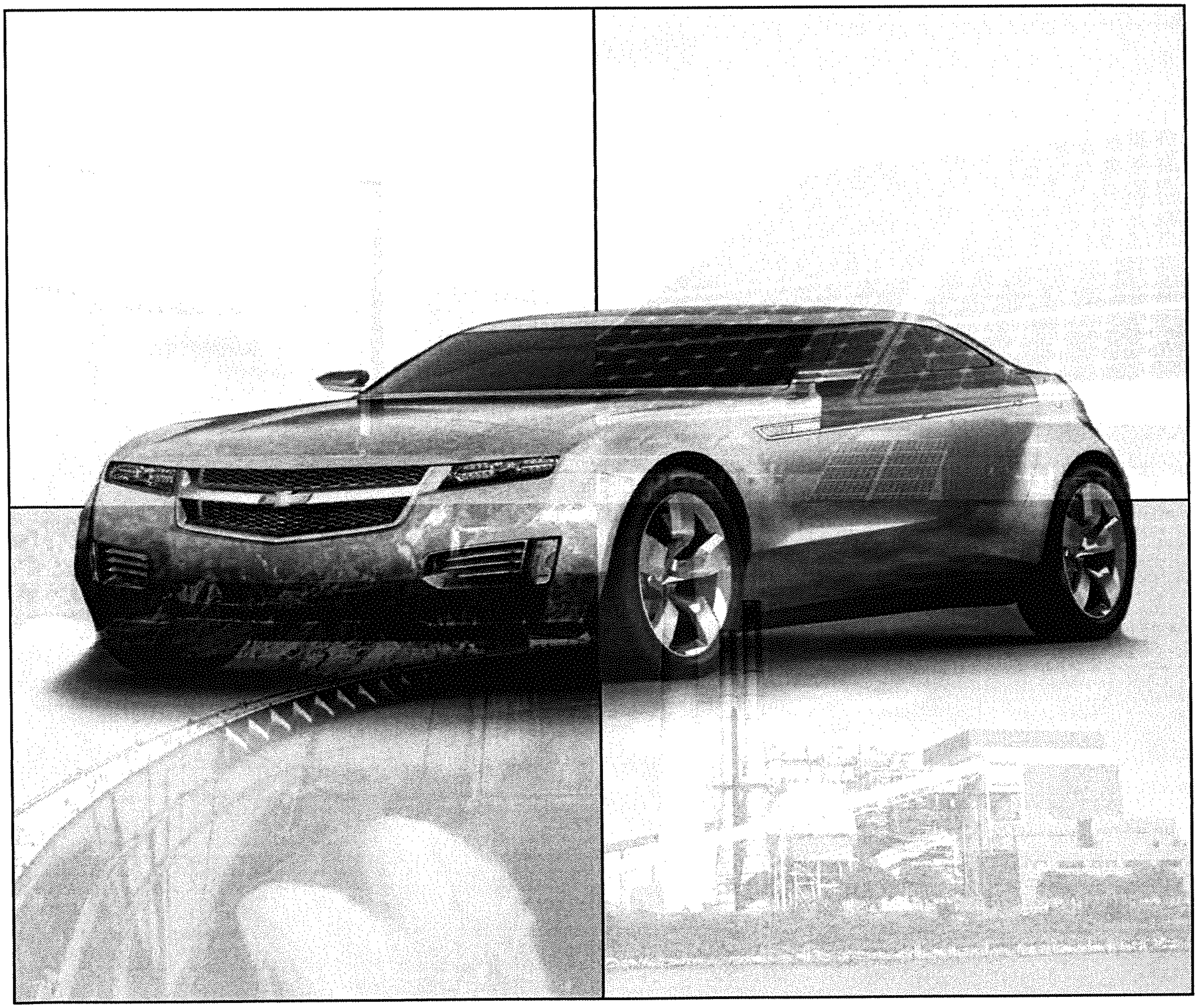
THE EARTH'S BEST DEFENSE

Environmental Assessment of Plug-In Hybrid Electric Vehicles

Volume 1: Nationwide Greenhouse Gas Emissions



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Environmental Assessment of Plug-In Hybrid Electric Vehicles

Volume 1: Nationwide Greenhouse Gas Emissions

1015325

Final Report, July 2007

> *Each of the ... scenarios showed significant Greenhouse Gas reductions due to PHEV fleet penetration ...*
>
> *... PHEVs adoption results in significant reduction in the consumption of petroleum fuels.*

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NRDC
THE EARTH'S BEST DEFENSE

Executive Summary

Environmental Assessment of Plug-In Hybrid Electric Vehicles

Volume 1: Nationwide Greenhouse Gas Emissions

Environmental Assessment of Plug-in Hybrid Electric Vehicles

In the most comprehensive environmental assessment of electric transportation to date, the Electric Power Research Institute (EPRI) and the Natural Resources Defense Council (NRDC) are examining the greenhouse gas emissions and air quality impacts of plug-in hybrid electric vehicles (PHEV). The purpose of the program is to evaluate the nationwide environmental impacts of potentially large numbers of PHEVs over a time period of 2010 to 2050. The year 2010 is assumed to be the first year PHEVs would become available in the U.S. market, while 2050 would allow the technology sufficient time to fully penetrate the U.S. vehicle fleet.

A Collaborative Study

The objectives of this study are the following:

- Understand the impact of widespread PHEV adoption on full fuel-cycle greenhouse gas emissions from the nationwide vehicle fleet.
- Model the impact of a high level of PHEV adoption on nationwide air quality.
- Develop a consistent analysis methodology for scientific determination of the environmental impact of future vehicle technology and electric sector scenarios.

NRDC and EPRI collaborated to conduct this eighteen-month study. The scenarios and key study parameters were generated, analyzed, and approved by both organizations. NRDC contributed its substantial experience in wide-ranging environmental studies, EPRI its operating knowledge of the electric sector and prior simulation and modeling work on plug-in hybrids[1]. Both organizations analyzed, reviewed, and approved of the resulting data and report findings.

Two Study Components, Two Reports

Phase 1 of the study, completed in July 2007, has two major components. The first is a scenario-based modeling analysis to determine the greenhouse gas emissions impacts of PHEVs over a timeframe of 2010 to 2050. The second component is a nationwide air quality analysis for the year 2030 that assumes an aggressive market penetration of PHEVs.

The methodology and findings of these two analyses are presented separately in two technical reports:

- Environmental Assessment of Plug-In Hybrid Electric Vehicles, Volume 1: Nationwide Greenhouse Gas Emissions (1015325)

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[1] Initial study data on PHEV performance characteristics and on future power plant technology availability and performance were drawn from prior EPRI work.

- Environmental Assessment of Plug-In Hybrid Electric Vehicles, Volume 2: United States Air Quality Analysis Based on AEO-2006 Assumptions for 2030 (1015326)

PHEV Impact on Nationwide Greenhouse Gas Emissions

Overview of Study and Results

This report describes the first detailed, nationwide analysis of greenhouse gas (GHG) impacts of plug-in hybrid electric vehicles. The "well-to-wheels" analysis accounted for emissions from the generation of electricity to charge PHEV batteries and from the production, distribution and consumption of gasoline and diesel motor fuels.

Researchers used detailed models of the U.S. electric and transportation sectors and created a series of scenarios to examine assumed changes in both sectors over the 2010 to 2050 timeframe of the study.

- Three scenarios represent high, medium, and low levels of both CO_2 and total GHG[2] emissions intensity for the electric sector as determined by the mix of generating technologies and other factors.
- Three scenarios represent high, medium, and low penetration of PHEVs in the 2010 to 2050 timeframe.

From these two sets of scenarios emerge nine different outcomes spanning the potential long-term GHG emissions impacts of PHEVs, as shown in the following table.

Annual greenhouse gas emissions reductions from PHEVs in the year 2050.

2050 Annual GHG Reduction (million metric tons)		**Electric Sector CO_2 Intensity**		
		High	Medium	Low
PHEV Fleet Penetration	Low	163	177	193
	Medium	394	468	478
	High	474	517	612

Researchers drew the following conclusions from the modeling exercises:

- Annual and cumulative GHG emissions are reduced significantly across each of the nine scenario combinations.
- Annual GHG emissions reductions were significant in every scenario combination of the study, reaching a maximum reduction of 612 million metric tons in 2050 (High PHEV fleet penetration, Low electric sector CO_2 intensity case).
- Cumulative GHG emissions reductions from 2010 to 2050 can range from 3.4 to 10.3 billion metric tons.
- Each region of the country will yield reductions in GHG emissions.

More detailed results are presented below and in Chapter 5 of this report.

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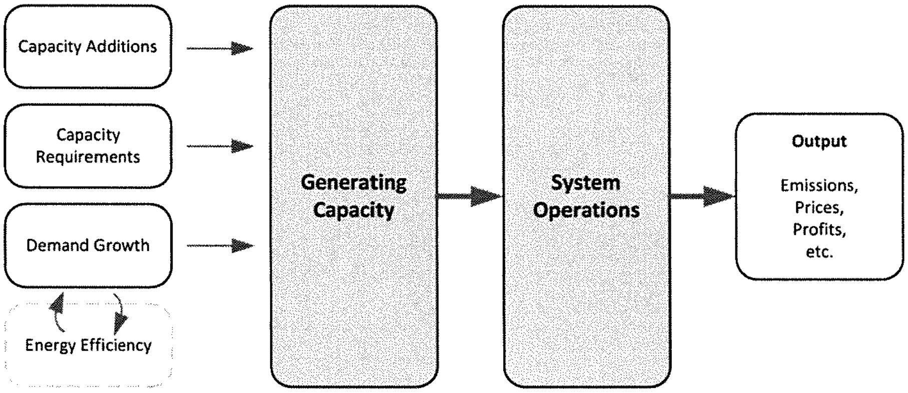
[2] CO_2 is the dominant greenhouse gas resulting from operation of natural gas and coal-fired power plants. Full fuel cycle GHG emissions include N_2O and CH_4, primarily from upstream processes related to the production and transport of the fuel source.

Study Methodology

The project team developed detailed and comprehensive models of the U.S. electric and transportation sectors that simulated the evolution of both sectors over the 2010 to 2050 study timeframe. The researchers also developed a series of scenarios to assess the impact of PHEVs over a range of different possible futures depending on the evolution of the energy and transportation sectors.

Electric Sector Model

To determine the GHG emissions from the electricity generated to charge PHEV batteries, EPRI developed a modeling framework that provides a detailed simulation of the electric sector. The EPRI framework integrates two sophisticated computer models. The first model, the Energy Information Agency's National Energy Modeling System (NEMS) covers the entire U.S. energy-economy system and calculates energy supply and demand nationwide. NEMS outputs—prices and electric loads—are the inputs to the second model, the EPRI National Electric System Simulation Integrated Evaluator (NESSIE). The NESSIE model represents the U.S. electricity sector from 2010 to 2050.



Structure of U.S. Electric Sector Model (NESSIE)

The model simulates decisions to add new capacity and to retire existing capacity. This component is extremely important for tracking the evolution of the generation capacity over time as it serves existing load and new load from PHEV charging. New generating capacity is generally lower in GHG emissions than existing capacity. Capacity retirements increase the rate at which newer, lower emitting capacity is created. In addition, NESSIE simulates how technologies change over time, including gradual performance improvements for commercially available technologies such as combustion turbines or the emergence of advanced technologies such as Integrated Gasification Combined Cycle (IGCC) coal plants. Technology improvement is an important factor for reducing the GHG intensity of the future electric grid.

After simulating capacity additions and retirements, the model operates this capacity to meet electricity demand. Electric sector analysts call this a "production simulation" or "dispatch." The load varies across the year. Each generating technology has a bid price for energy that it offers to the market based on its variable cost of production. The market selects the lowest possible bids. The price for all operating generators is set by the technology with the highest bid price that is operating at the time. This production simulation identifies the load served by every technology, cost of electricity, and emissions of SO_2, NOx, Hg, and GHG.

The electric sector model of the United States is divided into 13 distinct study regions based on the North American Electric Reliability Corporation (NERC) Regional Reliability Councils and Federal Energy Regulatory Commission (FERC) regions. The representation of these regions allows a careful accounting of how different regional capacity mixes affect GHG emissions.

Electric Sector Scenarios

The future of the U.S. electric sector may follow different paths, depending on the evolution of environmental policies, electricity demand, and available technologies. Rather than trying to develop a single consensus view, the team created three scenarios to span the impact of PHEVs over different possible futures.

The scenarios represent different levels of CO_2 intensity for the sector.

1. High CO_2 intensity scenario: There is limited availability of higher efficiency and non-emitting generation technologies and a low cost associated with allowances to emit CO_2 and other GHGs in this scenario. Total annual electric sector GHG emissions increase by 25% from 2010 to 2050.
2. Medium CO_2 intensity scenario: Advanced renewable and non-emitting generation technologies, such as biomass and IGCC with carbon capture and storage, are available in this scenario. There is a moderate cost associated with allowances to emit CO_2 and other GHGs. Total annual electric sector emissions decline by 41% between 2010 and 2050.
3. Low CO_2 scenario: Carbon capture and storage retrofit technology for existing coal plants are available in this scenario. In addition, there is significantly slower load growth indicative of a nationwide adoption of energy efficiency, or other demand reduction, and a high cost to emit CO_2 and other GHGs. Total electric sector emissions decline by 85% in this scenario from 2010 to 2050.

The NESSIE model was used to model each of the above scenarios and to output the detailed results. Each scenario used a different set of input data and was run through the entire model to produce the measures of interest. The following table shows the key differences among electric sector scenarios.

Key parameters of the High, Medium, and Low CO_2 Intensity electric scenarios.

Scenario Definition	High CO_2 Intensity	Medium CO_2 Intensity	Low CO_2 Intensity
Price of Greenhouse Gas Emission Allowances	Low	Moderate	High
Power Plant Retirements	Slower	Normal	Faster
New Generation Technologies	Unavailable: Coal with CCS New Nuclear New Biomass	Available: IGCC Coal with CCS New Nuclear New Biomass Advanced Renewables	Available: Retrofit of CCS to Existing IGCC and PC Plants
	Lower Performance: SCPC, CCNG, GT, Wind, and Solar	Nominal EPRI Performance Assumptions	Higher Performance: Wind and Solar
Annual Electricity Demand Growth	1.56% per year on average	1.56% per year on average	2010-2025: 0.45% 2025-2050: None

PC – Pulverized Coal
SCPC – Supercritical Pulverized Coal
CCNG – Combined Cycle Natural Gas
GT – Gas Turbine (Natural Gas)
CCS – Carbon Capture and Storage

Vehicle Emissions Model

The vehicle emissions model represents the energy consumption and other performance attributes of three vehicle types: PHEVs, hybrid electric vehicles (HEVs), and conventional vehicles (CV) powered by internal combustion engines. The model also represents the penetration rate of each configuration across multiple vehicle categories (passenger cars to light trucks) throughout the 48 continental United States over the 2010-2050 timeframe.

The study assumes that PHEVs will be available in vehicles up to 19,500 lb gross vehicle weight (Class 5 Heavy Duty Vehicles). PHEVs will also be available in configurations offering different levels of electric range—the number of miles a vehicle can travel on the energy in its battery for a single charge. A vehicle's electric range is denoted by attaching the electric range after the term PHEV. For example, a PHEV 10 is a plug-in hybrid with 10 miles of electric range.

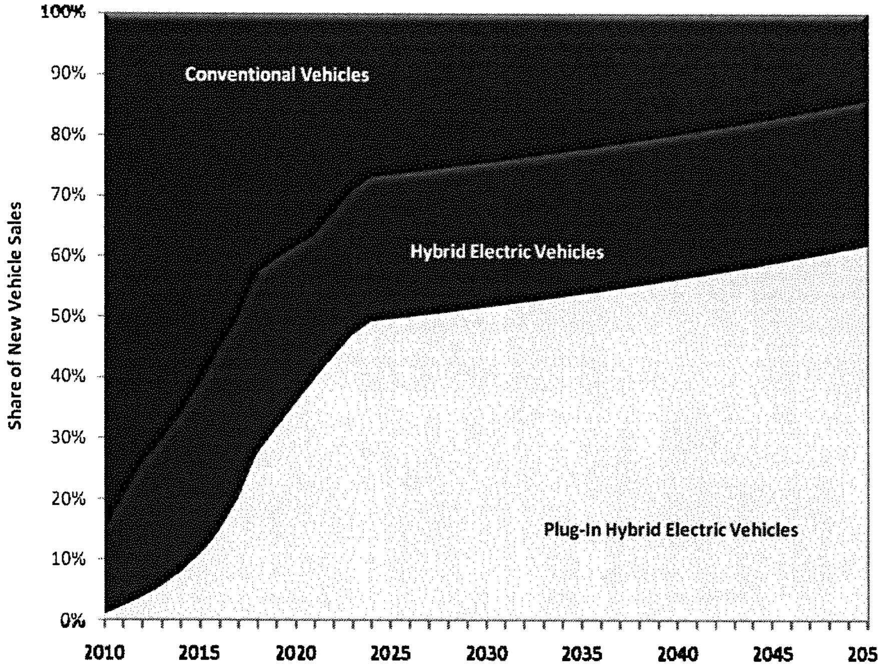
The use of electricity is an important attribute of PHEVs. Use of electricity reduces both gasoline consumption and emissions—starting emissions, refueling emissions, running emissions and even upstream refinery emissions.

Market Adoption

The project team developed three distinct market adoption scenarios, each based on PHEVs entering the market in 2010 and achieving maximum new vehicle market share in 2050. As shown in the following table, PHEVs reach a maximum of 20% new vehicle market share in the Low PHEV scenario, 62% in the Medium PHEV scenario, and 80% in the High PHEV scenario.

Peak new vehicle market share in 2050 for the three PHEV adoption scenarios

2050 New Vehicle Market Share by Scenario		Vehicle Type		
		Conventional	Hybrid	Plug-In Hybrid
PHEV Fleet Penetration Scenario	Low PHEV Fleet Penetration	56%	24%	20%
	Medium PHEV Fleet Penetration	14%	24%	62%
	High PHEV Fleet Penetration	5%	15%	80%

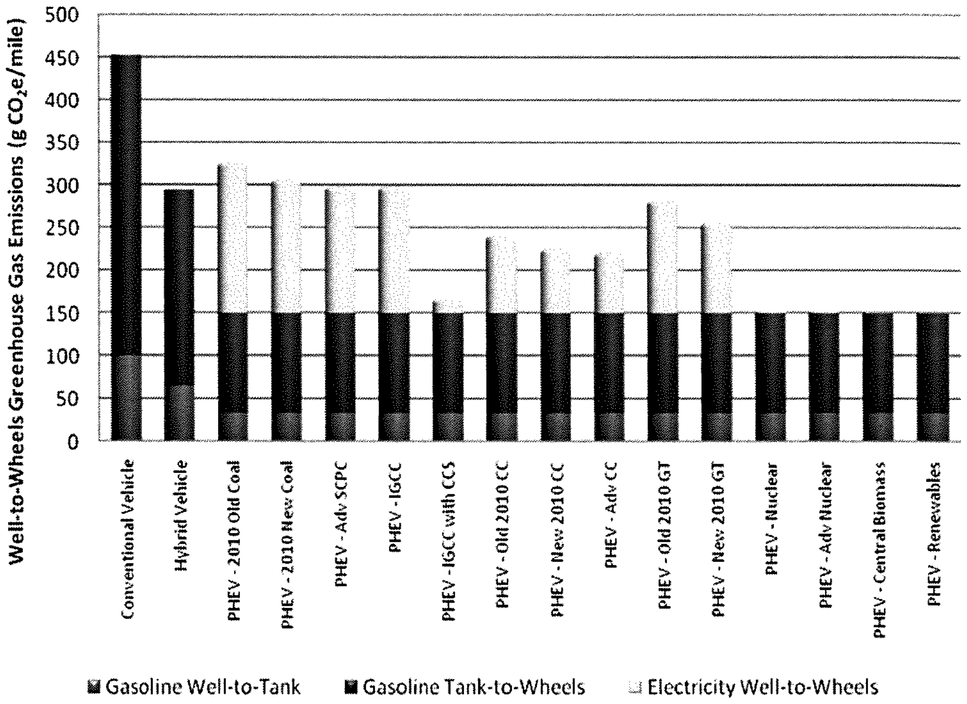


Assumed new car market share for the Medium PHEV scenario for conventional vehicles, hybrid electric vehicles, and plug-in hybrid electric vehicles for each vehicle category

Results

Emissions Decline as Electric and Transportation Sectors Evolve

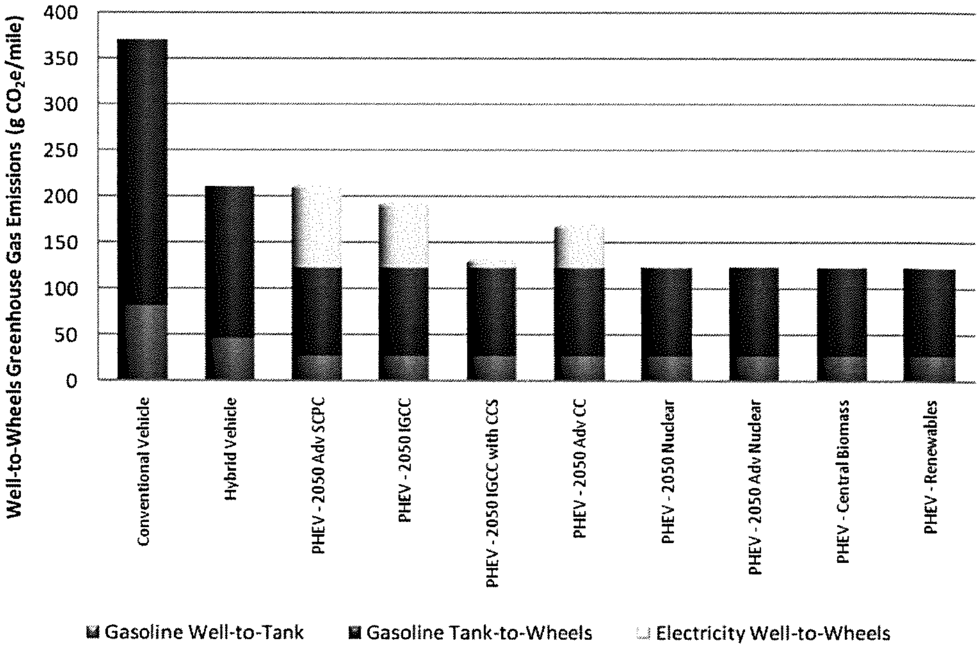
The study generated a wealth of information that enables researchers to examine the GHG emissions impacts of different vehicle categories and generating technologies over time. The following figure is a year 2010 comparison of total GHG emissions from conventional vehicles, hybrid electric vehicles, and a PHEV with 20 miles of all-electric range for a typical case of 12,000 miles driven per year. For PHEVs, the figure includes GHG emissions associated with all-electric and hybrid-electric operation.



Year 2010 comparison of PHEV 20 GHG emissions when charged entirely with electricity from specific power plant technologies (12,000 miles driven per year).

From this figure, it is clear that the carbon intensity of the generation technology plays a significant role in the total GHG emissions from PHEVs. In 2010, current coal technologies result in 28% to 34% lower GHG emissions compared to the conventional vehicle and 1% to 11% higher GHG emissions compared to the hybrid electric vehicle.

In year 2050, however, GHG emissions fall as higher emitting technologies are assumed to phase out of the electric generating fleet. In 2050, vehicle efficiency has improved, so all three components of well-to-wheel GHG emissions are lower. The PHEV 20 produces approximately the same GHG emissions as an HEV if powered by electricity from coal-fired power plants that do not capture CO_2, and has 37% lower GHG emissions than the HEV if powered by coal-fired power plants with CO_2 capture and storage.



Year 2050 comparison of PHEV 20 GHG emissions charged entirely with electricity from specific power plant technologies (12,000 miles driven per year)

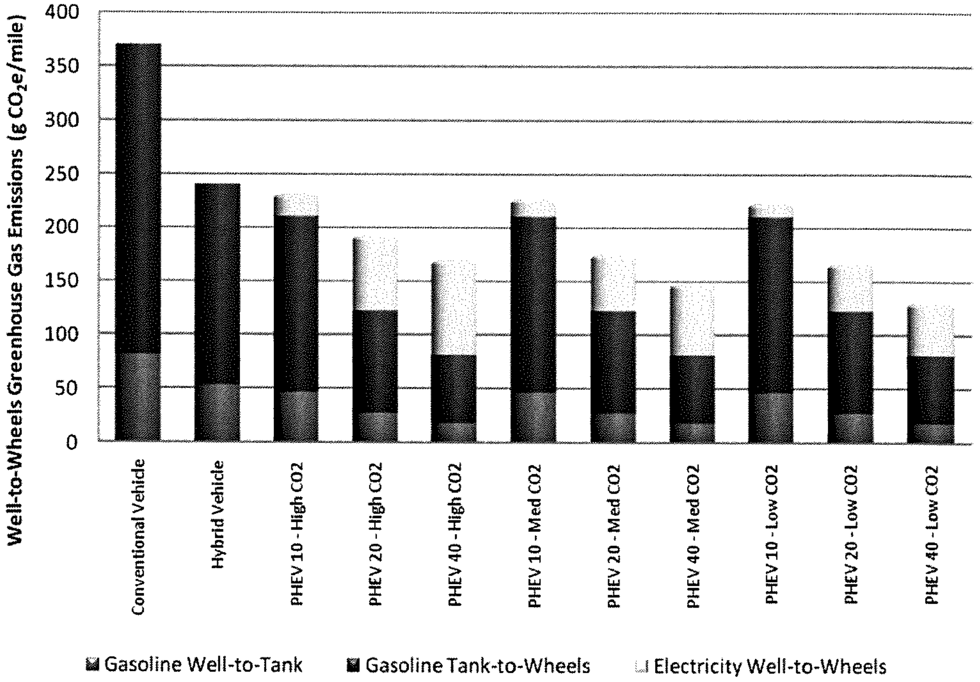
Electric Sector Simulation Results

The preceding examples show the strong dependence of PHEV GHG emissions on the source of electricity. In reality, PHEVs will not be drawing power solely from individual generating technologies but rather from a mix of resources that include fossil, nuclear, hydroelectric and renewable technologies.

Total system emissions from a given level of PHEV use will be determined by a combination of the vehicle type (PHEV with a 10, 20 or 40 miles of electric range), annual vehicle miles traveled by vehicle type, and the types of generating resources that are built and dispatched to serve the electrical load from grid-connected PHEVs.

The following figure compares GHG emissions of model year 2050 conventional and hybrid vehicles to the three PHEV types (10, 20 and 40 miles of electric range) in each of the three electric sector scenarios (High CO_2, Medium CO_2, and Low CO_2 Intensity).

PHEVs have lower GHG emissions in all nine cases than either the conventional or the hybrid vehicles, ranging from a 40% to 65% improvement over the conventional vehicle to a 7% to 46% improvement over the hybrid electric vehicle.



Year 2050 comparison of PHEV GHG emissions from within the High CO_2, Medium CO_2, and Low CO_2 Intensity electric sector scenarios (12,000 miles driven per year)

EPRI Perspective

This report describes a study to explore the air quality impacts of large numbers of plug-in hybrid electric vehicles (PHEVs) in year 2030 using a combination of transportation-sector, electric-sector and atmospheric (air quality) models.

PHEVs represent an important technical step toward increased fuel efficiency, decreased emissions, and greater energy independence. EPRI has supported the development of PHEV technology and continues to support its deployment with collaborative R&D and analyses.

Policymakers, technology developers, and utility and environmental planners need objective and accurate information to make sound decisions about developing and deploying PHEVs in support of national energy and environmental policy. PHEVs offer the potential for reducing both emissions and fuel consumption, simultaneously addressing the issues of global warming and the nation's dependence on imported oil. Quantifying these benefits has proved challenging, however, and misinformation has circulated about the environmental performance of PHEVs.

The objective of this study was to evaluate the impact of PHEVs on key air quality parameters for a future-year scenario with substantial penetration of PHEVs in the U.S. light-duty vehicle fleet (passenger cars and light-trucks).

This study is one component of a comprehensive environmental assessment of PHEVs conducted in collaboration with the Natural Resources Defense Council (NRDC). A second component is a nationwide analysis of the nationwide impacts on air quality of a large PHEV fleet in the year 2030. Results of the air quality analysis are presented in an EPRI technical report, Environmental Assessment of Plug-In Hybrid Electric Vehicles, Volume 2: United States Air Quality Analysis Based on AEO-2006 Assumptions for 2030 (1015326).

Study findings will help support informed decision-making regarding PHEV development and deployment in support of national energy and environmental policy. Study results will also dispel misunderstandings about PHEVs and emissions—such as the common misunderstanding that PHEVs would worsen air quality due to emissions from electricity generation for battery charging.

NRDC Perspective

The Natural Resources Defense Council's purpose is to safeguard the Earth: its people, its plants and animals and the natural systems on which all life depends. The organization uses law, science, and the support of its members to promote solutions to our environmental challenges.

- Participation in this study does not imply NRDC endorses the power plant emission control assumptions in the air quality report. The study's air quality modeling and analysis are based on an assumption that regulatory caps govern NOx, SO_2 and mercury emissions during the study period, and that EPA rules do not change during the study time horizon. However, the actual situation is more complex—for example, a number of states have declined to participate in EPA's model cap-and-trade rule for mercury in favor of more stringent approaches. In addition, EPA's Clean Air Mercury Rule and Clean Air Interstate Rule (resulting in tighter NOx and SO_2 caps in the eastern U.S.) are currently being challenged in court. NRDC firmly believes that stronger emissions controls are necessary to protect human health. This study does not attempt to determine the adequate level of power plant controls or adequate levels of ambient air pollution and strives only to determine the specific impacts of large-scale PHEV penetration given the assumptions of the study.
- NRDC does not support trading off pollution benefits in some regions for pollution increases in others regions. NRDC believes that no areas or populations should be allowed to experience increases in air pollution exposures and that further emission controls from all sources are needed in order to protect public health. Consequently, NRDC supports more stringent emissions control requirements for the electric and transportation sectors, as well as other economic sectors.
- NRDC does believe that with sufficient emissions controls in place PHEVs have the potential to improve air quality and to substantially contribute to meeting our long term GHG reduction goals of 80% below 1990 levels by 2050.
- NRDC supports the introduction of PHEVs accompanied by substantial additional improvements in power plant emission rates. In areas where there are potential adverse impacts from air pollution as a result of PHEV charging, NRDC believes it is not appropriate to promote introduction until the public can be assured that air pollution will not increase.

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1 Introduction

National interest in electric transportation, particularly plug-in hybrid electric vehicles (PHEVs), has increased dramatically. In addition to near-daily media exposure and the strong support of scientists, politicians, and other prominent figures, PHEVs are now receiving very strong support from the federal government. The Energy Policy Act of 2005 contained language supporting PHEVs and directed the Department of Energy to initiate the formation of PHEV research and development effort under the FreedomCAR and Vehicle Technologies Program. PHEVs were also featured prominently as one of four strategic technologies for the reduction of U.S. petroleum dependence in the Advanced Energy Initiative developed by the National Economic Council. Major automobile manufacturers have earmarked PHEV development as part of a strategy to develop alternate fuel vehicle options.

Much of this interest is based on the potential societal benefits of electrifying transportation in general, and PHEVs in particular, including:

- A reduction in petroleum consumption leading to reduced dependence on imported oil and increased energy security;
- A net reduction in greenhouse gas emissions due to the electrification of transportation; and
- The potential to improve air quality, particularly in urban areas with high levels of vehicle-related pollution.

Environmental Assessment of Plug-In Hybrid Electric Vehicles

This study was conducted by the Natural Resources Defense Council (NRDC) and the Electric Power Research Institute (EPRI). The motivation for this study is to address critical and persistent knowledge gaps regarding the environmental impacts from the use of electricity as a transportation fuel, specifically:

- Net effect of PHEVs on vehicle fleet greenhouse gas emissions
- Impact of widespread use of electricity as a transportation fuel on air quality

These issues are separately addressed by two distinct reports:

Environmental Assessment of Plug-In Hybrid Electric Vehicles, Volume 1: Nationwide Greenhouse Gas Emissions (1015325)

Environmental Assessment of Plug-In Hybrid Electric Vehicles, Volume 2: United States Air Quality Analysis Based on AEO-2006 Assumptions for 2030 (1015326)

The objectives of this study are the following:

- Understand the impact of widespread PHEV adoption on full fuel-cycle greenhouse gas emissions from the nationwide vehicle fleet.
- Model the impact of a high level of PHEV adoption on nationwide air quality.
- Develop a consistent analysis methodology for scientific determination of the environmental impact of future vehicle technology and electric sector scenarios.

NRDC and EPRI collaborated to conduct this eighteen-month study. The scenarios and key study parameters were generated, analyzed, and approved by both organizations. NRDC contributed its substantial experience in wide-ranging environmental studies, EPRI its operating knowledge of the electric sector and prior simulation and modeling work on plug-in hybrids[1]. Both organizations analyzed, reviewed, and approved of the resulting data and report findings.

Plug-In Hybrid Electric Vehicles

Plug-in hybrid electric vehicles combine operational aspects of both battery electric vehicles (BEVs) and power-assist hybrid electric vehicles (HEVs). A PHEV, like a BEV, can be recharged from the electric grid, stores significant energy in an onboard battery, and then uses this energy, depleting the battery, during daily driving. Unlike a BEV, a PHEV has an internal combustion engine that is also used for propulsion, therefore never suffering from a "dead" battery. Due to this versatility, a PHEV can serve as a direct replacement for a conventional internal combustion engine vehicle (ICEV or CV) or HEV.

The potential of PHEV technology is primarily due to their close technological kinship with hybrid vehicles. Hybrid vehicles with sophisticated, high-power traction drive systems, power electronics, and high-voltage systems are already in the marketplace. PHEVs leverage much of this existing technology foundation—the primary difference is the incorporation of an "energy" battery that allows the PHEV to directly use grid electricity for propulsion.

A number of significant environmental benefits accompany the use of grid electricity in a plug-in hybrid. Electricity is produced largely from diverse domestic resources, in contrast to the high level of dependence on imported petroleum in the transportation sector. PHEVs can reduce direct emissions at the vehicle, with positive implications for transportation-dense urban areas that suffer from poor air quality due to mobile-source emissions. PHEVs recharged by electricity produced by efficient combustion, non-emitting, or renewable generation technologies will emit significantly lower fuel-cycle greenhouse gas emissions than either conventional or hybrid vehicles.

Definition of Greenhouse Gas Emissions

Carbon dioxide (CO_2) is the dominant greenhouse gas emitted by the combustion of fossil fuels in electric generating units (EGUs) or internal combustion engines in automobiles. CO_2 is a stable product of combustion (along with water). There are two other components common in fuel combustion emissions that also exhibit a global warming potential: methane (CH_4) and nitrous oxide (N_2O). While typically emitted in trace amounts, both demonstrate many times the global warming potential of CO_2—a given mass of CH_4 has approximately 23 times the global warming impact as the equivalent mass of CO_2. For N_2O, the multiple is 296[2]. In this study, greenhouse gas emissions are always shown as "carbon dioxide equivalents", or CO_2e using the following formula:

$$CO_2e = CO_2 + 23 \times CH_4 + 296 \times N_2O$$

In this study, the terms *"greenhouse gas (GHG) emissions"* and *"CO_2e emissions"* are used interchangeably.

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[1] Initial study data on PHEV performance characteristics and future power plant technology availability and performance were derived from EPRI based on prior studies.

[2] Intergovernmental Panel on Climate Change, *Climate Change 2001: The Scientific Basis* (Cambridge, UK: Cambridge University Press, 2001).

2

Electric Sector Model

A detailed simulation of the electric sector is necessary to determine the emissions associated with the electricity used to charge PHEVs. This simulation must take into account the location and time of the increased load on the electric grid. EPRI has developed an electric sector model to calculate the GHG emissions of PHEV charging electricity (for a given fleet penetration timeline) in five year time steps on a 2010 to 2050 timeframe. This timeframe was chosen since PHEVs — as with any new automotive technology — would require several years to achieve significant fleet penetration.

Modeling Framework

Figure 2-1 shows a top level depiction of the models used to study GHG emissions from the electric sector. The modeling framework starts by running the Energy Information Agency's (EIA) National Energy Modeling System (NEMS)[3]. This model covers the economics of the entire U.S. energy system and calculates a supply and demand based on its inputs.

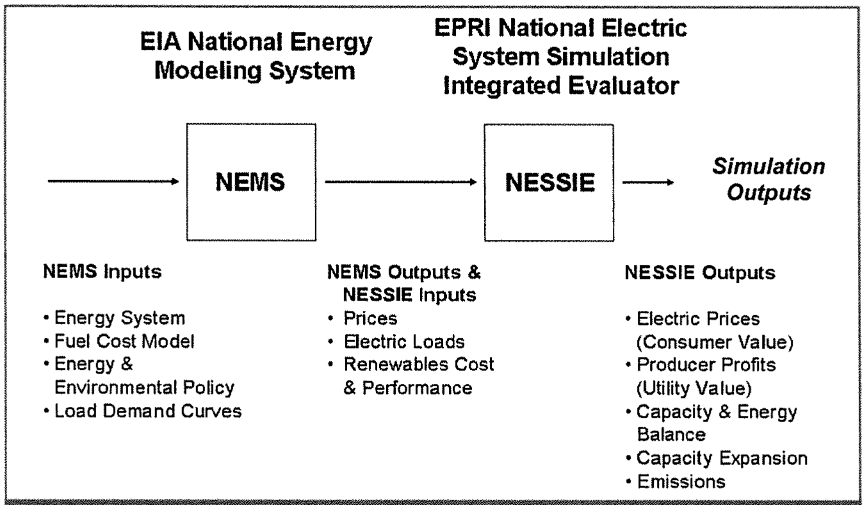

Figure 2-1
Input and Outputs of the Models Used to Calculate Grid CO_2e Impacts

The role of NEMS is to incorporate nationwide information on the U.S. energy system and to output relevant data required for electric sector modeling. This includes estimating the future prices of fuels and emissions allowances, based on demand as well as energy and environmental policies. Electricity load demand curves dictate the quantity of electrical energy required for delivery by the electric sector over time.

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[3] *The National Energy Modeling System: An Overview 2003.* Energy Information Administration, Washington D.C., DOE/EIA-0581 (2003).

The EPRI National Electric System Simulation Integrated Evaluator (NESSIE) modeling framework used is a representation of the U.S. electric sector.[4, 5,6] In this study, both NEMS and NESSIE are run in five-year time steps from 2010 to 2050.

The basic model structure is shown below in **Figure 2-2**. The analysis tracks the evolution of the electric system over time, particularly important for the PHEV technology that will take a significant amount of time to alter the on-the-road fleet through new vehicle sales.

Varying Electrical Demand

The model requires an estimate of the demand for electricity as an input, which is supplied by NEMS. The demand received from NEMS can be altered by changes in customer loads. This is denoted by the energy efficiency box in Figure 2-2.

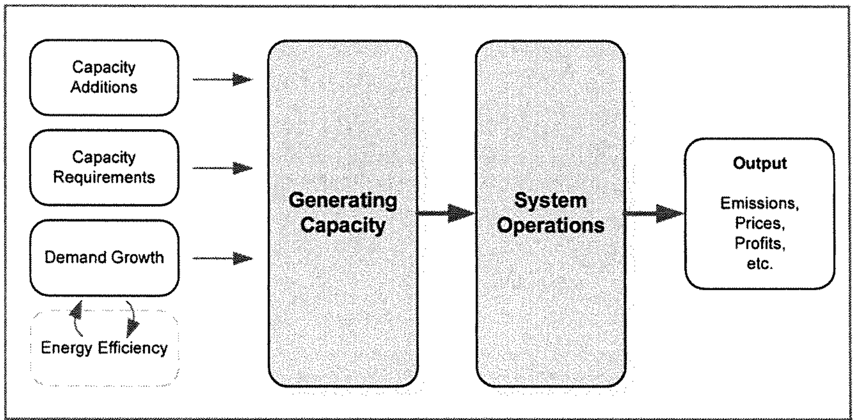

Figure 2-2
Structure of U.S. Electric Sector Model (NESSIE)

Modeling different PHEV market penetration scenarios has the effect of altering demand by increasing customer loads. This incremental load requires a specification of its timing so that it can augment the NEMS load. This allows the NESSIE model to track the impact of the new load on system energy and capacity needs as well as allowing delineation of the generating units that will serve the loads.

Marginal Modeling

A "marginal" or incremental modeling approach is used to forecast the GHG emissions that result from the PHEV scenarios. The purpose of this modeling is to determine specific changes that occur in both the evolution of electric sector capacity and how this capacity is dispatched to serve the new load represented by the charging of PHEVs. The marginal results from NESSIE output are more useful in determining the specific impacts of PHEV charging to the electric grid.

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[4] *Evaluating the Potential Effects of Environmental Regulation and Other Variables on Future Non-Emitting Generation Profitability.* Palo Alto, CA: 1007732.

[5] *Preliminary Analysis of the Role of Nuclear Power in Achieving a Sustainable Electric System.* Palo Alto, CA: 1011513.

[6] *Program on Technology Innovation: Analysis of the Role of Nuclear Power in Achieving a Sustainable Electric System.* Palo Alto, CA: 1011772.

Capacity Retirement and Expansion

The model simulates decision-making within the electric sector to add new capacity and to retire existing capacity. This component is extremely important for tracking the evolution of the generation capacity over time as it serves existing load and new load from PHEV charging. New capacity that is added over the model time horizon is generally lower in GHG emissions than the current generating capacity. Capacity retirements increase the rate at which newer, lower emitting capacity is created. In addition, NESSIE simulates how technologies change over time, including gradual performance improvements for commercially available technologies such as combustion turbines or the emergence of advanced technologies such as Integrated Gasification Combined Cycle (IGCC) coal plants. Technology improvement is an important factor for reducing the GHG intensity of the future electric grid.

In the model, decision-making algorithms simulated capacity choices from among the alternative generation technologies based on their costs, which represent additional model inputs. The costs cover all of the cash flows that occur over the operating life of the technology, including those for capital costs and all commodities. Commodities include fuel and allowances for SO_2, NOx, Hg, and CO_2 emissions. The prices for these emissions allowances are also sensitive to the quantities of emissions, through an elasticity of supply. All cash flows are present valued to startup and divided by the plant output to produce a $/MWh measure that may be compared across technologies. Thus, technologies with higher capital costs and lower operating costs can compete with options having lower capital costs and higher operating costs. The model also recognizes three duty cycles—baseload, intermediate, and peaking service—so that the chosen capacity mix reflects the different economics of the different cycles.

Dispatch Modeling

After simulating the capacity additions and retirements, the model operates this capacity to meet the electricity demand. Electric sector analysts call this a "production simulation" or "dispatch modeling." The load varies across the year. The capacity available to serve the load depends on both planned (maintenance) and unplanned (forced) outages. Since forced outages are random, the model solves for system operations with several different available capacities, and it combines these results using the likelihood of each capacity state. Each technology has a bid price for energy that it offers to the market based on its variable cost of production. The market selects the lowest possible bids. The price for all operating generators is set by the technology with the highest bid price that is operating at the time. This production simulation identifies the load served by every technology, cost of electricity, and emissions of SO_2, NOx, Hg, and GHG.

The electric sector model of the United States is divided into thirteen distinct study regions based on the North American Electric Reliability Corporation (NERC) Regional Reliability Councils and Federal Energy Regulatory Commission (FERC) regions. The members of these Regional Reliability Councils comprise all segments of the electric industry, including investor-owned utilities; public utilities; federal power agencies; rural electric cooperatives; and independent power producers and marketers. The existence of the regions allows a careful accounting of how different regional capacity mixes affect GHG emissions and presents the opportunity to make some preliminary comments on the regional GHG impacts of the PHEV.

Power Plant Technologies

The power plant technologies used in NESSIE are an important determinant in electric sector carbon intensity. In this study NESSIE incorporates eighteen different generation technologies. Fourteen technologies are thermal plants based on coal, natural gas, oil, nuclear power, and biomass. There are additional renewable technologies based on geothermal, wind, solar, and hydroelectric. The thermal technologies are defined below, and the heat rate and greenhouse gas emissions performance of each are listed in **Table 2-1**.

The cost, performance, and other characteristics of these generation technologies are derived from EPRI data and extensive experience with fossil, nuclear, and renewable generation technologies.[7] With respect to the performance of future technologies, the assumptions used in this report represent consensus industry and supplier views on the rate of improvement in plant technology.

Coal

- *Old 2010 Coal* – Older subcritical pulverized coal (PC) plants in operation in 2010. This technology has the highest emissions and operating and maintenance costs (O&M) of the PC plants.
- *New 2010 Coal* – Newer, slightly more efficient pulverized coal plants in operation in 2010.
- *Advanced SCPC* – More efficient, lower emitting, supercritical PC plants built in 2010 or later.
- *IGCC* – Integrated Gasification Combined Cycle coal plants built in 2010 or later, without carbon capture and storage (CCS).
- *IGCC with CCS* – Integrated Gasification Combined Cycle coal plants built in 2010 or later, with carbon capture and storage (CCS).

Natural Gas

- *Old 2010 CC* – Combined cycle natural gas plants in operation in 2010.
- *New 2010 CC* – New combined cycle natural gas plants in operation in 2010. Plant efficiency and O&M costs are significantly improved over Old 2010 CC.
- *Advanced CC* – Improved efficiency combined cycle plants built in 2010 or later.
- *Old 2010 GT* – Older gas turbine "peaking" plants in operation in 2010
- *New 2010 GT* – Newer, more efficient gas turbine peaking plants either in operation or built after 2010.

Oil/Gas

- *Oil/Gas Boiler* – Older gas-fired or oil-fired plants in operation in 2010. No further plants of this type are built in the future.

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[7] *Role of Renewable Energy in Sustainable Electricity Generation Portfolios: Preliminary Results and Next Steps.* EPRI, Palo Alto, CA: 2007. 1012730.

Nuclear

- *Nuclear* – Existing light-water reactors of current generation of technology either in operation in 2010 or built during the study horizon.
- *Advanced Nuclear* – Next-generation nuclear plants built after 2010 with lower heat rate and improved O&M costs.

Biomass

- *Central Biomass* – Central station biomass plants either in operation in 2010 or built after 2010.

Other Renewable Generation

In addition to central biomass, other renewable technologies include geothermal, central station solar, wind, and hydroelectric generation. In this study all are considered non-emitting with respect to greenhouse gas emissions. The study also assumes zero marginal availability of new hydroelectric capacity.

Table 2-1
EPRI cost and performance data of thermal power plant technologies used by NESSIE. Plant heat rate and greenhouse gas emissions performance is shown in 2010 and 2050

Technology	Fuel Type	2010 Heat Rate (Btu/kWh)	2010 GHG Emissions (gCO_2e/kWh)	2050 Heat Rate (Btu/kWh)	2050 GHG Emissions (gCO_2e/kWh)
Old 2010 Coal	Coal	10,500	1,041	10,500	1,041
New 2010 Coal	Coal	9,300	922	9,300	922
Advanced Coal (SCPC)	Coal	8,800	872	6,539	649
IGCC	Coal	8,800	872	5,144	510
IGCC with CCS	Coal	11,300	100	8,292	73
Old 2010 CCNG	Natural Gas	9,000	538	9,000	538
New 2010 CCNG	Natural Gas	7,440	445	7,002	419
Advanced CCNG	Natural Gas	7,000	419	5,725	342
Old 2010 GT	Natural Gas	13,000	778	13,000	778
New 2010 GT	Natural Gas	10,500	628	8,109	485
Oil/Gas Boiler	Oil/Gas	9,800	586	9,800	586
Nuclear	Nuclear Fuel	10,000	15	9,004	14
Advanced Nuclear	Nuclear Fuel	8,000	12	7,004	11
Central Biomass	Biomass	12,200	3	9,013	2

SCPC	Supercritical Pulverized Coal
CCNG	Combined Cycle Natural Gas
GT	Gas Turbine (Natural Gas)
CCS	Carbon Capture and Storage

Technology Improvement in the Future

Power plant technology cost and performance improves over time. In certain technology categories plants built in out years are more efficient, less costly to build and operate, and produce fewer emissions. Capacity that either already exists in 2010 or is added in NESSIE has the characteristic performance of the year it was built for its entire operating life. Advanced coal, natural gas, nuclear, and biomass plants built after 2010 will demonstrate improved efficiency, shown in Table 2-1. The impact of technology improvement on greenhouse gas emissions is most evident with coal and natural gas plants as illustrated in **Figure 2-3**.

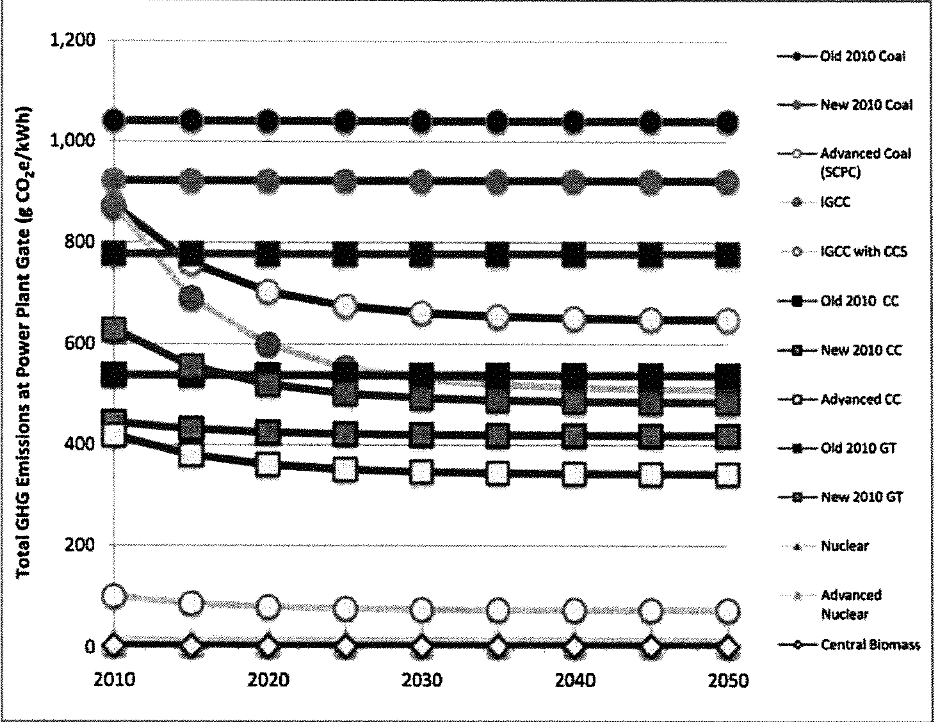

Figure 2-3
Evolution of greenhouse gas emissions intensity of different plant technologies between 2010 and 2050

3 Electric Sector Scenarios

The future of the U.S. electric sector may follow different paths. These paths would differ in such aspects as the environmental policies applied to its operations, the electricity demand that the sector serves, and the generating technologies that are available. Rather than trying to generate a single consensus view of the future, the team decided to produce scenarios that span the impact of the PHEV technology over many different futures.

EPRI and NRDC developed scenarios to represent three possible futures of the U.S. electric sector. The scenarios are distinguished by the following attributes:

1. Price of CO_2 emissions allowances.
2. Rate at which older power plants are retired.
3. Availability and performance on new generation technologies.
4. Annual growth in electricity demand.

These attributes are modified in each scenario to create different levels of carbon intensity in the different scenarios. The three scenarios are defined as:

1. High CO_2 intensity scenario: There is limited availability of higher efficiency and non-emitting generation technologies and a low cost associated with allowances to emit CO_2 in this scenario. Total annual electric sector CO_2 emissions increase by 25% from 2010 to 2050.
2. Medium CO_2 intensity scenario: Advanced renewable and non-emitting generation technologies, such as biomass and IGCC with carbon capture and storage, are available in this scenario. There is a moderate cost associated with allowances to emit CO_2. Total annual electric sector emissions decline by 41% between 2010 and 2050.
3. Low CO_2 intensity scenario: Similar to the medium CO_2 intensity scenario, with the addition of carbon capture and storage retrofit technology for existing coal plants. In addition, there is significantly slower load growth indicative of nationwide adoption of energy efficiency, or other demand reduction, and a higher cost to emit CO_2. Total electric sector emissions decline by 85% from 2010 to 2050 in this scenario.

The NESSIE model described in Chapter 2 was used to model each of the above scenarios and to output the detailed results. Each scenario used a different set of input data and was run through the entire model to produce the measures of interest.

Table 3-1 shows the key differences between each electric sector scenario that govern input data for each.

Table 3-1
Key parameters of the High, Medium, and Low CO_2 Intensity electric scenarios

Scenario Definition	High CO_2 Intensity	Medium CO_2 Intensity	Low CO_2 Intensity
Price of Greenhouse Gas Emission Allowances	Low	Moderate	High
Power Plant Retirements	Slower	Normal	Faster
New Generation Technologies	Unavailable: Coal with CCS New Nuclear New Biomass	Available: IGCC Coal with CCS New Nuclear New Biomass Advanced Renewables	Available: Retrofit of CCS to Existing IGCC and PC Plants
	Lower Performance: SCPC, CCNG, GT, Wind, and Solar	Nominal EPRI Performance Assumptions	Higher Performance: Wind and Solar
Annual Electricity Demand Growth	1.56% per year on average	1.56% per year on average	2010-2025: 0.45% 2025-2050: None

PC – Pulverized Coal
SCPC – Supercritical Pulverized Coal
CCNG – Combined Cycle Natural Gas
GT – Gas Turbine (Natural Gas)
CCS – Carbon Capture and Storage

Treatment of Greenhouse Gas Emissions

The NESSIE model accounts for all emissions related to the production of electricity, including greenhouse gases, by monetizing emissions allowances. These are model inputs generated either by assumption or by prior modeling work. In the case of greenhouse gases, a temporally varying value is given to CO_2e emissions allowances from CO_2, N_2O, and CH_4 emissions associated with fuel production, transport, and combustion.

For each electric sector scenario, a relationship of the value of GHG emissions versus time was determined by using NESSIE model runs to determine appropriate emission allowance values. The monetization of greenhouse gas emissions impacts both power plant capacity and dispatch decisions as it raises the cost of electricity produced from higher-emitting technologies.

It should be noted that the effect of the value of GHG emissions allowances is directly related to the specific characteristics of the electric system in each of the scenarios constructed for this study. The GHG emissions allowance values used are meaningful only to the narrow framework of this study and are not meant to represent the opinion, expectation, or recommendations of either EPRI or NRDC regarding the future value of CO_2 and other greenhouse gas emissions.

Capacity Retirement

Power plant capacity retirement is an important component of electric sector modeling. Older plants tend to have higher emissions and lower efficiency. Older power plant capacity is generally replaced by newer units with significantly better performance.

Coal and natural gas-fired capacity that exists in 2010 is gradually retired over time. Several factors determine the quantity and timing of the retirements. The age of the equipment influences the rate of retirement, with older equipment more likely to be shut down. Retirement is also based on economic decisions about the economic performance of capacity. A higher assumed cost for emitting GHGs erodes profitability of higher emitting plants. In addition the introduction of newer and lower variable cost generators further reduces the dispatch of existing higher-cost units.

The new technologies that replace retired units and serve new growth in demand also differ between the scenarios. The High CO_2 intensity emissions scenario assumes limited improvement from today's suite of options. In the Medium CO_2 intensity scenario, improved technologies are assumed to be deployed, such as Integrated Gasification Combined Cycle (IGCC), IGCC with CO_2 capture and storage (CCS), nuclear, and biomass. This scenario also assumes differences in the long-run efficiency (for thermal plants) and better wind and solar options. Finally, the Low CO_2 intensity scenario assumes some additional improvements in wind and solar. In addition, the scenario incorporates the retrofit of CCS to existing coal-fired power plants if the GHG allowance cost is high enough to make this a least-cost option for marginal emission reductions. There is one final change in the Low CO_2 intensity scenario: the demand growth is lower due to an assumed widespread deployment of energy-efficiency technologies that reduce electricity demand from the other scenarios.

Base Electric Sector Scenario Results

Table 3-2 shows some of the summary results for each of the electric sector CO_2 emission scenarios. As expected, both aggregate and annual GHG emissions vary significantly across the scenarios. In general, GHG intensity is significantly affected by capacity retirements, value of GHG allowances, electricity demand, and technology availability, cost, and performance. No single factor has a dominant impact on the GHG intensity of a given scenario. These results indicate that varying these key parameters is an effective strategy to create three distinctive future scenarios of the electric sector.

Table 3-2
Selected results from electric sector carbon emissions scenarios

Selected Results		Electric Sector CO_2 Emissions		
		High	Medium	Low
Cumulative CO_2e Emissions from 2010 to 2050 (billion metric tons)		116.3	89.4	60.4
Annual CO_2e Emissions in 2050 (billion metric tons)		3.25	1.57	0.45
Electric Sector Average CO_2e Intensity (g/kWh)	2010	573		
	2050	412	199	97

For comparison, the average CO_2 intensity of the electric sector in 2005 is 612 g/kWh.[8]

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[8] Energy Information Administration, *Annual Energy Outlook 2006.*

4 Vehicle Emissions Model

There are two primary components to the vehicle emissions model:

1. Vehicle Characterization— Assumptions about the energy consumption and other performance attributes of a single plug-in hybrid electric vehicle.
2. Fleet Expansion — Assumptions about the penetration rate of the characterized vehicles (plug-in hybrid, hybrid, and conventional) across multiple vehicle categories, throughout the lower 48 states, over a time horizon of 2010 to 2050.

Vehicle Characterization

The first step in the process of developing nationwide fleet emissions is to determine the properties of the individual vehicles in the model. This study accounts for three different vehicle configurations:

1. Conventional vehicles (CV), powered by an internal combustion engine and using either gasoline or diesel fuel.
2. Hybrid electric vehicle (HEV), powered by a combination of internal combustion engine and electric drive system and using either gasoline or diesel fuel.
3. Plug-in hybrid electric vehicles (PHEV), powered by a combination of internal combustion engine and electric drive system and using electricity plus either gasoline or diesel vehicles. This report examines three different PHEV battery capacity assumptions: sufficient energy in the onboard battery system to power the vehicle from the battery alone for the equivalent of 10, 20, or 40 miles.

Data Sources

The development of the nationwide fleet emissions model relied on three primary data sources:

1. Prior EPRI analysis – *Comparing the Benefits and Impacts of Hybrid Electric Vehicle Options* and *Comparing the Benefits and Impacts of Hybrid Electric Vehicle Options for Compact Sedans and Sport Utility Vehicles*. These reports contain detailed modeling comparisons of conventional, hybrid, and plug-in hybrid vehicles of equivalent performance and capabilities.[9,10]
2. Mobile Source Emission Factor Model (MOBILE6) – MOBILE6 contains vehicle miles traveled (VMT) data for the entire lower 48 states and 28 different vehicle classifications. MOBILE6 also contains "real-world" fuel economy data per vehicle classification. This allowed adjustment of the energy consumption of each vehicle to be tailored to its vehicle category[11].
3. Emissions Factor Model (EMFAC) – EMFAC is a similar emissions model to MOBILE6 preferred by the state of California.[12]

In this study, MOBILE6 parameters are used to calculate vehicle energy consumption. EMFAC is used to determine fleetwide emissions and petroleum consumption in California, while MOBILE6 is used outside California.

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[9] EPRI, 2001. *Comparing the Benefits and Impacts of Hybrid Electric Vehicle Options*, EPRI, Palo Alto, CA: 2001. 1000349.

[10] EPRI, 2002. *Comparing the Benefits and Impacts of Hybrid Electric Vehicle Options for Compact Sedans and Sport Utility Vehicles*, EPRI, Palo Alto, CA: 2002. 1006892.

[11] *User's Guide to MOBILE6.1 and MOBILE6.2 Mobile Source Emission Factor Model*, U.S. EPA, EPA420-R-03-010. 2004.

[12] *Public Meeting to Consider Approval of Revisions to the State's On-Road Motor Vehicle Emissions Inventory: Technical Support Document*, California Air Resources Board, Sacramento, CA. May 2000.

Vehicle Model Inputs

MOBILE6 and EMFAC vehicle emission models use similar, but not identical categorizations of the vehicle fleet. EMFAC vehicle emissions have been correlated and added to the MOBILE6 data to provide a complete 48-state dataset.

Table 4-1 shows the 29 different vehicle categories in the MOBILE6 vehicle inventory. Vehicles are categorized by fuel (gasoline and diesel) and by Gross Vehicle Weight Rating (GVWR). In general, vehicle classifications that were eligible for PHEV market share were limited to those with GVWR of less than 19,500 lbs. Motorcycles, specific bus categories, and vehicles of greater than 19,500 lb GVWR were excluded. These classifications were excluded not because of their unsuitability for

Table 4-1
MOBILE6 Vehicle Classifications

Individual Vehicle Type	GVWR (lb)	Individual Vehicle Type – Description
LDGV	-	Light-Duty Gasoline Vehicles (Passenger Cars)
LDGT1	0-6000	Light-Duty Gasoline Trucks 1 (0-6,000 lb GVWR, 0-3750 lb LVW)
LDGT2	0-6001	Light Duty Gasoline Trucks 2 (0-6,001 lb GVWR, 3751-5750 lb LVW)
LDGT3	6001-8500	Light Duty Gasoline Trucks 3 (6,001-8500 lb GVWR, 0-3750 lb LVW)
LDGT4	6001-8500	Light Duty Gasoline Trucks 4 (6,001-8500 lb GVWR, 3751-5750 lb LVW)
HDGV2B	8501-10000	Class 2b Heavy Duty Gasoline Vehicles (8501-10,000 lb GVWR)
HDGV3	10001-14000	Class 3 Heavy Duty Gasoline Vehicles (10,001-14,000 lb GVWR)
HDGV4	14001-16000	Class 4 Heavy Duty Gasoline Vehicles (14,001-16,000 lb GVWR)
HDGV5	16001-19500	Class 5 Heavy Duty Gasoline Vehicles (16,001-19,500 lb GVWR)
HDGV6	19501-26000	Class 6 Heavy Duty Gasoline Vehicles (19,501-26,000 lb GVWR)
HDGV7	26001-33000	Class 7 Heavy Duty Gasoline Vehicles (26,001-33,000 lb GVWR)
HDGV8A	33001-60000	Class 8a Heavy Duty Gasoline Vehicles (33,001-60,000 lb GVWR)
HDGV8B	>60000	Class 8b Heavy Duty Gasoline Vehicles (>60,000 lb GVWR)
LDDV	-	Light Duty Diesel Vehicles (Passenger Cars)
LDDT12	0-6000	Light Duty Diesel Trucks 1 (0-6,000 lb GVWR)
HDDV2B	8501-10000	Class 2b Heavy Duty Diesel Vehicles (8501-10,000 lb GVWR)
HDDV3	10001-14000	Class 3 Heavy Duty Diesel Vehicles (10,001-14,000 lb GVWR)
HDDV4	14001-16000	Class 4 Heavy Duty Diesel Vehicles (14,001-16,000 lb GVWR)
HDDV5	16001-19500	Class 5 Heavy Duty Diesel Vehicles (16,001-19,500 lb GVWR)
HDDV6	19501-26000	Class 6 Heavy Duty Diesel Vehicles (19,501-26,000 lb GVWR)
HDDV7	26001-33000	Class 7 Heavy Duty Diesel Vehicles (26,001-33,000 lb GVWR)
HDDV8A	33001-60000	Class 8a Heavy Duty Diesel Vehicles (33,001-60,000 lb GVWR)
HDDV8B	>60000	Class 8b Heavy Duty Diesel Vehicles (>60,000 lb GVWR)
MC	-	Motorcycles (Gasoline)
HDGB	-	Gasoline Busses (School, Transit and Urban)
HDDBT	-	Diesel Transit and Urban Busses
HDDBS	-	Diesel School Busses
LDDT34	6001-8500	Light Duty Diesel Trucks 1 (6,001-8500 lb GVWR)

adaptation to a PHEV architecture, but due to a desire to account for the categories with a combination of the highest fraction of fleet vehicle miles traveled (VMT) and relatively high confidence that PHEV technology could be applied to the category in the near-term.

Table 4-2 shows the seventeen categories selected for PHEV and HEV market share in the PHEV scenarios. Energy consumption for both hybrid and plug-in hybrid vehicles is based on existing EPRI simulation data and adjusted for relative compatibility with MOBILE6 fuel economy data. For this study, a hybrid vehicle is assumed to have 35% lower fuel consumption than a conventional vehicle. This number is comparable to both simulated and EPA-certified differentials between conventional and hybrid vehicles.[11,12]

Table 4-2
Initial attributes of conventional, hybrid and plug-in hybrid per category in 2006

Individual Vehicle Type	GVWR (lb)	Test Mass (kg)	DC Electricity Consumption Wh/mile	Mobile6 Fuel Economy (mpg)	Adjusted Mobile6 HEV Fuel Economy (mpg)	Mobile6 Adjusted DC Wh/mile	Mobile6 Adjusted AC Wh/mile
Gasoline Vehicles							
LDGV	-	1651	237	24.1	37.1	280.0	318.2
LDGT1	0-6000	2268	296	18.5	28.5	346.9	394.2
LDGT2	0-6001	2268	296	18.5	28.5	346.9	394.2
LDGT3	6001-8500	3289	393	14.2	21.8	434.0	493.2
LDGT4	6001-8500	3289	393	14.2	21.8	434.0	493.2
HDGV2B	8501-10000	3776	439	10.1	15.6	584.7	664.4
HDGV3	10001-14000	4899	547	9.4	14.4	626.1	711.5
HDGV4	14001-16000	6124	663	9.4	14.4	628.5	714.3
HDGV5	16001-19500	7246	771	8.0	12.3	723.8	822.5
Diesel Vehicles							
LDDV	-	1726	244	32.4	49.8	288.5	327.9
LDDT12	0-6000	2375	306	22.1	34.0	358.8	407.8
HDDV2B	8501-10000	3886	450	13.0	19.9	598.6	680.2
HDDV3	10001-14000	5042	560	11.7	17.9	641.7	729.2
HDDV4	14001-16000	6303	681	10.2	15.7	644.8	732.7
HDDV5	16001-19500	7460	791	9.9	15.2	742.9	844.2
HDDV6	19501-26000						
LDDT34	6001-8500	3446	408	17.0		450.6	512.1

For this study, we assume a PHEV has equivalent fuel consumption attributes to a hybrid for the portion of VMT not powered by electricity.[13] Electric energy consumption attributes of each vehicle category are calculated from EPRI simulation data for plug-in hybrid vehicles[11,12] and adjusted for baseline MOBILE6 fuel consumption. DC Electricity Consumption represents the average performance of that

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[13] For a given battery chemistry, a PHEV will carry more total battery mass, resulting in a slight decrease in fuel economy relative to a hybrid vehicle. Detailed studies of this effect have shown that the higher electric drive system performance of a PHEV will typically compensate for the slight increase in additional weight.[11,12]

vehicle category on the Federal Urban Driving Schedule (FUDS). MOBILE6 Adjusted DC Electricity Consumption (column 6) represents "real-world" electrical energy consumption at the vehicle and is calculated by applying a correction factor based on MOBILE6 Fuel Economy.

MOBILE6 Adjusted AC Electricity Consumption represents AC electricity consumption per mile, used to calculate vehicle energy demand to the electric sector. DC electrical energy is converted to AC electrical energy from the wall outlet (supplied by the electrical grid) using an 88% conversion efficiency from AC energy at the outlet to stored DC energy in the battery pack of the vehicle. This conversion efficiency includes charger and battery losses and is based on prior simulation data[7] and adjusted for recent Lithium Ion battery charging test data.[14]

The nationwide fleet of PHEVs is distributed to seventeen different vehicle categories specified from the MOBILE6 database. The first four categories, LDGV, LDGT1, LDGT2, and LGDT3, account for 82.2% of the total vehicle miles traveled in the study.

Vehicle Fuel Economy

The three vehicle types in this study all use liquid fuels and fuel consumption is an important parameter for determining total GHG emissions. The MOBILE6 and EMFAC databases assume that vehicle fuel efficiency does not improve over time.

For logical consistency, this study assumes that market conditions sufficient to produce significant market shares for PHEVs will also create similar motivation for automotive manufacturers to offer, and for consumers to purchase, more fuel efficient conventional and hybrid vehicles. This reasoning creates the following study assumptions, expressed for the gasoline Light-Duty Gasoline Vehicle (LDGV) category, but applied consistently—in terms of percentage energy consumption reduction—throughout the other vehicle categories:

1. Initial fuel economy for a model year 2006 conventional gasoline LDGV is 24.1 mpg.
2. Initial fuel economy for a model year 2006 gasoline HEV LDGV is 37.1 mpg.
3. PHEVs, when not using electrical energy, have identical fuel economy to the HEV
4. Fuel consumption for both CVs and HEVs improves by 0.5% per year, therefore
    - 2010 new vehicle fuel economy is 24.6 for the CV and 37.9 for the HEV (LDGV)
    - 2050 new vehicle fuel economy is 30.0 mpg for the CV and 46.3 mpg for the HEV (LDGV)

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[14] *Sprinter PHEV Battery Testing,* Project Report No. TC-04-176-TR06, Southern California Edison, Pomona, CA. January 2007.

Figure 4-1 shows the improvement in fuel economy over the study timeframe of 2010 to 2050 for the gasoline LDGV category.[15]

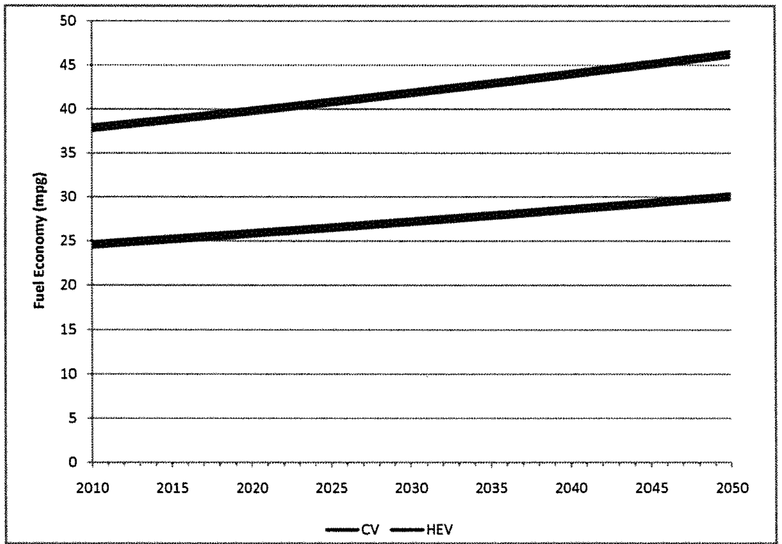

Figure 4-1
Evolution of conventional and hybrid vehicle fuel economy for the LDGV category

PHEV Utility Factor

Utility factor is a term used to describe the fraction of driving in a PHEV that is performed by electricity. Utility factor varies with each individual vehicle and is limited by opportunities to charge the vehicle. In general, vehicles that are driven extremely long distances between recharging events will have a low utility factor. Vehicles that are driven on many short trips will have a very high utility factor. On average, utility factor is heavily (but not entirely) dependent on two primary factors—annual VMT and vehicle All-Electric Range (AER). AER is a design parameter of the vehicle and indicates the number of miles the vehicle is capable of being driven using only battery energy (between recharges). EPRI identifies AER by attaching the AER, in miles, immediately after the term PHEV. For example, a PHEV 10 is a plug-in hybrid with 10 miles of electric range. For simplicity, this study considers PHEV 10, PHEV 20, and PHEV 40 configurations. Over time, the new vehicle market shares of PHEV 20 and PHEV 40 increases.

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[15] The assumptions regarding vehicle energy efficiency represent a simplified assumption of improvement in fuel consumption over time.

Figure 4-2 shows the Utility Factor relationships that have been established for each of the PHEV configurations. This data is derived from prior EPRI data,[9] taking into account charging frequency, annual mileage in different driving scenarios, and proportion of urban and highway driving.

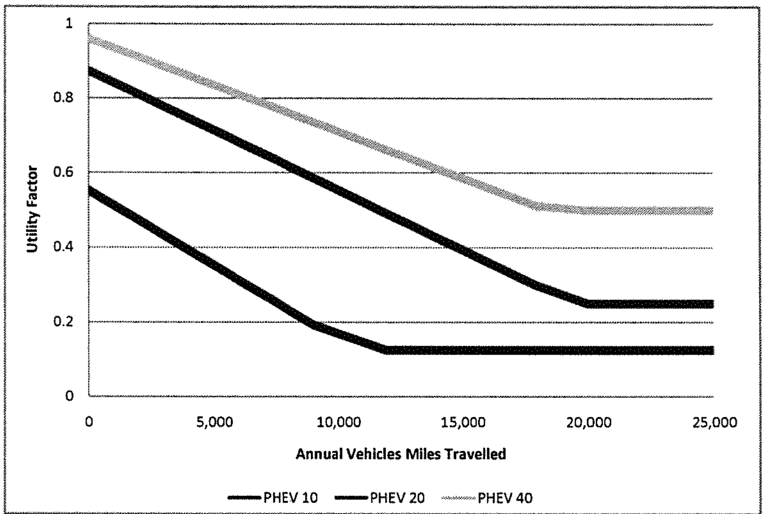

Figure 4-2
PHEV Utility Factor as a function of AER and annual VMT, assuming nightly charging

PHEV Market Penetration

Three distinct PHEV market adoption scenarios were developed, each based on PHEVs entering the market gradually in 2010, experiencing rapid adoption and achieving maximum new vehicle market share in 2050. As shown in **Figure 4-3**, PHEVs reach a maximum of 20% new vehicle market share in the Low PHEV fleet penetration scenario, 62% in the Medium PHEV fleet pentration scenario, and 80% in the High PHEV fleet penetration scenario. Market share is based on each of the seventeen vehicle types considered in this study.

For the purpose of calculating GHG reductions, each PHEV scenario is compared to a base case without PHEVs. In the absence of PHEVs, HEVs and conventional vehicles expand their market share under the assumption that the proportion of conventional vehicles to HEVs remains the same as for the respective PHEV case in question (**Table 4-3**). For example, under the High PHEV scenario in 2050, the new vehicle market shares of HEVs and CVs are 15% and 5%, respectively. This proportion of HEVs to CVs (3:1) is constant when PHEVs are removed, resulting in respective market shares of 75% and 25%. This has the practical effect of comparing fleet GHG reductions with PHEVs to a base fleet of similar level of hybridization.

The MOBILE6 and EMFAC databases contain the entire nationwide fleet inventory of all vehicles of all ages. For each year, new vehicles are added to the model databases and a certain percentage of older vehicles are retired. Average VMT assigned to a single vehicle declines over time—newer cars tend to be driven more than older cars.

Table 4-3
Peak new vehicle market share in 2050 for the three PHEV adoption scenarios

2050 New Vehicle Market Share by Scenario		Vehicle Type		
		Conventional	Hybrid	Plug-In Hybrid
PHEV Scenario	Low PHEV	56%	24%	20%
	Medium PHEV	14%	24%	62%
	High PHEV	5%	15%	80%

Table 4-4
Baseline market share of Conventional and Hybrid vehicles for each PHEV scenario but without PHEVs

2050 New Vehicle Market Share by Scenario		Vehicle Type		
		Conventional	Hybrid	Plug-In Hybrid
PHEV Scenario	Low PHEV	70%	30%	0%
	Medium PHEV	37%	63%	0%
	High PHEV	25%	75%	0%

Figure 4-3 shows the annual new vehicle market share of conventional, hybrid, and plug-in hybrid vehicles for the Medium PHEV fleet penetration case from 2006 to 2050. The market shares of each vehicle are assumptions developed from choice based market modeling of customer preference between PHEV, HEV, and conventional vehicle options. Market adoption is initially limited by vehicle cost and assumed maximum new vehicle availability. In each year, the new vehicles added to the model will be added in the proportion for that year. In the absence of PHEVs, HEVs and CVs occupy the market in the same relative proportions.[16]

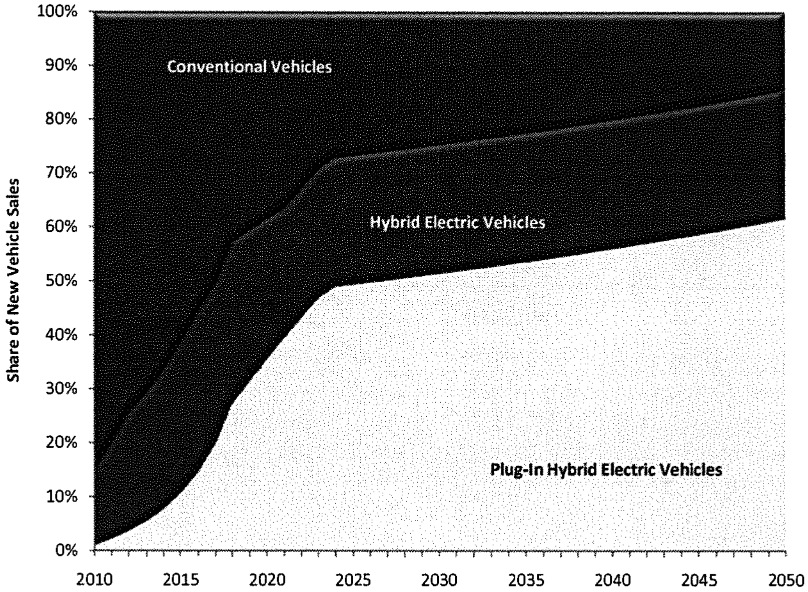

Figure 4-3
Assumed new car market share for the Medium PHEV scenario conventional vehicles (CV), hybrid electric vehicles (HEV) and plug-in hybrid electric vehciles (PHEV) for each vehicle category

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[16] For example, in the High PHEV scenario in the absence of PHEV, HEVs would comprise 75% of the new vehicle market and CVs 25% in 2050.

Upon market entry, PHEVs are a relatively small percentage of new vehicle sales. It will also take many years for the fleet to "turn over" as older vehicles are retired. MOBILE6 assigns different vehicle lifetime projections to the different vehicle classes. **Figure 4-4** shows this evolution of the PHEV component of the fleet over the 2010 to 2050 time horizon.

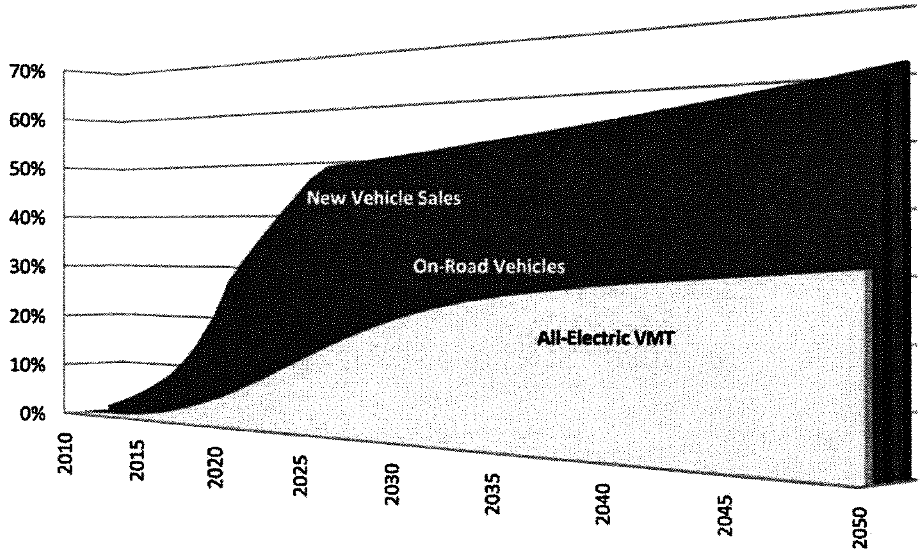

Figure 4-4
Fleet share growth over time of PHEVs in the Light Duty Gasoline Vehicle (LDGV) category for the Medium PHEV case

In Figure 4-4, the ***New Vehicle Sales*** curve shows the percentage of new vehicles sales in each year attributed to PHEVs. ***PHEV VMT*** is the fraction of LDGV miles driven in each year by PHEVs. ***All Electric VMT*** represents the fraction of total LDGV miles attributed to electric energy. The fraction of LDGV VMT attributed to PHEVs lags PHEV new vehicle market share, indicative of the time necessary for them to significantly penetrate the existing vehicle fleet. The two converge over time as PHEVs market penetration increases. New vehicles have higher VMT than older vehicles, accounting for the close correlation between PHEV market share and fleet VMT fraction after about 2035.

PHEV Charge Profile

An aggregated charge profile was created for the fleet of PHEVs in the model (**Figure 4-5**, below). 100% of the charge energy requirements are apportioned to each hour of the day. The analysis assumes that the highest charging loads occur during late night and early morning hours, with modest loads—presumably from daytime public or workplace charging -- occurring in the middle of the day. Hours of minimal charging correspond roughly with commute times.

This specific charge profile creates a scenario where 74% of the charging energy is delivered from 10:00 p.m. to 6:00 a.m. (nominally off-peak). The remaining 26% is provided between 6:00 a.m. to 10:00 p.m. This is simply one of many possible scenarios and represents an initial approximation of aggregate charging behavior in a fleet of PHEVs. The scenario is supported by the following assumptions:

1. *PHEVs are charged primarily, but not exclusively, at each vehicle's "home base".*
2. *Owners are incentivized or otherwise encouraged to use less expensive off-peak electricity.*
3. *Near-term vehicles are likely to have charge onset delays built into their systems to allow battery system rest and cooling before recharge.*
4. *Long-term, large PHEV fleets will likely encourage utilities to use demand response or other programs to actively manage the charging load.*

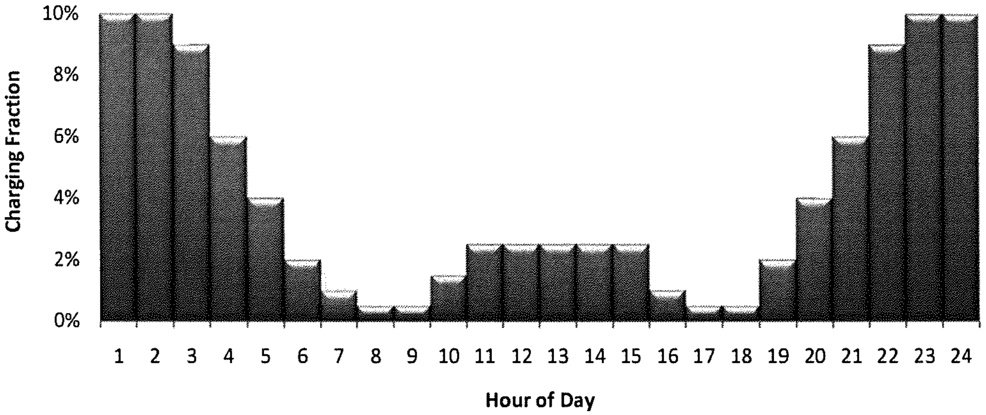

Figure 4-5
PHEV Charge Profile (Hour 1 represents 12:01 a.m. to 1:00 a.m. Hour 24 represents 11:01 p.m. to 12:00 a.m.)

5 Results

The methodology followed in this assessment starts with specific performance characteristics of both vehicles and electric power plants of different configurations, technologies and levels of performance. The attributes of these single entities are then expanded in scope and numbers to allow for analysis of a nationwide approach. For the transportation sector, vehicle performance characteristics are propagated throughout the MOBILE6 database of light-duty and medium-duty vehicles for the United States. For the electric sector, power plant characteristics are incorporated into a nationwide capacity retirement/ expansion model and electricity production simulation.

The results of this analysis are presented in two ways:

1. Individual vehicle type examples comparing GHG emissions of conventional, hybrid, and plug-in hybrid vehicles; and
2. Nationwide scenario results comparing total GHG emissions of the different scenarios constructed from High CO_2, Medium CO_2, and Low CO_2 Intensity electric sector emissions cases and Low, Medium, and High PHEV market adoption cases.

Individual Vehicle Results

The combination of a forty-year time horizon, seventeen vehicle categories, and nine scenarios results in thousands of distinct individual vehicle results within the model. The following is a single example, or snapshot, of the comparative performance of conventional, hybrid and plug-in hybrids in the Light Duty Gasoline Vehicle (LDGV) category. There are five possible configurations for each vehicle category—conventional, hybrid, and plug-in hybrid (10, 20, and 40 miles of electric range).

Table 5-1 shows the energy efficiency, gasoline consumption, and AC electrical usage of each of the five vehicle types—all model year 2010 (MY2010) vehicles in the year 2010, with an assumed annual VMT of 15,000 miles. The CV, with a fuel economy of 24.6 mpg, consumes 488 gallons of gasoline in 2010. The hybrid, with higher fuel economy of 37.9 mpg, consumes 317 gallons. Each PHEV has a utility factor (Figure 4-2) dependent on range and annual VMT that dictates the quantity of VMT that are powered by electricity (eVMT fraction). For the PHEV 20, the utility factor, or eVMT fraction is 0.49, resulting in the consumption of 161 gallons of fuel and 1,840 kWh of electricity. In this example, the PHEV 10 has a lower eVMT fraction of 0.125 and correspondingly higher gasoline consumption. The PHEV 40 has an eVMT fraction of 0.66 and consumes only 107 gallons of gasoline (and 2,477 kWh of electricity).

Table 5-1
Example of Vehicle Energy Consumption in 2010 (LDGV)

		CV	HEV	PHEV 10	PHEV 20	PHEV 40
Annual mileage	mi	12,000	12,000	12,000	12,000	12,000
Utility Factor		n/a	n/a	0.12	0.49	0.66
Gasoline consumption	gal	487.8	316.6	277.1	161.0	107.2
Electricity consumption	kWh	-	-	467	1,840	2,477
Fuel economy	mpg	24.6	37.9	37.9	37.9	37.9
Electric efficiency	AC kWh/mi	n/a	n/a	0.312	0.312	0.312

Figure 5-1 compares total GHG emissions of the CV, HEV, and the PHEV 20, with the PHEV 20 receiving its energy entirely from each of the fourteen distinct power plant technologies defined in Chapter 2. The bottom bar (blue) represents all of the GHGs emitted in the process of producing and delivering gasoline to the vehicle (well-to-tank). The next bar (red) represents GHGs emitted at the vehicle level (tank-to-wheels). The top bar (yellow) represents GHGs emitted during the generation of electricity for the PHEV 20.

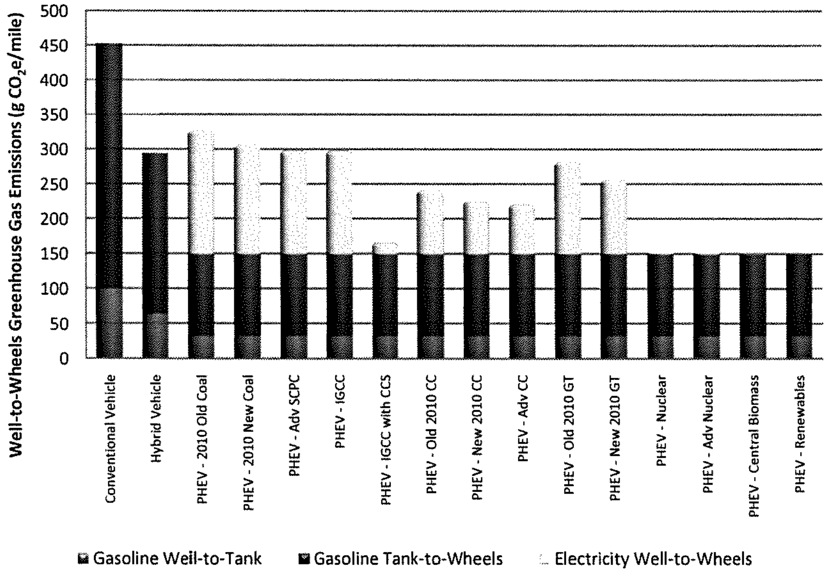

Figure 5-1
Year 2010 comparison of LDGV PHEV 20 GHG emissions when charged entirely with electricity from specific power plant technologies (12,000 miles driven per year)

There are a number of conclusions from this comparison of PHEV 20 GHG emissions to the CV and HEV in Figure 5-1. **For the PHEV 20**:

- Both HEV and PHEV 20 regardless of electricity supply, result in significantly lower GHG emissions than a comparable conventional vehicle (28% to 67% lower)
- With power provided by current coal generation technologies, the PHEV 20 has somewhat higher GHG emissions than HEV (11.1% and 4.3% higher, respectively)
- With power provided by the assumed advanced coal technologies (Advanced SCPC and IGCC) PHEV 20 GHG emissions are comparable to the HEV (1.4% higher)
- With power provided by combined cycle natural gas technologies (current and advanced) show significant GHG reductions compared to HEV (18% to 25% lower).
- The two "peaking" technologies (Old 2010 Gas Turbine and New 2010 Gas Turbine) show modest reductions compared to HEV (4% and 13% lower, respectively)
- The PHEV 20 recharged by low- and non-emitting generation technologies emits the lowest level of GHGs per mile (Note the analysis conducted for this report assumes Adv Nuclear and IGCC with carbon capture and storage are not available in 2010).

From this examination of generation options for PHEVs in 2010, it is clear that the carbon intensity of the generation technology plays a significant role in the total GHG emissions due to PHEV use. In 2010, current coal technologies result in somewhat higher GHG emissions compared to the hybrid and 28% to 34% reductions compared to the conventional vehicle.

Table 5-2
Example of Vehicle Energy Consumption in 2050 (LDGV)

		CV	HEV	PHEV 10	PHEV 20	PHEV 40
Annual mileage	mi	12,000	12,000	12,000	12,000	12,000
Utility Factor		n/a	n/a	0.12	0.49	0.66
Gasoline consumption	gal	400.0	259.2	226.8	131.8	87.7
Electricity consumption	kWh	-	-	382	1,504	2,024
Fuel economy	mpg	30.0	46.3	46.3	46.3	46.3
Electric efficiency	AC kWh/mi	n/a	n/a	0.255	0.255	0.255

Table 5-2 shows five different LDGV types for MY2050 vehicles. Cumulative annual decreases in fuel consumption of 0.5% have resulted in MY2050 fuel economy of 30 mpg for the conventional vehicle and 46.3 mpg for the hybrids. PHEV electric energy consumption has decreased from 0.312 kWh/mi to 0.255 kWh/mi.

Figure 5-2 is similar to Figure 5-1 with higher emitting conventional generation technologies (2010 Old Coal, New Coal, Old CC, New CC, Old GT) removed as they no longer form part of the generating fleet. In 2050, vehicle efficiency has improved, so all three components of well-to-wheels GHG emissions are lower. The PHEV 20 produces approximately the same GHG emissions as an HEV if powered by electricity from coal plants that do not capture CO_2 and has 37% lower GHG emissions than the HEV if coal with CO_2 capture and storage is the power source.

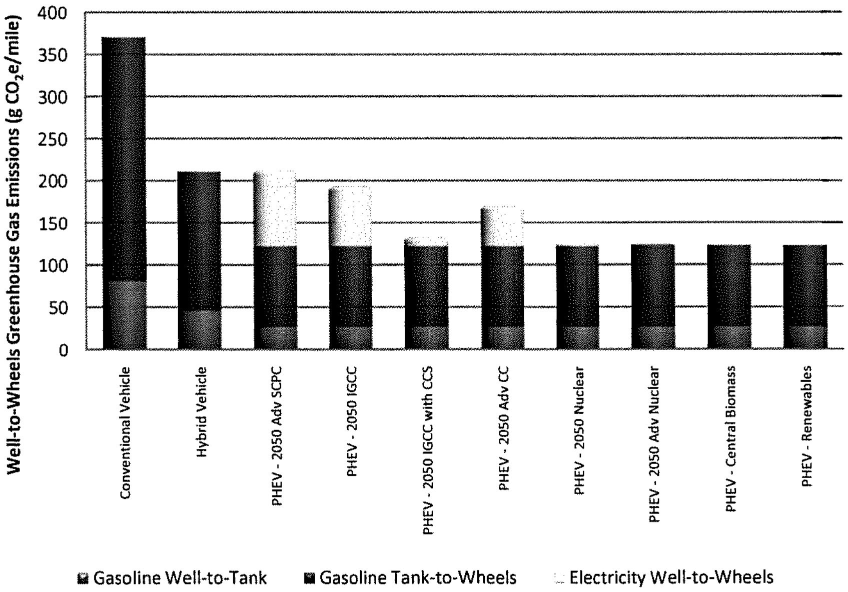

Figure 5-2
Year 2050 comparison of LDGV PHEV 20 GHG emissions charged entirely with electricity from specific power plant technologies (12,000 miles driven per year)

Electric Sector Scenario Impact on GHG Emissions

The previous analyses illustrate the strong dependence of PHEV GHG emission intensity on the source of electricity. Total system emissions from a given level of PHEV use will be determined by a combination of the vehicle type (PHEV 10, 20, 40), annual VMT patterns by vehicle type, and the type of generating resources that are built and dispatched to serve the electrical load from grid-connected PHEVs. These aggregate impacts are discussed in this section.

In **Figure 5-3** GHG emissions of MY2050 conventional and hybrid vehicles are compared to the three PHEV types (10, 20 and 40 miles of electric range) in each of the three electric sector scenarios (High CO$_2$, Medium CO$_2$, and Low CO$_2$, intensity). PHEVs have lower GHG emissions in all nine cases than either the conventional or the hybrid vehicles, ranging from a 40% to 65% improvement over the conventional to a 7% to 46% improvement over the hybrid. It should be noted that substantial improvements in electric sector intensities are assumed even for the High CO$_2$ case in 2050. The high CO$_2$ intensity case electric sector emission rate in 2050 is 33% lower than 2006 electric sector rate (Table 3-2).

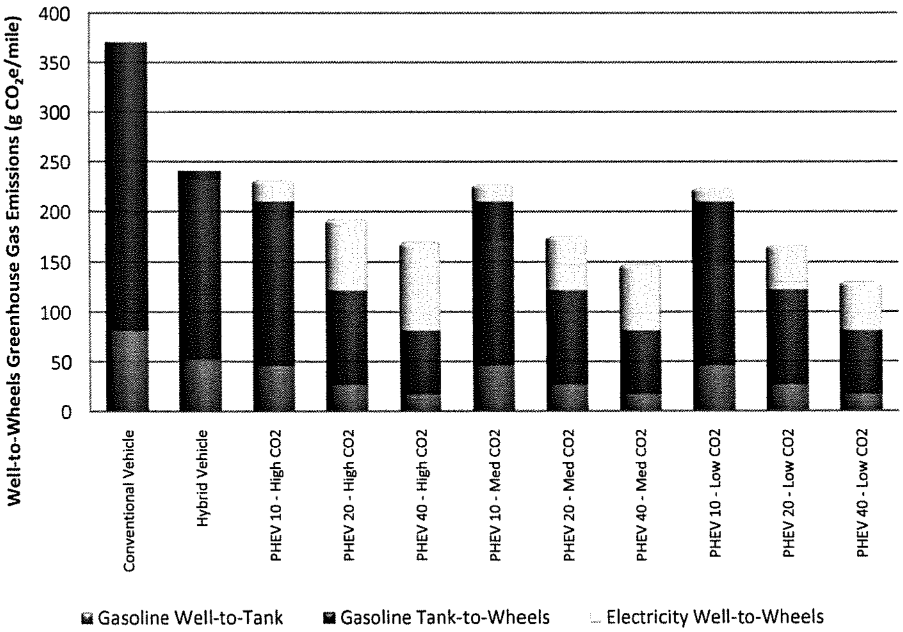

Figure 5-3
Year 2050 comparison of LDGV PHEV GHG emissions from within the High CO$_2$, Medium CO$_2$, and Low CO$_2$ electric sector scenarios (12,000 miles driven per year)

Table 5-3 lists the reduction in GHG emissions of each PHEV versus the HEV for each level of electric range and each electric sector scenario. The PHEV 10, by nature of its smaller battery system and the 12,000-mile annual VMT assumption, shows the smallest percentage gains.

Table 5-3
GHG Emissions Reductions of PHEVs Compared to the HEV for MY2050

Relative GHG Emissions Reductions vs. Hybrid MY2050		Electric Sector CO_2 Scenario		
		High	Medium	Low
Vehicle Type	PHEV 10	-6.9%	-7.7%	-8.6%
	PHEV 20	-27.1%	-30.5%	-34.0%
	PHEV 40	-36.5%	-41.4%	-45.8%

Annual Nationwide Fleet GHG Reductions

The previous section showed effect of each of the electric sector scenarios on the individual GHG emissions of different PHEV configurations. In aggregate, PHEVs enter the nationwide fleet at varying rates of market penetration for each vehicle configuration, represent numerous vehicle classifications, and age over time, affecting annual VMT and utility factor. The Vehicle Emissions Model described in Chapter 4 tracks the aggregate energy consumption and GHG emissions on a fleetwide basis from 2010 to 2050.

Figure 5-4 tracks annual GHG reductions due to PHEVs in the nationwide fleet for the Medium PHEV fleet penetration/Medium CO_2 intensity case. Three comparisons are made:

1. A nationwide fleet consisting of only conventional gasoline and diesel vehicles
2. A nationwide fleet consisting of only hybrid electric vehicles
3. A baseline fleet composed of both hybrid and conventional vehicles (Table 4-3)

Each of the three comparisons provide perspective on the relative contributions on PHEVs to mobile source GHG reductions. When compared to the hybrid-only fleet, the aggregate GHG reductions (433 million tons in 2050) are attributed entirely to the effect of electricity as a transportation fuel.[17]

The three electric-sector CO_2 scenarios (High CO_2, Medium CO_2, and Low CO_2 intensity) are combined with the three PHEV scenarios (Low PHEV, Medium PHEV, and High PHEV fleet penetration) to create a 3x3 matrix of nine different outcomes or modeling results. **Table 5-4** lists the annual GHG reductions in the nationwide fleet from PHEV adoption in each of the nine combined scenarios. Annual reductions are significant in each case, ranging from 163 million metric tons in the high CO_2 intensity/Low PHEV fleet scenario to 612 million metric tons in the Low CO_2 intensity/High PHEV fleet penetration scenario.

The impacts of each parameter are straightforward—as PHEV fleet penetration increases, the fraction of electric VMT rises, displacing higher quantities of liquid fuels with electricity and increasing demand on the electric sector. As the CO_2 intensity of the electric sector decreases, the GHG emissions from a

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[17] It is important to note that market shares of different vehicle technologies are input assumptions to this study. The fraction of diesel vs. gasoline vehicles is taken directly from MOBILE6 and EMFAC data. One important market share assumption of this study is that the total combined market penetration of PHEVs and HEVs is greater than the market penetration of either vechicle type alone.

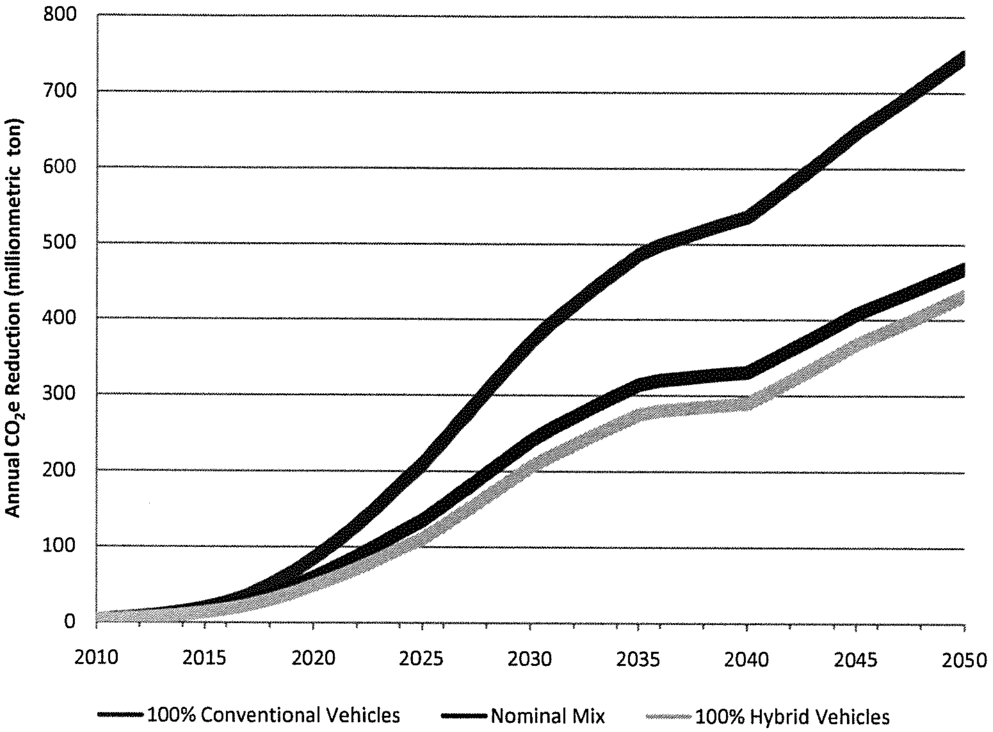

Figure 5-4
Annual GHG reductions of the Medium PHEV penetration scenario compared to a fleet of (1) 100% conventional vehicles, (2) base vehicle fleet of conventional and hybrid vehicles, and (3) 100% hybrid vehicles (no PHEVs)

Table 5-4
Annual CO_2 reduction from PHEVs in the year 2050

2050 Annual CO_2 Reduction (million tons)		**Electric Sector CO_2 Intensity**		
		High	Medium	Low
PHEV Fleet Penetration	Low	163	177	193
	Medium	394	468	478
	High	474	517	612

Aggregate Greenhouse Gas Reductions from 2010 to 2050

Cumulative GHG emissions over the study horizon of 2010 to 2050 are a measure of the overall impact of a technology's potential contribution to GHG reduction. **Table 5-5** presents the results of the nine modeling scenarios. In each case, GHG reductions represent the total GHG reductions of the nationwide vehicle fleet, with its specified penetration of PHEVs versus the GHG of the base vehicle fleet, a proportional mix of hybrid and conventional vehicles.

Table 5-5
Cumulative 2010 - 2050 GHG reduction from PHEVs (billion tons of GHG)

2010 -2050 Total GHG Reduction (billion metric tons)		Electric Sector CO_2 Intensity		
		High	Medium	Low
PHEV Fleet Penetration	Low	3.4	3.4	3.4
	Medium	7.9	8.9	8.0
	High	9.8	10.1	10.3

The key conclusion from this table is that in each of the nine scenarios, GHG emissions are reduced significantly. Each modeling scenario represents a distinct simulation of the electric system with numerous complex interactions. PHEVs reduce GHG emissions in two general ways. First, a PHEV uses gasoline more efficiently—in this study a PHEV has equivalent fuel consumption to a hybrid vehicle. Second, if the carbon intensity of the electricity used to recharge PHEV batteries is below a certain level, this electricity will function as an inherently lower carbon fuel compared with gasoline. The three electric sector carbon emission scenarios assumed in this study each would result in an electric sector that will deliver marginal electricity to PHEVs at a low enough carbon intensity to achieve significant reductions from scenarios where gasoline or diesel fuel is used instead of electricity to provide energy for VMT.

A secondary conclusion from Table 5-5 is that the aggregate 2010 – 2050 GHG reductions are less dependent on electric sector GHG intensity than Table 5-4 would indicate, particularly for the Medium CO_2 Intensity/Medium PHEV case, which shows greater aggregate reductions than the Low CO_2 Intensity/High PHEV case. This analysis uses marginal analysis of the electric sector to determine the origin and environmental characteristics of the electricity that is specifically sourced to charge PHEVs. In the intermediate years of the study time horizon, significant changes are occurring in the electric sector in terms of new plant construction and its effect on plant dispatch order. This has the effect of pushing some higher-emitting plants upward in the dispatch order—the net effect is that these plants contribute less electricity to existing loads, but are somewhat more likely to be dispatched to charge PHEVs.

Another result of the marginal analysis is that combined cycle natural gas is an important contributor to PHEV charging. In general, CCNG is an important marginal resource in the electric sector. The lower capital cost of CCNG relative to coal and nuclear baseload plants tends to favor the construction of CCNG for plants that run at lower capacity factors. The use of CCNG for PHEV charging has a number of interesting effects on GHG emissions, including:

1. In the early years of the study, CCNG reduces GHG intensity in all electric sector scenarios
2. For the High CO_2 intensity scenario, the GHG intensity of CCNG is lower than the average.
3. For the Medium CO_2 and Low CO_2 intensity scenarios, the GHG intensity of CCNG is higher than the average of the entire electric sector.

It is necessary to place these results in context—each of the nine scenarios results in significantly lower GHG emissions from PHEV adoption. In addition, average GHG intensity in the Medium CO_2 and Low CO_2 intensity scenarios is quite low, below that of electricity from efficient combined cycle natural gas plants. The periodic appearance of older, higher emitting plants on the margin for charging PHEVs will serve to increase the specific emissions signature of the PHEV, but is a very minor contribution to total electric sector emissions.

Figure 5-5 places the relative impact of the added load of PHEVs (High PHEV penetration case with 80% new vehicle market share by 2050) on the three electric sector scenarios. In each case, average GHG intensity decreases over time without PHEVs. Adding PHEVs to the High CO_2 intensity case has the effect of slightly reducing total electric sector GHG intensity: CCNG is less GHG intense than the sector average and is a large marginal contributor to PHEV charging. In the Medium CO_2 and Low CO_2 intensity cases, renewable and other low-emitting and non-emitting technologies tend to dominate—adding PHEVs in these cases slightly increases average GHG intensity.

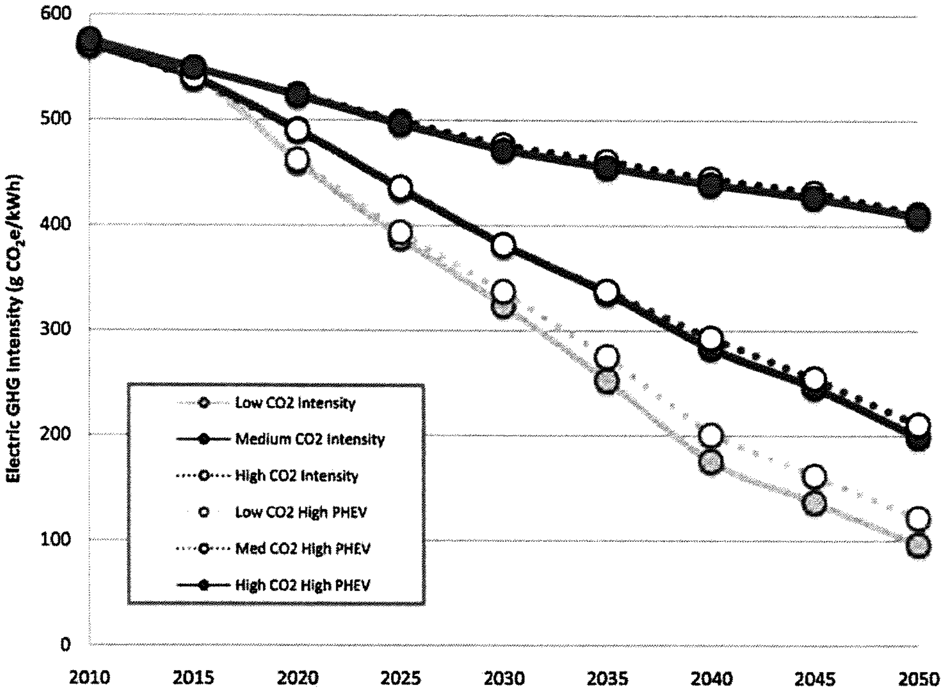

Figure 5-5
Effect of High PHEV market share on average electric sector GHG intensity

The Low CO_2 intensity case also has one specific difference from the high and medium cases. The assumption of greater progress in improving the efficiency of electricity use results in an electric sector of lower capacity than either the high or medium cases (**Figure 5-6**). As the electric sector in the Low CO_2 intensity case features less total capacity, the impact of PHEV charging is somewhat higher than for the other sectors.

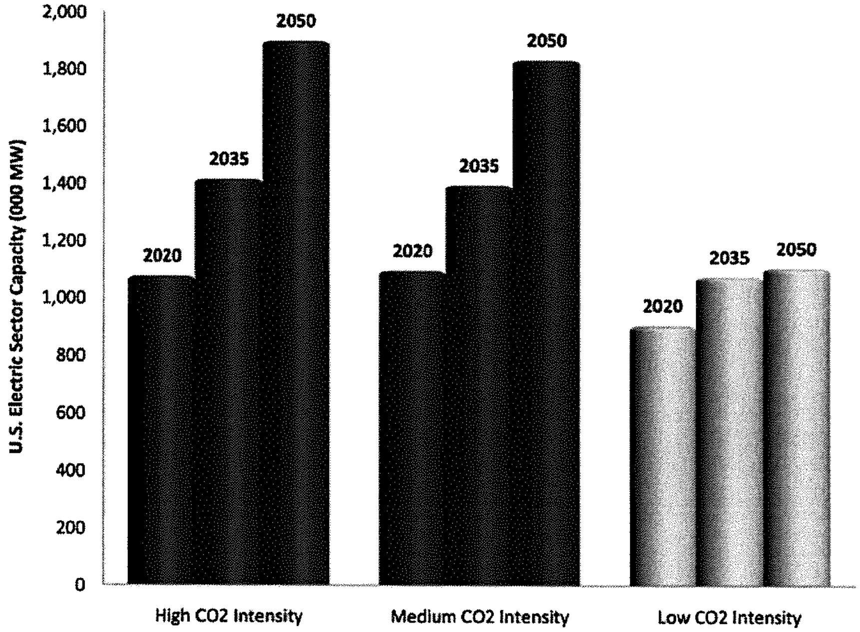

Figure 5-6
U.S. electric sector generating capacity for low, medium, and high CO_2 intensity cases

PHEV Energy Usage

The nationwide fleet model also outputs the energy consumption of PHEVs. For the Medium PHEV case, petroleum consumption of the light-duty and medium-duty vehicle fleet was reduced by the equivalent of 2.0 million barrels per day in 2030 and 3.7 million barrels per day in 2050. Electricity consumption due to PHEVs increases by 282 MMWh (million megawatt hours) in 2030 and 598 MMWh in 2050. These increases in electricity production and delivery over the base case (no PHEVs) are 4.8% and 7.6%, respectively.

Summary

This report represents the first nationwide detailed analysis of likely GHG impacts of plug-in hybrid electric vehicles. For this study, both transportation sector and electric sector modeling tools are used to examine assumed changes in these sectors over the 2010 to 2050 timeframe of the study.

To account for a range of future transportation and electric sector scenarios, nine total modeling scenarios were created at the intersection of High CO_2, Medium CO_2, and Low CO_2 Intensity electric sectors and low, medium, and high fleet penetrations of PHEVs. The following conclusions were drawn from these modeling exercises:

- Each of the nine scenarios showed significant GHG reductions due to PHEV fleet penetration;
- Cumulative GHG savings from 2010 to 2050 can be large, ranging from 3.4 to 10.3 billion metric tons CO_2e;
- Annual GHG savings were significant in every scenario for every year of the study timeframe —reaching a maximum of 612 million tons in 2050 (High PHEV fleet penetration, Low CO_2 intensity case);
- Marginal GHG intensity of the PHEV charging load can vary significantly from average GHG intensity, particularly for the Low CO_2 Intensity scenario.
- PHEVs adoption results in significant reduction in the consumption of petroleum fuels. In the Medium PHEV case, fuel savings were equivalent to 3.7 million barrels per day by 2050.

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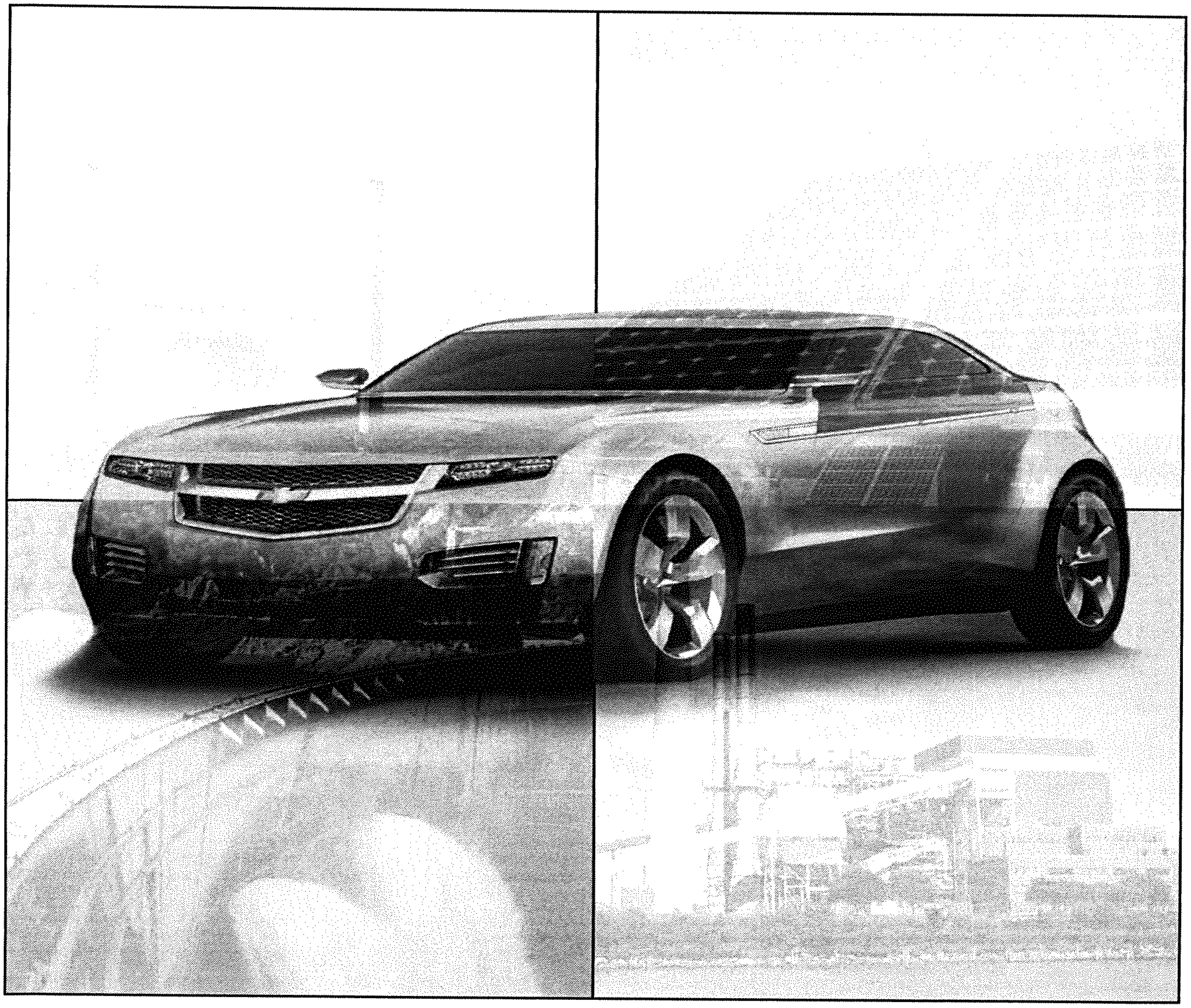
Environmental Assessment of Plug-In Hybrid Electric Vehicles

Volume 2: United States Air Quality Analysis Based on AEO-2006 Assumptions for 2030



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Environmental Assessment of Plug-In Hybrid Electric Vehicles

Volume 2: United States Air Quality Analysis Based on AEO-2006 Assumptions for 2030

1015326

Final Report, July 2007

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>
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EPRI Project Managers

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Executive Summary

Environmental Assessment of Plug-In Hybrid Electric Vehicles

Volume 2: United States Air Quality Analysis Based on AEO-2006 Assumptions for 2030

Environmental Assessment of Plug-In Hybrid Electric Vehicles

In the most comprehensive environmental assessment of electric transportation to date, the Electric Power Research Institute (EPRI) and the Natural Resources Defense Council (NRDC) are examining the greenhouse gas emissions and air quality impacts of plug-in hybrid electric vehicles. The purpose of the program is to quantify the nationwide environmental impacts of potentially large numbers of PHEVs over a time period of 2010 to 2050. 2010 is assumed to be the first year PHEVs would be available, while 2050 would allow the technology sufficient time to fully penetrate the U.S. fleet.

Two Study Components, Two Reports

Phase 1 of the study, completed in June 2007, has two major components. The first is a scenario-based modeling analysis to determine the greenhouse gas impacts of PHEVs over a timeframe of 2010 to 2050. The second component is a nationwide air quality analysis for the year 2030 that assumes an aggressive market penetration of PHEVs.

The methodology and findings of these two analyses are presented separately in two technical reports:

- *Environmental Assessment of Plug-In Hybrid Electric Vehicles, Volume 1: Nationwide Greenhouse Gas Emissions* (1015325)
- *Environmental Assessment of Plug-In Hybrid Electric Vehicles, Volume 2: United States Air Quality Analysis Based on AEO-2006 Assumptions for 2030* (1015326)

Summary of Air Quality Methodology

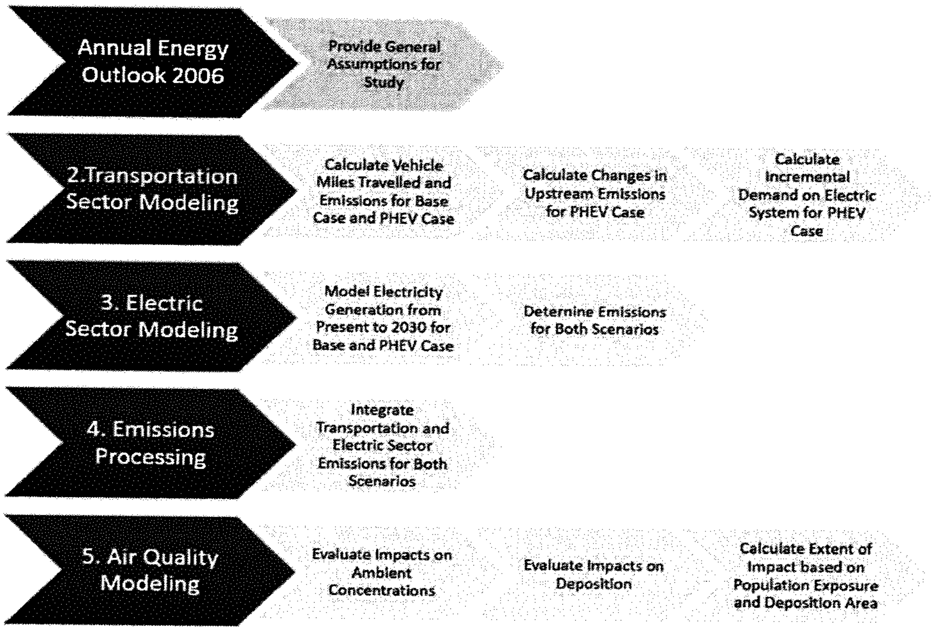
The air quality study evaluated two scenarios for the year 2030: (1) a base case without any penetration of PHEVs in the U.S. vehicle fleet and (2) a PHEV case with PHEVs having reached 50% of new vehicle sales and constituting 40% of on-road vehicles by 2030. In the PHEV case, the overall fraction of vehicle miles traveled by the U.S. vehicle fleet using electricity stored in PHEV batteries is 20%.

The air quality study models both the transportation and electric power sectors in the year 2030 to explore the impact of PHEVs on criteria emissions and subsequent effects on air quality and deposition. The study examined a high electric-sector emission case where nearly all additional electricity demand needed to power an aggressive market penetration of PHEVs was assumed to be met by an increase in the use of present-day coal-fired generation technology with only currently required environmental controls. This is consistent with the U.S. Department of Energy's 2006 Annual Electric Outlook, which assumes no national greenhouse gas policies or constraints, and a sizable increase in coal-fired generation.

The study consisted of four key steps:

1. ***Transportation Sector Modeling*** – For both the base case and the PHEV case, the transportation sector and its emissions were modeled out to 2030. Emissions offset due to vehicle miles traveled using electricity (and reductions in upstream emissions) are calculated by the transportation models. In addition, the incremental electricity demand due to PHEVs was calculated for the PHEV case. The incremental load takes into account losses during transmission and battery charging. This incremental load is also attributed to different hours of the day assuming an overall charging profile for the fleet.
2. ***Electric Sector Modeling*** – For both the base case and PHEV case, the U.S. electric sector was modeled from 2006 to 2030. New generation capacity and electricity dispatch is simulated by the models to account for increased load due to population and economic growth. Emissions associated with electricity generation is also calculated and constrained by environmental regulations as explained earlier. In the PHEV case, the incremental electrical load due to PHEVs is added for all intermediate years in which PHEVs are present as well as 2030.
3. ***Emissions Processing*** – For each scenario, emissions from the transportation sector and electric sector are merged with emissions from all other sectors into an emissions inventory. Natural emissions from vegetation and soil are also added into the emissions inventory. The emissions inventory is then transformed into a format suitable for use in a three-dimensional model of air quality for the entire continental United States.
4. ***Air Quality Modeling*** – The U.S. Environmental Protection Agency's Community Multiscale Air Quality (CMAQ) model was used to simulate U.S. air quality in 2030 in each scenario. The key air quality indicators investigated in the air quality modeling were:
    - ozone mixing ratios;
    - daily and annual particulate matter concentrations (for both PM_{10} and $PM_{2.5}$);
    - deposition of sulfate, nitrate, total nitrogen (sum of oxidized and reduced nitrogen) and mercury; and
    - visibility at Class I areas (e.g. national parks).

In addition, population-weighted exposure indicators were also calculated for ozone and particulate matter.



Roadmap of Study Methodology

Summary of Results

Because of the significant reduction in emissions from gasoline and diesel fuel use and because caps are in place for some conventional pollutants for the electric power sector, the study finds that in many regions deployment of PHEVs would reduce exposures to ozone and particulate matter, and reduce deposition rates for acids, nutrients, and mercury.

On the other hand, because of assuming no further controls beyond existing regulations for the power sector, ozone levels would increase locally in some areas. Similarly, the direct emissions of particulate matter and mercury would increase somewhat and some regions and populations would experience marginal increases in exposures to those pollutants. However, as explained in the key findings, PHEVs do not increase the U.S. contribution to the global mercury budget over the long term.

The air quality study is not meant to project carbon dioxide (CO_2) emissions and does not include any climate-change policies or greenhouse gas emissions constraints. As explained earlier, it is based on the U.S. Department of Energy's 2006 Annual Electric Outlook. A separate report modeled both the transportation and electricity sectors out to 2050 in order to analyze greenhouse gas emissions.

Overall, the air quality benefits from PHEVs are due to a reduction of vehicle emissions below levels required by current regulation (due to their non-emitting operation in all-electric mode), and because most electricity generation emissions are constrained by existing regulatory caps. Any additional increase in the amount of all-electric vehicle miles traveled or further emissions constraints on the electric sector would tend to magnify these benefits.

The key results of the air quality study are summarized below:

- In most regions of the United States, PHEVs result in small but significant improvements in ambient air quality and reduction in deposition of various pollutants such as acids, nutrients and mercury.
- On a population weighted basis, the improvements in ambient air quality are small but numerically significant for most of the country.
- The emissions of gaseous criteria pollutants (NOx and SO_2) are constrained nationally by regulatory caps. As a result, changes in total emissions of these pollutants due to PHEVs reflect slight differences in allowance banking during the study's time horizon.
- Considering the electric and transportation sector together, total emissions of VOC, NOx and SO_2 from the electric sector and transportation sector decrease due to PHEVs. Ozone levels decreased for most regions, but increased in some local areas. When assuming a minimum detection limit of 0.25 parts per billion, modeling estimates that 61% of the population would see decreased ozone levels and 1% of the population would see increased ozone levels.
- Mercury emissions increase by 2.4% with increased generation needs to meet PHEV charging loads. The study assumes that mercury is constrained by a cap-and-trade program, with the option for using banked allowances, proposed by EPA during the execution of the study. The electric sector modeling indicates that utilities take advantage of the banking provision to realize early reductions in mercury that result in greater mercury emissions at the end of the study timeframe (2030).
- Primary emissions of particulate matter (PM) increase by 10% with the use of PHEVs due primarily to the large growth in coal generation assumed in the study.
- In most regions, particulate matter concentrations decrease due to significant reductions in VOC and NOx emissions from the transportation sector leading to less secondary PM.

EPRI Perspective

This report describes a study to explore the air quality impacts of large numbers of plug-in hybrid electric vehicles (PHEVs) in year 2030 using a combination of transportation-sector, electric-sector and atmospheric (air quality) models.

PHEVs represent an important technical step toward increased fuel efficiency, decreased emissions, and greater energy independence. EPRI has supported the development of PHEV technology and continues to support its deployment with collaborative R&D and analyses.

Policymakers, technology developers, and utility and environmental planners need objective and accurate information to make sound decisions about developing and deploying PHEVs in support of national energy and environmental policy. PHEVs offer the potential for reducing both emissions and fuel consumption, simultaneously addressing the issues of global warming and the nation's dependence on imported oil. Quantifying these benefits has proved challenging, however, and misinformation has circulated about the environmental performance of PHEVs.

The objective of this study was to evaluate the impact of PHEVs on key air quality parameters for a future-year scenario with substantial penetration of PHEVs in the U.S. light-duty vehicle fleet (passenger cars and light-trucks).

This study is one component of a comprehensive environmental assessment of PHEVs conducted in collaboration with the Natural Resources Defense Council (NRDC). A second component is a nationwide analysis of the greenhouse gas (GHG) emissions from 2010-2050. Results of the GHG emissions analysis are presented in an EPRI technical report, Environmental Assessment of Plug-In Hybrid Electric Vehicles, Volume 1: Nationwide Greenhouse Gas Emissions (1015325).

Study findings will help support informed decision-making regarding PHEV development and deployment in support of national energy and environmental policy. Study results will also dispel misunderstandings about PHEVs and emissions—such as the common misunderstanding that PHEVs would worsen air quality due to emissions from electricity generation for battery charging.

NRDC Perspective

The Natural Resources Defense Council's purpose is to safeguard the Earth: its people, its plants and animals and the natural systems on which all life depends. The organization uses law, science, and the support of its members to promote solutions to our environmental challenges.

- Participation in this study does not imply NRDC endorses the power plant emission control assumptions in the air quality report. The study's air quality modeling and analysis are based on an assumption that regulatory caps govern NOx, SO_2 and mercury emissions during the study period, and that EPA rules do not change during the study time horizon. However, the actual situation is more complex—for example, a number of states have declined to participate in EPA's model cap-and-trade rule for mercury in favor of more stringent approaches. In addition, EPA's Clean Air Mercury Rule and Clean Air Interstate Rule (resulting in tighter NOx and SO_2 caps in the eastern U.S.) are currently being challenged in court. NRDC firmly believes that stronger emissions controls are necessary to protect human health. This study does not attempt to determine the adequate level of power plant controls or adequate levels of ambient air pollution and strives only to determine the specific impacts of large-scale PHEV penetration given the assumptions of the study.
- NRDC does not support trading off pollution benefits in some regions for pollution increases in others regions. NRDC believes that no areas or populations should be allowed to experience increases in air pollution exposures and that further emission controls from all sources are needed in order to protect public health. Consequently, NRDC supports more stringent emissions control requirements for the electric and transportation sectors, as well as other economic sectors.
- NRDC does believe that with sufficient emissions controls in place PHEVs have the potential to improve air quality and to substantially contribute to meeting our long term GHG reduction goals of 80% below 1990 levels by 2050.

- NRDC supports the introduction of PHEVs accompanied by substantial additional improvements in power plant emission rates. In areas where there are potential adverse impacts from air pollution as a result of PHEV charging, NRDC believes it is not appropriate to promote introduction until the public can be assured that air pollution will not increase.

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EPRI Perspective

This report describes a study to explore the air quality impacts of large numbers of plug-in hybrid electric vehicles (PHEVs) in year 2030 using a combination of transportation-sector, electric-sector and atmospheric (air quality) models.

PHEVs represent an important technical step toward increased fuel efficiency, decreased emissions, and greater energy independence. EPRI has supported the development of PHEV technology and continues to support its deployment with collaborative R&D and analyses.

Policymakers, technology developers, and utility and environmental planners need objective and accurate information to make sound decisions about developing and deploying PHEVs in support of national energy and environmental policy. PHEVs offer the potential for reducing both emissions and fuel consumption, simultaneously addressing the issues of global warming and the nation's dependence on imported oil. Quantifying these benefits has proved challenging, however, and misinformation has circulated about the environmental performance of PHEVs.

The objective of this study was to evaluate the impact of PHEVs on key air quality parameters for a future-year scenario with substantial penetration of PHEVs in the U.S. light-duty vehicle fleet (passenger cars and light-trucks).

This study is one component of a comprehensive environmental assessment of PHEVs conducted in collaboration with the Natural Resources Defense Council (NRDC). A second component is a nationwide analysis of the greenhouse gas (GHG) emissions from 2010-2050. Results of the GHG emissions analysis are presented in an EPRI technical report, Environmental Assessment of Plug-In Hybrid Electric Vehicles, Volume 1: Nationwide Greenhouse Gas Emissions (1015325).

Study findings will help support informed decision-making regarding PHEV development and deployment in support of national energy and environmental policy. Study results will also dispel misunderstandings about PHEVs and emissions—such as the common misunderstanding that PHEVs would worsen air quality due to emissions from electricity generation for battery charging.

NRDC Perspective

The Natural Resources Defense Council's purpose is to safeguard the Earth: its people, its plants and animals and the natural systems on which all life depends. The organization uses law, science, and the support of its members to promote solutions to our environmental challenges.

- Participation in this study does not imply NRDC endorses the power plant emission control assumptions in the air quality report. The study's air quality modeling and analysis are based on an assumption that regulatory caps govern NOx, SO_2 and mercury emissions during the study period, and that EPA rules do not change during the study time horizon. However, the actual situation is more complex—for example, a number of states have declined to participate in EPA's model cap-and-trade rule for mercury in favor of more stringent approaches. In addition, EPA's Clean Air Mercury Rule and Clean Air Interstate Rule (resulting in tighter NOx and SO_2 caps in the eastern U.S.) are currently being challenged in court. NRDC firmly believes that stronger emissions controls are necessary to protect human health. This study does not attempt to determine the adequate level of power plant controls or adequate levels of ambient air pollution and strives only to determine the specific impacts of large-scale PHEV penetration given the assumptions of the study.
- NRDC does not support trading off pollution benefits in some regions for pollution increases in others regions. NRDC believes that no areas or populations should be allowed to experience increases in air pollution exposures and that further emission controls from all sources are needed in order to protect public health. Consequently, NRDC supports more stringent emissions control requirements for the electric and transportation sectors, as well as other economic sectors.
- NRDC does believe that with sufficient emissions controls in place PHEVs have the potential to improve air quality and to substantially contribute to meeting our long term GHG reduction goals of 80% below 1990 levels by 2050.
- NRDC supports the introduction of PHEVs accompanied by substantial additional improvements in power plant emission rates. In areas where there are potential adverse impacts from air pollution as a result of PHEV charging, NRDC believes it is not appropriate to promote introduction until the public can be assured that air pollution will not increase.

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List of Abbreviations

AC – Alternating Current
ACC – Arizona Corporation Commission
ACI – Activated Carbon Injection
AEO – Annual Energy Outlook
AER – All-Electric Range
BEV – Battery Electric Vehicle
BEIS – Biogenic Emissions Inventory System
BELD – Biogenic Emission Land Cover
b_{ext}– Light Extinction
CAA – Clean Air Act
CAFE – Corporate Average Fuel Economy
CAIR – Clean Air Interstate Rule
CAMR – Clean Air Mercury Rule
CARB – California Air Resources Board
CAVR – Clean Air Visibility Rule
CEC – California Energy Commission
CENRAP – Central Regional Air Planning Association
CMAQ – Community Multiscale Air Quality
CMAS – Community Modeling and Analysis System
CO – Carbon Monoxide
CO_2 – Carbon Dioxide
CONUS – Continental United States
CPUC – California Public Utilities Commission
CRA – Charles River Associates International
CV – Conventional Vehicle
DC – Direct Current
DPV2 – Devers-Palo Verde 2
dv – Deciview
DV – Design Value
DVE – Design Value Exposure
ECAR – East Central Area Reliability Coordination Agreement
EGU – Electrical Generating Unit
EIA – Energy Information Agency
EMFAC – Emissions Factor
EPA – Environmental Protection Agency
ERC – Emission Reduction Credits
ERCOT – Electricity Reliability Council of Texas
ES&D – Electricity Supply and Demand
FDDA – Four Dimensional Data Analysis
FF – Fabric Filter
FGD – Flue Gas Desulfurization
FUDS – Federal Urban Driving Schedule
GIS – Geographic Information System
GVWR – Gross Vehicle Weight Rating
HEV – Hybrid Electric Vehicle
HDGV – Heavy Duty Gasoline Vehicle
HDDV – Heavy Duty Diesel Vehicle
Hg – Mercury
Hg^0 – Elemental Mercury
Hg^{2+} – Oxidized Mercury
HgP – Particulate Mercury
ICEV – Internal Combustion Engine Vehicle
IDA – Inventory Data Analyzer
IEPR – Integrated Energy Policy Report
IMPROVE – Interagency Monitoring of Protected Visual Environments
IPM – Integrated Planning Model
LDGV – Light Duty Gasoline Vehicle
LDGT – Light Duty Gasoline Truck
LDDV – Light Duty Diesel Vehicle
LDDT – Light Duty Diesel Truck
LSM – Land Surface Model
MAAC – Mid-Atlantic Area Council
MAIN – Mid-America Interconnected Network
MAPP – Mid-Continent Area Power Pool
MC – Motorcycles
MCIP – Meteorology-Chemistry Interface Processor
MM5 – Mesoscale Model, version 5
MOBILE – EPA Mobile Emissions Model
MRPO – Midwest RPO
MSAT – Mobile Source Air Toxics
$\mu g\ m^{-3}$ – micrograms per cubic meter
NAAQS – National Ambient Air Quality Standard
NEI – National Emissions Inventory
NEEM – North American Electricity & Environmental Model
NEMS EMM – National Energy Modeling System: Electric Markets Module

List of Abbreviations

NERC – North American Electric Reliability Corporation

NIET – National Interest Electric Transmission

NMIM – National Mobile Inventory Model

NWP – Northwest Power Pool

NH_3 – Ammonia

NH_4^+ – Ammonium

NO – Nitric Oxide

NO_2 – Nitrogen Dioxide

NO_3 – Nitrate

NOx – Nitrogen Oxides (NO + NO_2)

NSR – New Source Review

O_3 – Ozone

O&M – Operation and Maintenance

PBL – Planetary Boundary Layer

PHEV – Plug-In Hybrid Electric Vehicle

PM – Particulate Matter

PM_{10} – Particulate Matter with an Aerodynamic Diameter less than 10 micrometers (Coarse and Fine Particulate Matter)

$PM_{2.5}$ – Particulate Matter with an Aerodynamic Diameter less than 2.5 micrometers (Fine Particulate Matter)

ppb – Parts per Billion (also ppbv – parts per billion per volume)

PRB – Powder River Basin

PSD – Prevention of Significant Deterioration

RA – Rocky Mountain Power Area, AZ, NM, Southern Nevada

RECLAIM – Regional Clean Air Incentives Market

RH – Relative Humidity

RHR – Regional Haze Rule

RGGI – Regional Greenhouse Gas Initiative

RMC – Regional Modeling Center

RPO – Regional Planning Organization

RPS – Renewable Portfolio Standards

SCAQMD – South Coast Air Quality Management District

SCR – Selective Catalytic Reduction

SERC – Southeastern Reliability Council

SIP – State Implementation Plan

SMOKE – Sparse-Matrix Operation Kernel Emissions

SNCR – Selective Non-Catalytic Reduction

SO_2 – Sulfur Dioxide

SO_4^{2-} – Sulfate

SOx – Sulfur Oxides

SoCAB – South Coast Air Basin

SPP – Southwest Power Pool

TOG – Total Organic Gases

TOMS – Total Ozone Mapping Spectrometer

VISTAS – Visibility Improvement State and Tribal Association of the Southeast

VMT – Vehicles Miles Travelled

VOC – Volatile Organic Compounds

WRAP – Western Regional Air Partners

1 Introduction

National interest in electric transportation, particularly plug-in hybrid electric vehicles (PHEVs), has increased dramatically in recent years. Much of this interest is based on the potential societal benefits of electrifying transportation in general, and PHEVs in particular, including:

- A reduction in petroleum consumption leading to reduced dependence on imported oil and increased energy security;
- A net reduction in greenhouse gas emissions due to the electrification of transportation; and
- The potential to improve air quality, particularly in urban areas with high levels of vehicle-related pollution.

Volume 1 of this study evaluated the impact of PHEVs on greenhouse emissions from the transportation and electric sectors. This volume evaluates the net impact on air quality and deposition due to changes in transportation and electric sector emissions resulting from electrifying on-road transportation. In contrast to other studies, the analysis in this report takes accounts for the evolution of the electric and transportation sectors and how their evolution may be impacted by an aggressive penetration of PHEVs in the study timeframe.

Electrification of transportation reduces direct emissions from on-road vehicles. Refueling emissions also decline because of lower fuel consumption. Greater electricity demand as a result of PHEVs charging requirements affects electricity generation and associated emissions. However, the electric sector would still need to satisfy the emissions cap[1] requirements of existing environmental regulations, such as the Clean Air Interstate Rule (CAIR) and the model cap-and-trade program proposed by the EPA following the Clean Air Mercury Rule (CAMR).

This study calculates the magnitudes of emissions changes, including any changes in spatial and temporal patterns of emissions from electrical generating units, assuming an aggressive rate of PHEV penetration into the vehicle fleet (50% of new vehicle sales and ~40% of the total vehicle fleet). These changes are implemented in a future year (2030) emissions inventory for the United States. Detailed air quality model simulations for a full calendar year are performed to evaluate the impact of these net emission changes on ozone, particulate matter, visibility, and deposition of nutrients (sulfate, nitrate, and total nitrogen) and mercury.

Plug-In Hybrid Electric Vehicles

Plug-in hybrid electric vehicles combine operational aspects of both battery electric vehicles (BEVs) and power-assist hybrid electric vehicles (HEVs). Similar to a BEV, a PHEV can store significant energy within an onboard battery and use this energy during daily driving, thereby depleting the battery which can be recharged from the electric grid. In addition, a PHEV has an internal combustion engine that is also used for propulsion. Therefore, unlike a BEV, a PHEV will not suffer from a "dead" battery. Due to this versatility, a PHEV can serve as a direct replacement for a conventional internal combustion engine vehicle (ICEV) or an HEV.

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[1] Regulatory caps are limits on the total emissions that the electric sector as a whole may emit during a year regardless of electricity demand. EPA distributes emissions allowances (the right to emit a unit of a pollutant) in an open market. Electric companies can trade allowances in a cap-and-trade system or choose to "bank" allowances for use in the future if they emit below their total emissions allowance.

The potential for widespread adoption of PHEV technology is primarily due to their close technological kinship with hybrid vehicles. HEVs with sophisticated, high-power traction drive systems, power electronics, and high-voltage systems are already in the marketplace. PHEVs leverage much of this existing technology foundation—the primary difference is the incorporation of an "energy" battery that allows the PHEV to directly use grid electricity for propulsion.

The use of electricity in a PHEV results in environmental impacts that have to be evaluated from a perspective that includes both the transportation and electric sector. As shown in Volume 1 of this report, PHEVs recharged by electricity generated from efficient combustion, non-emitting, or renewable technologies emit significantly lower fuel-cycle greenhouse gas emissions than either conventional or hybrid electric vehicles. PHEVs also reduce direct emissions at the vehicle, with potential positive implications for transportation-dense urban areas that suffer from poor air quality due in part to mobile source emissions. In this volume, the air quality impacts of PHEVs are explored in a comprehensive manner.

Objectives

The objective of this study is to evaluate the impact of PHEVs on key air quality parameters for a future-year scenario with substantial penetration of PHEVs in the U.S. light-duty vehicle fleet (passenger cars and light-trucks). In order to meet this objective, a suite of computational modeling tools are used to compare two scenarios:

- a base case scenario assuming no PHEVs in the vehicle fleet, and
- a PHEV case scenario assuming a high penetration of PHEVs in the vehicle fleet (approximately 40% of on-road vehicles and 50% of new vehicle sales in 2030).

Methodology

The air quality impacts of PHEVs are compared to a baseline scenario developed using assumptions consistent with the U.S. Department of Energy's 2006 Annual Energy Outlook (AEO). The scenarios have also been modified to ensure consistency with the California Energy Commission's 2005 Integrated Energy Policy Report (IEPR). As a result, this study explores the impact of PHEVs on criteria emissions and subsequent air quality and deposition impacts in 2030 based on a scenario without any national CO_2 or greenhouse gas policies or constraints.[2] However, the study does include all U.S. Environmental Protection Agency (EPA) and California Air Resources Board (CARB) rulemaking under implementation as of January 1, 2006.[3] In addition, the analysis includes all Renewable Portfolio Standards (RPS) currently ratified or proposed within the continental United States (CONUS) as of January 1, 2006.

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[2] The scenario explored in this study represents an appropriate framework from an air quality perspective at this time. Determining the air quality impacts of PHEVs under national CO_2 or greenhouse gas policies or constraints would necessitate defining specific details, including (but not limited to) the nature of the policy and whether one uniform policy applies across different economic sectors or whether different policies apply to individual economic sectors (or groupings of economic sectors). This study does not seek to define potential CO_2 policies. Notwithstanding, any technologies implemented to satisfy a greenhouse gas policy on the electric sector are expected to lead to less air quality criteria emissions from the sector and result in a concomitant improvement to air quality from the adoption of PHEVs.

[3] Legislations such as California's Global Warming Solutions Act of 2006 (AB 32) and California's Greenhouse Gas Performance Standards (SB 1368) or the Regional Greenhouse Gas Initiative (RGGI) of Northeastern and Mid-Atlantic States not included in the analysis. In the 2005 Integrated Energy Policy Report (IEPR), the California Energy Commission recommended that the California "should specify a GHG performance standard and apply it to all utility procurement, both in-state and out-of-state, both coal and non-coal," but it was not until later that this standard was promulgated into law as SB1368. Both AB 32 and SB1368 were signed by Governor Schwarzenegger of California during the execution of this study and were not included in the analysis due to a lack of specific details on their implementation at the time. Similarly, it was not until late 2006 that the states participating in RGGI developed issued a model rule for the RGGI program. As a result, the study maintains a close similarity to AEO 2006.

In contrast to other studies that have attempted to evaluate the environmental impacts of PHEVs, the analysis presented in this report integrates comprehensive transportation, electric sector and atmospheric models. The key characteristics that differentiate this study from other analyses are as follows:

- This study simulates evolution of the electric sector from present day to 2030 for the two scenarios evaluated.
- For each year in the PHEV Case, this study evaluates the impact on the electric sector (capacity and generation) due to the incremental load from PHEVs as the technology increasingly penetrates the overall vehicle fleet.
- This study calculates emissions from the electric sector assuming compliance with all current federal air quality regulations on electricity generation and their associated levels of enforcement from present day to 2030.
- This study translates the changes in emissions from both the transportation and electric sector to metrics of ambient pollutant levels, exposure and deposition.

Transportation Sector Modeling

Chapter 2 describes development of emissions for the transportation sector that were used as input for the air quality model. The principal determinant for vehicle emissions, vehicle miles travelled (VMT) and corresponding emissions for each vehicle class in the transportation sector were modeled for calendar year 2030 for the base case and PHEV case.

Similar to the AEO, the transportation sector models used in this study tend to be cautious in projecting the impact of new technologies and therefore represent a "business-as-usual" approach to vehicle inventories. The analysis in this study includes current EPA regulations affecting the transportation sector, including the Tier II Gasoline Program, the Clean Air Highway Diesel Rule and the Clean Air Non-Road Diesel Rule. Notwithstanding, future projections of the transportation sector are sensitive to many important factors as discussed in Chapter 2. In particular, with respect to this study, the principal factors for defining the PHEV case include:

- PHEV market penetration,
- HEV and PHEV vehicle characteristics,
- PHEV utility factor,
- PHEV electrical consumption, and
- PHEV charge profile.

These factors and the corresponding assumptions necessary for performing this study are discussed in detail in Chapter 2.

Reductions in point-source and area-source upstream emissions due to reduced gasoline consumption resulting from the PHEV penetration are also included in order to provide a more complete analysis of the overall effect of PHEVs on emissions.

Electric Sector Modeling

Using the assumptions consistent with AEO 2006, U.S. electric sector generation operations are modeled from the present out to the year 2030 for both scenarios. In this study, the North American Electricity & Environmental Model (NEEM) system is used to simulate operation of individual generation units across the nation and their associated emissions in 2030.

There are several key technical requirements that impact electricity generation modeling:

- Incremental electricity demands due to PHEVs from 2010 to 2030 are required at the state level in order to provide region-specific information for NEEM modeling.
- Electricity load duration curves from 2010 to 2030 need to reflect impacts due to the timing of PHEV electrical charging.
- Electricity generation and corresponding emissions in 2030 need to be temporally and spatially consistent with the meteorological data used by the air quality modeling, i.e. the emissions should reflect the influence that meteorology exerts on electricity demand.
- Emission rates of all plume constituents in 2030 are required by unit and stack at the national level for input into the air quality modeling system.

Chapter 3 describes the electric sector modeling in detail and describes the impact of PHEVs on capacity, generation and emissions relative to the Base Case with no PHEVs present in the vehicle fleet.

Emissions Processing

Before air quality model simulations are performed, emissions from the transportation sector and electric sector are merged with emissions from all other economic sectors and from natural sources. Chapter 4 describes this process in detail and summarizes national emissions for both the base case and PHEV case.

Air Quality Modeling

An air quality model was used to simulate the air quality impacts of PHEVs in 2030. EPA's Community Multiscale Air Quality (CMAQ) modeling system was used to simulate both scenarios; the impact of PHEVs was determined by comparing results from the two simulations. Air quality impacts are presented for the following air quality parameters:

- ozone mixing ratios,
- particulate matter concentrations,
- nutrient (sulfate, nitrate and total nitrogen) deposition,
- mercury deposition, and
- visibility.

This comparison is presented in Chapter 5, accompanied by an evaluation of the extent of the PHEV impacts on air quality determined by calculating population exposure and deposition flux metrics.

Roadmap

Figure 1-1 provides an overview of the study methodology. The numbered items in blue in the first column represent individual chapters of this report. Chapter 6 provides a final interpretation of the results, including important caveats, discusses key insights from the study.

The final modeling results are discussed in Chapters 5 and 6. Because of the significant reduction in emissions from gasoline and diesel fuel use and because caps are in place for some conventional pollutants for the electric power sector, the study finds that in many regions deployment of PHEVs would reduce exposures to ozone and particulate matter, and reduce deposition rates for acids, nutrients, and mercury.

On the other hand, because of assuming no further controls beyond existing regulations for the power sector, ozone levels would increase locally in some areas. Similarly, the direct emissions of particulate matter and mercury would increase somewhat and some regions and populations would experience marginal increases in exposures to those pollutants. However, as explained in the report, PHEVs do not increase the U.S. contribution to the global mercury budget over the long term.

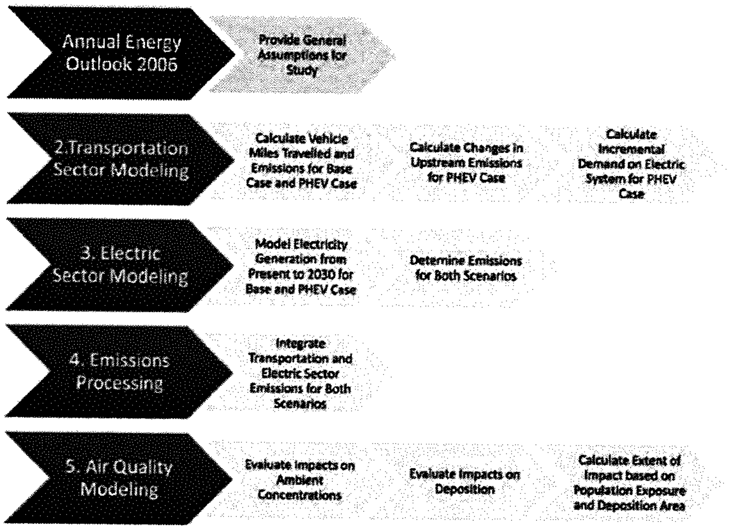

Figure1-1
Methodology of the Study

The air quality study is not meant to project carbon dioxide (CO_2) emissions and does not include any climate-change policies or greenhouse gas emissions constraints. As explained earlier, it is based on the U.S. Department of Energy's 2006 Annual Electric Outlook. A separate report modeled both the transportation and electricity sectors out to 2050 in order to analyze greenhouse gas emissions.

Overall, the air quality benefits from PHEVs are due to a reduction of vehicle emissions below levels required by current regulation (due to their non-emitting operation in all-electric mode), and because most electricity generation emissions are constrained by existing regulatory caps. Any additional increase in the amount of all-electric vehicle miles traveled or further emissions constraints on the electric sector would tend to magnify these benefits.

2 Transportation Sector Modeling

This chapter describes the development of emissions for the transportation sector to be used as an input to the air quality model. The principal determinant for vehicle emissions, vehicle miles travelled (VMT) and corresponding emissions for each vehicle class in the transportation sector were modeled for calendar year 2030 for two scenarios:

1. **Base Case** – assumes no penetration of PHEVs, and
2. **PHEV Case** – assumes high penetration of PHEVs (approximately 40% of on-road vehicles and 50% of new vehicle sales in 2030) in the vehicle fleet.

The starting point for developing on-road emissions for these two scenarios was the 36-km gridded emission inventories for 2018 developed by the five Regional Planning Organizations (RPOs) for visibility modeling. The RPOs have been established to address regional haze impairment in federally-protected parks and wilderness areas (Class I areas) and to develop implementation plans to demonstrate progress in improving visibility in those areas in accordance with the Regional Haze Rule (RHR). These emissions inventories were provided in a format ready to be used by air quality models. Scaling factors to project from 2018 to 2030 conditions were first developed to estimate 2030 Base Case emissions; scaling factors were then developed to estimate 2030 PHEV Case emissions from the 2030 Base Case emissions. These scaling factors were developed using EPA emissions models and EPA VMT projections for the continental United States, except in California for which scaling factors were developed based on California Air Resources Board (CARB) models and CARB VMT projections. Reductions in point-source and area-source upstream emissions due to reduced gasoline consumption resulting from the PHEV penetration were also included in order to provide a more complete analysis of the overall effect of PHEVs on emissions.

Development of 2030 Base Case Emissions

As described in Chapter 4, the starting point for the development of 2030 Base Case emissions for this project was the 36-km gridded Western Regional Air Partnership (WRAP) emission inventory for regional visibility modeling for 2018. This inventory compiles the work of the five RPOs—each RPO developed comprehensive emission inventories for all source categories for each of their states. In the development of emission inventories, emissions for most source categories are estimated as activity data (e.g. VMT for on-road vehicles) multiplied by an emission factor. On-road emissions for all states (except California) in all RPOs were estimated (by county) as the product of VMT by vehicle class and gram per mile emission factors from EPA's MOBILE6 model (EPA, 2004). The VMT activity data and MOBILE6 modeling inputs were developed by WRAP with input from state and local air quality planning agencies. For California, CARB provided on-road emissions directly to WRAP; these were developed using CARB's Emissions Factor (EMFAC) model (CARB, 2003), which contains both activity data and emission factors at the county level.

To project the WRAP 2018 emissions to 2030, scaling factors were developed for each county. These scaling factors were derived using EPA's National Mobile Inventory Model 2005 (NMIM) (EPA, 2006) for all states except California. The NMIM model is a tool developed by the EPA for estimating emissions from on-road and non-road vehicles for all counties in the United States during the development of the National Emission Inventory (NEI). The NMIM model uses a county database which specifies MOBILE6 and VMT inputs by county (version NCD20060725 provided by the EPA was used in this study). NMIM uses the MOBILE6 model to generate emission factors and internally applies VMT estimates to these emission factors to generate emissions by county and vehicle class.

The NMIM county database incorporates future year fuel characteristics based on refinery modeling of anticipated fuel changes developed by EPA, local fleet characteristics files submitted to the EPA, and 20-year average temperature and humidity data for each county (EPA, 2005) as well as limited VMT estimates. For this study, the county database was updated to reflect VMT estimates based on EPA projections in the Clean Air Interstate Rule (CAIR) and Mobile Source Air Toxics (MSAT) rulemakings (EPA, 2006). **Table 2-1** shows the state-level VMT projections from 2018 to 2030 based on the EPA MSAT VMT estimates; 2030 projected VMT by county are available upon request.

For California, county-level projections factors were estimated based on simulations for 2018 and 2030 using the CARB EMFAC model release available at the time of the development of the original emissions in the inventory, EMFAC 2002 version 2.2. The EMFAC model contains both VMT projections and emissions reductions due to fleet turnover.

Table 2-1
Annual MSAT VMT and VMT Growth Factors by State (000,000 mi y^{-1})

State	2018	2030 Base	Growth Factor
Alabama	69,429	84,225	1.213
Arizona	86,125	115,938	1.346
Arkansas	41,131	49,653	1.207
California*	393,273	461,722	1.174
Colorado	66,806	87,113	1.304
Connecticut	41,573	53,020	1.275
Delaware	12,269	15,508	1.264
District of Columbia	5,276	6,945	1.316
Florida	206,655	259,481	1.256
Georgia	152,794	193,506	1.266
Idaho	22,113	27,591	1.248
Illinois	144,702	181,214	1.252
Indiana	98,590	119,835	1.215
Iowa	38,252	46,251	1.209
Kansas	38,134	46,849	1.229
Kentucky	64,999	78,417	1.206
Louisiana	56,372	68,597	1.217

(Continued)

Table 2-1 (Continued)
Annual MSAT VMT and VMT Growth Factors by State (000,000 mi y^{-1})

State	2018	2030 Base	Growth Factor
Maine	16,644	20,929	1.257
Maryland	73,829	95,971	1.300
Massachusetts	71,173	92,449	1.299
Michigan	131,842	162,019	1.229
Minnesota	73,372	94,024	1.281
Mississippi	39,942	48,000	1.202
Missouri	94,483	117,060	1.239
Montana	15,289	19,249	1.259
Nebraska	24,376	30,144	1.237
Nevada	35,129	47,931	1.364
New Hampshire	17,655	22,902	1.297
New Jersey	92,556	117,525	1.270
New Mexico	36,670	47,589	1.298
New York	173,685	218,871	1.260
North Carolina	125,489	155,663	1.240
North Dakota	9,599	12,007	1.251
Ohio	146,386	179,220	1.224
Oklahoma	59,851	72,785	1.216
Oregon	59,290	75,993	1.282
Pennsylvania	142,349	177,687	1.248
Rhode Island	11,027	14,192	1.287
South Carolina	61,413	75,133	1.223
South Dakota	11,708	14,640	1.250
Tennessee	91,224	112,664	1.235
Texas	317,002	403,568	1.273
Utah	33,492	41,966	1.253
Vermont	10,060	12,755	1.268
Virginia	101,586	128,241	1.262

(Continued)

Table 2-1 (Continued)
Annual MSAT VMT and VMT Growth Factors by State (000,000 mi y^{-1})

State	2018	2030 Base	Growth Factor
Washington	81,957	107,110	1.307
West Virginia	20,186	23,700	1.174
Wisconsin	78,493	98,383	1.253
Wyoming	10,438	12,566	1.204

* Source: EMFAC 2002

While estimated growth in VMT from 2018 to 2030 contributes to increasing on-road emissions, fleet turnover from older, higher emitting engines to newer, lower emitting engines has the effect of decreasing on-road emissions. Factors used to project emissions from 2018 to 2030 were developed separately for summer and winter seasons for each county as a composite across all vehicle classes as available. Composite factors needed to be developed because the 2018 emissions are for total on-road emissions by 36-km grid cell. The emission projection factors for each grid cell were developed using Geographic Information System (GIS) software to map the county-level projection factors to the 36-km grid cells.

Table 2-2 shows the summer season emission projection factors by state; these incorporate both fleet turnover effects and VMT projections. The winter emission projection factors, not shown here, show strong agreement with the summer emission factors presented in Table 2-2. The emissions projection factors in Table 2-2 indicate that from 2018 to 2030, the increase in emissions due to increasing VMT is greater than the decrease in emissions due to fleet turnover (i.e., projection factor greater than one) in all states for PM_{10}, $PM_{2.5}$, SO_2, and NH_3, CO (except California) and CO_2. For NOx in all states and total organic gases (TOG) in most states, the fleet turnover effects dominate VMT growth effects from 2018 to 2030. Differences in emission projection factors among states other than California are primarily due to variation in VMT growth rates by state as shown in Table 2-1 as well as differences in the fleet composition across states.

Per emissions processing, modeling, and reporting requirements, TOG emissions are reported in some tables whereas VOC emissions are reported in others. On-road hydrocarbon emissions are commonly reported as volatile organic compounds (VOC); the regulatory definition of VOC excludes hydrocarbons that EPA defines as less ozone forming (e.g., methane and ethane). Air quality models use Total Organic Gases (TOG) as the measurement for hydrocarbons; TOG includes hydrocarbons not included in the regulatory definition of VOC.

Table 2-2
Summer 2018 to 2030 Emission Projection Factors

State	TOG	CO	NOx	PM_{10}	$PM_{2.5}$	SO_2	NH_3	CO_2*
Alabama	0.935	1.099	0.740	1.136	1.070	1.217	1.204	1.224
Arizona	0.900	1.175	0.753	1.240	1.164	1.332	1.319	1.340
Arkansas	0.925	1.092	0.712	1.120	1.044	1.212	1.199	1.219
California	0.642	0.574	0.548	1.137	1.123	1.176	1.180	1.175
Colorado	0.977	1.181	0.827	1.227	1.159	1.309	1.296	1.316
Connecticut	0.915	1.155	0.655	1.199	1.132	1.280	1.268	1.287
Delaware	0.999	1.168	0.650	1.151	1.057	1.268	1.256	1.276
District of Columbia	1.046	1.218	0.771	1.266	1.220	1.321	1.309	1.327
Florida	0.961	1.136	0.775	1.180	1.114	1.261	1.248	1.267
Georgia	0.938	1.133	0.692	1.182	1.110	1.270	1.258	1.277
Idaho	0.948	1.130	0.739	1.157	1.080	1.252	1.239	1.260
Illinois	1.004	1.161	0.717	1.175	1.109	1.256	1.245	1.262
Indiana	0.930	1.104	0.719	1.132	1.060	1.220	1.208	1.227
Iowa	0.900	1.078	0.694	1.121	1.044	1.214	1.201	1.221
Kansas	0.948	1.115	0.740	1.144	1.071	1.233	1.221	1.241
Kentucky	0.920	1.094	0.702	1.126	1.055	1.211	1.198	1.218
Louisiana	0.930	1.098	0.712	1.132	1.059	1.222	1.209	1.229
Maine	0.978	1.160	0.776	1.185	1.121	1.263	1.248	1.271
Maryland	1.017	1.202	0.703	1.215	1.140	1.305	1.292	1.312
Massachusetts	1.060	1.229	0.748	1.231	1.169	1.306	1.293	1.312
Michigan	0.953	1.121	0.758	1.150	1.081	1.234	1.221	1.241
Minnesota	1.070	1.192	0.790	1.187	1.106	1.287	1.274	1.295
Mississippi	0.957	1.095	0.648	1.092	1.002	1.204	1.187	1.217
Missouri	0.934	1.116	0.703	1.156	1.085	1.244	1.231	1.251
Montana	0.972	1.147	0.756	1.163	1.081	1.263	1.250	1.272
Nebraska	0.952	1.124	0.739	1.148	1.071	1.241	1.228	1.249
Nevada	1.033	1.240	0.813	1.278	1.203	1.369	1.356	1.377

(Continued)

Table 2-2 (Continued)
Summer 2018 to 2030 Emission Projection Factors

State	TOG	CO	NOx	PM_{10}	$PM_{2.5}$	SO_2	NH_3	CO_2*
New Hampshire	0.965	1.172	0.698	1.205	1.126	1.302	1.289	1.310
New Jersey	1.006	1.177	0.590	1.179	1.103	1.273	1.262	1.278
New Mexico	0.993	1.180	0.774	1.204	1.124	1.302	1.289	1.311
New York	0.947	1.161	0.638	1.168	1.092	1.267	1.254	1.271
North Carolina	0.933	1.112	0.687	1.156	1.083	1.245	1.232	1.252
North Dakota	0.965	1.138	0.743	1.157	1.076	1.255	1.242	1.264
Ohio	1.040	1.157	0.748	1.146	1.078	1.229	1.217	1.236
Oklahoma	0.938	1.104	0.738	1.133	1.062	1.221	1.208	1.228
Oregon	0.820	1.097	0.671	1.170	1.083	1.285	1.274	1.291
Pennsylvania	0.917	1.123	0.648	1.165	1.093	1.253	1.240	1.260
Rhode Island	0.988	1.178	0.772	1.237	1.191	1.292	1.280	1.298
South Carolina	0.942	1.110	0.725	1.135	1.059	1.228	1.215	1.236
South Dakota	0.958	1.137	0.740	1.155	1.074	1.255	1.241	1.263
Tennessee	0.929	1.099	0.695	1.152	1.081	1.240	1.227	1.247
Texas	0.988	1.168	0.772	1.212	1.159	1.275	1.265	1.281
Utah	0.844	1.112	0.696	1.171	1.100	1.259	1.246	1.266
Vermont	0.990	1.151	0.610	1.145	1.043	1.273	1.259	1.281
Virginia	0.984	1.160	0.825	1.208	1.160	1.266	1.255	1.271
Washington	0.731	1.060	0.671	1.204	1.119	1.313	1.299	1.321
West Virginia	0.929	1.082	0.698	1.097	1.028	1.180	1.165	1.189
Wisconsin	1.097	1.198	0.749	1.168	1.094	1.258	1.245	1.265
Wyoming	0.927	1.093	0.720	1.111	1.033	1.205	1.192	1.213

Table 2-3 shows the overall (continental U.S.) on-road emissions in 2018 and 2030 in metric tons,[4] and percent change from 2018 to 2030. These are consistent with the emission projection factors shown in Table 2-2, i.e. decreases in VOC and NOx emissions and increases in PM_{10} and SOx emissions.

Table 2-3
2018 and 2030 Continental U.S. On-Road Emissions (000 ton y^{-1})

Pollutant	**NOx**	**SOx**	**PM10**	**VOC**
2018	2,197	35	154	2,200
2030 Base	1,543	44	172	2,072
Percent Changes	-29.8%	25.8%	12.2%	-5.9%

Development of the PHEV Case

The MOBILE6 and EMFAC models were used in order to develop emissions for the PHEV Case. The development of a representative PHEV Case scenario is a complex task for a number of factors:

- Both MOBILE6 and EMFAC contain numerous discrete vehicle categories that aggregate hundreds of millions of vehicles in the nationwide fleet;
- Energy consumption of HEVs and PHEVs (pump fuels and electricity) must be representative of an entire category;
- Inherent uncertainties to any forecast extending decades into the future, particularly with respect to market penetrations of HEV and PHEV powertrain technologies; and
- National interest in diversifying the transportation sector fuel supply away from petroleum may create new emissions categories not currently taken into account in the models.

MOBILE6 and EMFAC use a cautious approach with respect to the incorporation of new technologies. This necessitates significant modification of the vehicle inventories in MOBILE6 and EMFAC to create future scenarios of high market penetrations for vehicles with HEV and PHEV powertrain technologies.

PHEV Case Assumptions

The principal elements for defining the PHEV case include:

1. PHEV market penetration,
2. HEV and PHEV vehicle characteristics,
3. PHEV utility factor,
4. PHEV electrical consumption, and
5. PHEV charge profile.

The assumptions for each of these elements are discussed in detail in the following sections.

PHEV Market Penetration

A simple market penetration model, described in more detail in Volume 1 of this report, was used in this study. This study assumes that the entry of PHEVs into the vehicle fleet takes future market share from both conventional vehicles (CVs) and HEVs. This study also assumes market conditions whereby PHEVs become the dominant powertrain technology during the study timeframe. This optimistic scenario is based on a combination of favorable factors, including (but not limited to) high fuel prices, societal

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[4] Throughout this report, the unit 'ton' corresponds to metric tons.

concerns about climate change and energy security, and improvements in the cost and performance of PHEV technology. **Figure 2-1** shows the market penetration of CVs, HEVs, and PHEVs for the PHEV case from 2010 to 2030 based on the assumptions used in the market penetration model. HEVs constitute approximately 15% of the market of new vehicle sales when PHEVs are assumed to enter the market in 2010. Both technologies displace CV sales.

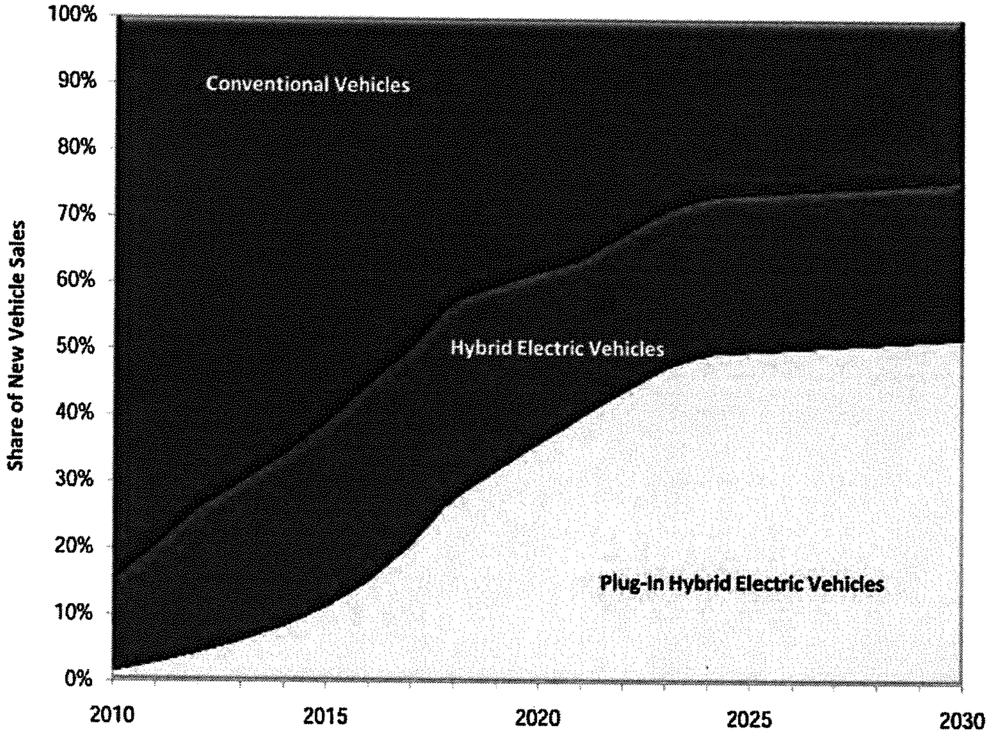

Figure 2-1
Assumed New Vehicle Market Share for Conventional Vehicles (CV), Hybrid Electric Vehicles (HEV), and Plug-In Hybrid Electric Vehicles (PHEV) for Each Vehicle Category

As shown in Chapter 3, the amount of electricity used to charge even these high numbers of PHEVs is small relative to the total amount of electrical energy generated each year by the electric sector. Therefore the aggressiveness of this market scenario was also driven by the necessity of building a large enough market penetration of PHEVs to create a significant incremental (marginal) electrical load consistent across both the air quality and greenhouse gas analyses. This market penetration scenario is not a prediction of actual future market share, which will be determined by many technological, economic, societal and political factors. The context of this market penetration assumption was to develop a scenario with a high probability of creating a noticeable impact on electricity sector generation. This noticeable impact will thereby enable us to determine the impact of PHEVs on the electric sector and consequent impacts on air quality and greenhouse gas emissions.

HEV and PHEV Vehicle Characteristics

Vehicle Model Inputs. MOBILE6 and EMFAC vehicle emission models use similar, but not identical categorizations of the automotive vehicle fleet. The vehicle model inputs are explained in detail for MOBILE6; a similar methodology was used for EMFAC to model the California vehicle fleet.

Table 2-4 shows the 29 different vehicle categories of the MOBILE6 vehicle inventory. Vehicles are categorized by fuel (gasoline or diesel) and by Gross Vehicle Weight Rating (GVWR). In general, vehicle classifications that were eligible for PHEV market share were limited to those with GVWR of less than 19,500 lb. Motorcycles, specific bus categories, and vehicles with a GVWR greater than 19,500 lb were excluded. These classifications were excluded not because of their unsuitability for adaptation to a PHEV architecture, but due to a desire to account for the categories with a combination of the highest fraction of fleet VMT and relatively high likelihood that PHEV technology could be applied to the category in the near-term.

Table 2-4
MOBILE6 Vehicle Classifications

Individual Vehicle Type	GVWR (lb)	Individual Vehicle Type - Description
LDGV	-	Light-Duty Gasoline Vehicles (Passenger Cars)
LDGT1	0-6000	Light-Duty Gasoline Trucks 1 (0-6,000 lb GVWR, 0-3750 lb LVW)
LDGT2	0-6001	Light Duty Gasoline Trucks 2 (0-6,001 lb GVWR, 3751-5750 lb LVW)
LDGT3	6001-8500	Light Duty Gasoline Trucks 3 (6,001-8500 lb GVWR, 0-3750 lb LVW)
LDGT4	6001-8500	Light Duty Gasoline Trucks 4 (6,001-8500 lb GVWR, 3751-5750 lb LVW)
HDGV2B	8501-10000	Class 2b Heavy Duty Gasoline Vehicles (8501-10,000 lb GVWR)
HDGV3	10001-14000	Class 3 Heavy Duty Gasoline Vehicles (10,001-14,000 lb GVWR)
HDGV4	14001-16000	Class 4 Heavy Duty Gasoline Vehicles (14,001-16,000 lb GVWR)
HDGV5	16001-19500	Class 5 Heavy Duty Gasoline Vehicles (16,001-19,500 lb GVWR)
HDGV6	19501-26000	Class 6 Heavy Duty Gasoline Vehicles (19,501-26,000 lb GVWR)
HDGV7	26001-33000	Class 7 Heavy Duty Gasoline Vehicles (26,001-33,000 lb GVWR)
HDGV8A	33001-60000	Class 8a Heavy Duty Gasoline Vehicles (33,001-60,000 lb GVWR)
HDGV8B	>60000	Class 8b Heavy Duty Gasoline Vehicles (>60,000 lb GVWR)
LDDV	-	Light Duty Diesel Vehicles (Passenger Cars)
LDDT12	0-6000	Light Duty Diesel Trucks 1 (0-6,000 lb GVWR)
HDDV2B	8501-10000	Class 2b Heavy Duty Diesel Vehicles (8501-10,000 lb GVWR)
HDDV3	10001-14000	Class 3 Heavy Duty Diesel Vehicles (10,001-14,000 lb GVWR)
HDDV4	14001-16000	Class 4 Heavy Duty Diesel Vehicles (14,001-16,000 lb GVWR)
HDDV5	16001-19500	Class 5 Heavy Duty Diesel Vehicles (16,001-19,500 lb GVWR)
HDDV6	19501-26000	Class 6 Heavy Duty Diesel Vehicles (19,501-26,000 lb GVWR)
HDDV7	26001-33000	Class 7 Heavy Duty Diesel Vehicles (26,001-33,000 lb GVWR)
HDDV8A	33001-60000	Class 8a Heavy Duty Diesel Vehicles (33,001-60,000 lb GVWR)
HDDV8B	>60000	Class 8b Heavy Duty Diesel Vehicles (>60,000 lb GVWR)
MC	-	Motorcycles (Gasoline)
HDGB	-	Gasoline Buses (School, Transit and Urban)
HDDBT	-	Diesel Transit and Urban Buses
HDDBS	-	Diesel School Buses
LDDT34	6001-8500	Light Duty Diesel Trucks 1 (6,001-8500 lb GVWR)

Table 2-5 shows the final seventeen categories selected for PHEV (and by relation HEV) market share in the PHEV scenario case. Energy consumption for both HEVs and PHEVs is based on existing EPRI simulation data and adjusted for compatibility with MOBILE6 fuel economy data. For this study, a HEV is assumed to have 35% lower fuel consumption than a CV. This number is comparable to both simulated (EPRI, 2001; EPRI, 2002) and EPA-certified differentials between CVs and HEVs.

For this study, a PHEV has equivalent fuel consumption attributes to a HEV for the portion of VMT not powered by electricity. Electric energy consumption attributes of each vehicle category are calculated from EPRI simulation data for PHEVs (EPRI, 2001; EPRI, 2002) and adjusted for baseline MOBILE6 fuel consumption. Direct current (DC) electricity consumption represents the average performance of that vehicle category on the federal urban driving schedule (FUDS). MOBILE6-adjusted DC electricity consumption (Table 2-5, Column 6) represents "real-world" electrical energy consumption by the vehicle and is calculated by applying a correction factor based on MOBILE6 fuel economy. MOBILE6-adjusted alternating current (AC) electricity consumption is the AC electricity consumption figure, per mile, used to calculate vehicle energy demand to the electric sector. DC electrical energy is converted to AC electrical energy from the wall outlet (supplied by the electrical grid) using an 88% conversion efficiency from AC energy at the outlet to stored DC energy in the battery pack of the vehicle. This conversion efficiency includes charger and battery losses and is based on prior simulation data (EPRI, 2001) and adjusted for recent lithium ion battery charging test data (SCE, 2007).

Table 2-5
HEV and PHEV Attributes of the Vehicle Categories Selected for Hybridization

Individual Vehicle Type	GVWR (lb)	Test Mass (kg)	DC Electricity Consumption (Wh mi^{-1})	MOBILE6 Fuel Economy (mpg)	Adjusted MOBILE6 HEV Fuel Economy (mpg)	MOBILE6 Adjusted DC Electricity Consumption (Wh mi^{-1})	MOBILE6 Adjusted AC Electricity Consumption (Wh mi^{-1})
Gasoline Vehicles							
LDGV	-	1651	237	24.1	37.1	280.0	318.2
LDGT1	0-6000	2268	296	18.5	28.5	346.9	394.2
LDGT2	0-6001	2268	296	18.5	28.5	346.9	394.2
LDGT3	6001-8500	3289	393	14.2	21.8	434.0	493.2
LDGT4	6001-8500	3289	393	14.2	21.8	434.0	493.2
HDGV2B	8501-10000	3776	439	10.1	15.6	584.7	664.4
HDGV3	10001-14000	4899	547	9.4	14.4	626.1	711.5
HDGV4	14001-16000	6124	663	9.4	14.4	628.5	714.3
HDGV5	16001-19500	7246	771	8.0	12.3	723.8	822.5
Diesel Vehicles							
LDDV	-	1726	244	32.4	49.8	288.5	327.9
LDDT12	0-6000	2375	306	22.1	34.0	358.8	407.8
HDDV2B	8501-10000	3886	450	13.0	19.9	598.6	680.2
HDDV3	10001-14000	5042	560	11.7	17.9	641.7	729.2
HDDV4	14001-16000	6303	681	10.2	15.7	644.8	732.7
HDDV5	16001-19500	7460	791	9.9	15.2	742.9	844.2
HDDV6	19501-26000						
LDDT34	6001-8500	3446	408	17.0		450.6	512.1

Vehicle Fuel Economy. The three vehicle types in this study all use liquid pump fuels; thus, fuel consumption is an important parameter for determining total emissions. The MOBILE6 and EMFAC databases assume that vehicle fuel efficiency does not improve over time. Historically, the last significant increase in United States fleet fuel efficiency occurred due to the implementation of the Corporate Average Fuel Economy (CAFE) standard.

For logical consistency, this study assumes that the market conditions which are sufficient to produce significant market shares for PHEVs will also create similar motivation for automotive manufacturers to offer, and for consumers to purchase, more fuel efficient conventional and hybrid vehicles. This reasoning creates the following study assumptions, expressed for the light-duty gasoline vehicle (LDGV) category, but propagated consistently throughout the other vehicle categories:

1. Initial fuel economy of conventional LDGV is 24.1 mpg.
2. Initial fuel economy of the HEV LDGV is 37.1 mpg.
3. PHEVs, when not using electrical energy, have identical fuel economy to a corresponding HEV.
4. Fuel economy (fuel efficiency) for both CVs and HEVs improves by 0.5% per year, resulting in 2050 new vehicle fuel economy of 30.0 mpg and 46.3 mpg, respectively.

Figure 2-2 shows the improvement in fuel economy for the gasoline LDGV.

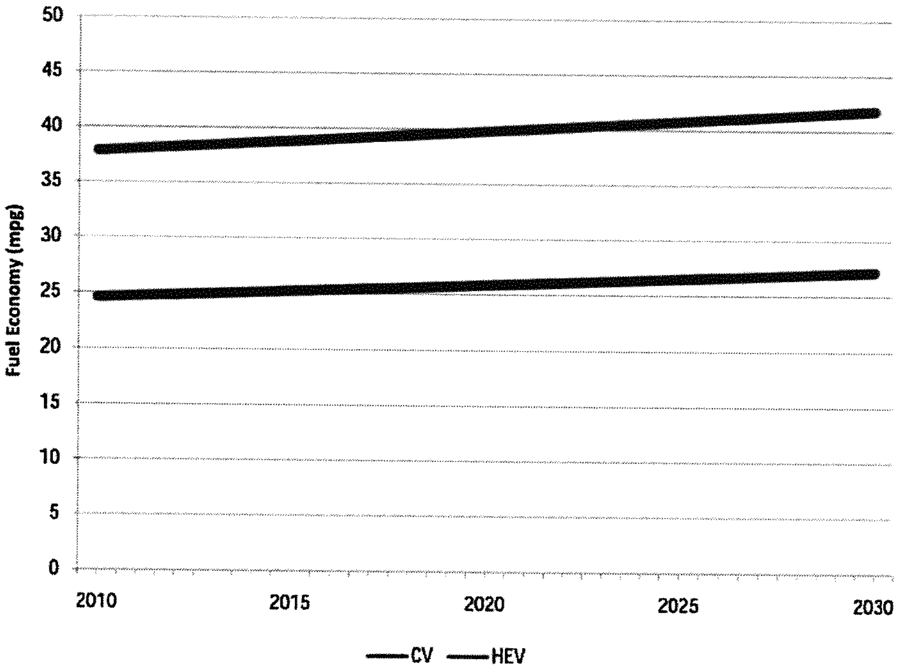

Figure 2-2
Evolution of Conventional and Hybrid Electric Vehicle Fuel Economy for the LDGV Category

PHEV Utility Factor

Utility factor is a term used to describe the fraction of driving in a PHEV that is performed by electricity. Utility factor varies with each individual vehicle and is limited by opportunities to charge the vehicle. In general, vehicles that are driven extremely long distances between recharging events will have a low utility factor. Vehicles that are driven on many short trips will have a high utility factor. On average, utility factor is heavily (but not entirely) dependent on two primary factors—annual VMT and vehicle All-Electric Range (AER). AER is a design parameter of the vehicle and indicates the number of miles the vehicle is capable of being driven using only battery energy (between recharges). AER is identified by attaching a numerical term (representing the AER in miles) immediately after the PHEV acronym. For example, a PHEV10 is a plug-in hybrid with 10 miles of electric range. For simplicity, this study considers PHEV10, PHEV20, and PHEV40 configurations.

Figure 2-3 shows the Utility Factor relationships that have been established for each of the PHEV configurations. These data are derived from prior EPRI driver models and assume that vehicles are generally charged once per day, may not be driven on all days, and experience a number of longer or overnight trips where the vehicle would not be recharged at the end of the day. Using these utility factors and VMT data, **Figure 2-4** shows the subsequent calculation of percentage of VMT provided in all-electric mode (eVMT) per MOBILE6 vehicle class. **Figure 2-5** illustrates a similar calculation based on EMFAC vehicle classes for use in California transportation sector modeling.

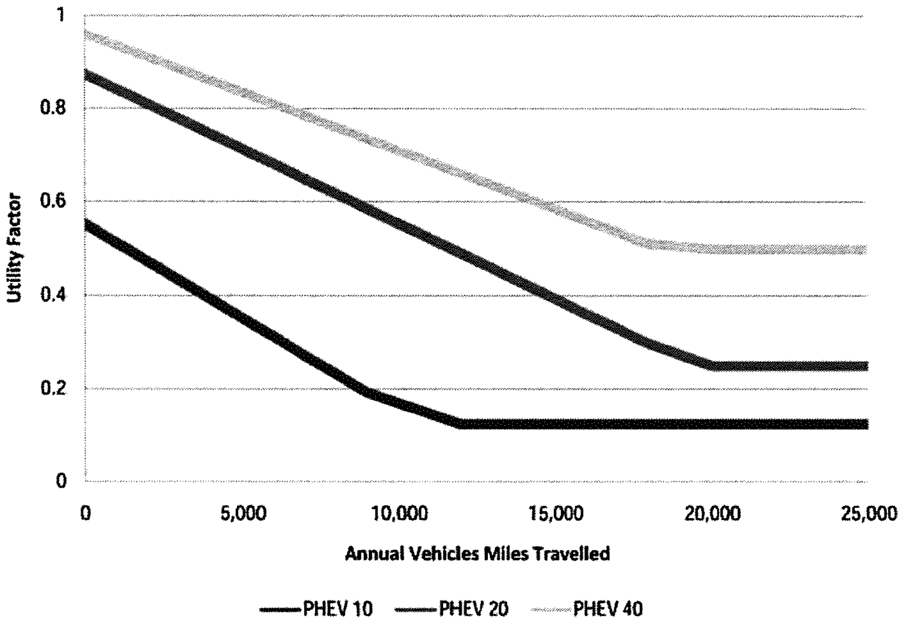

Figure 2-3
PHEV Utility Factor as a Function of AER and Annual VMT, Assuming Nightly Charging

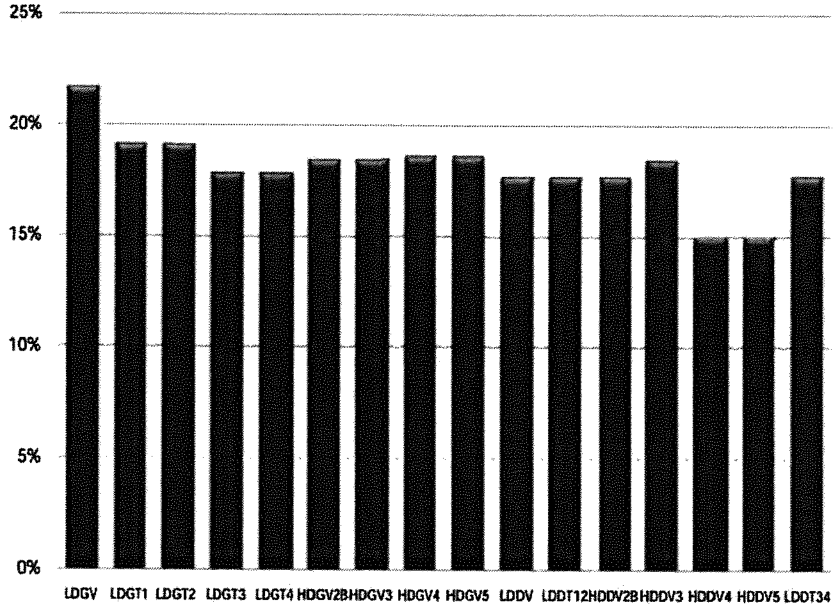

Figure 2-4
2030 47-State PHEV All-Electric VMT Fractions by MOBILE6 Vehicle Class

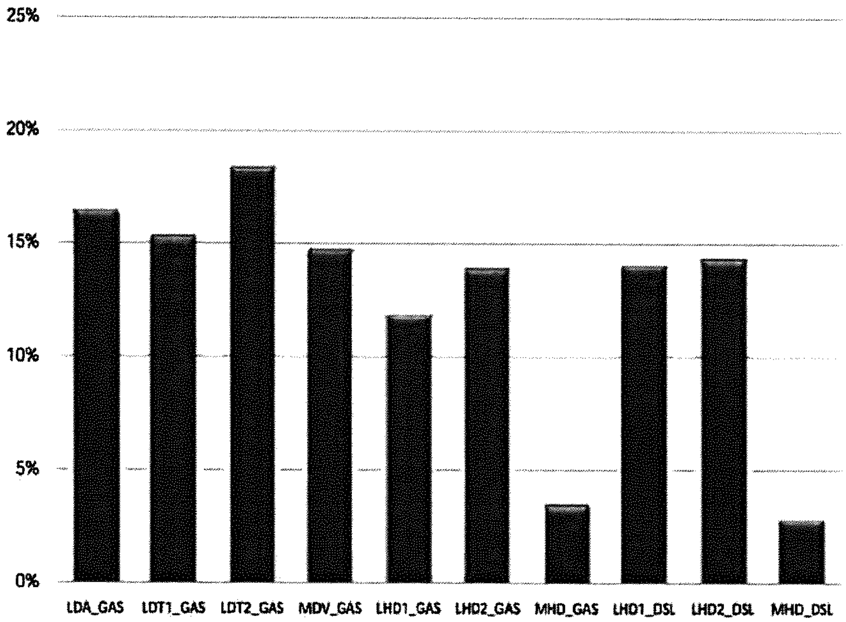

Figure 2-5
2030 California PHEV All-Electric VMT Fractions by EMFAC Vehicle Class

PHEV Electrical Energy Consumption

Figure 2-6 shows the distribution of total VMT by vehicle category for each of the 47 states in the MOBILE6 model. It is important to note that the selected categories account for almost 90% of total VMT. Although the same PHEV market penetration formulas were used for each category, the largest majority of electrical energy consumption is by gasoline vehicles from the LDPV category up to HDGV2B (10,000 lb maximum GVWR). It is important to note that this encompasses the majority of residential and light-duty commercial vehicles where gasoline vehicles are dominant. For example, popular pickup trucks like the Ford F-250 are classified as HDGV2B.

The categories inputs from Table 2-5 are multiplied by the VMT and by the utility factor (for each PHEV configuration and annual VMT) to determine the total PHEV electrical energy consumption. The estimate of total PHEV electrical energy requirements in 2030 is 32.7 MMWh at the power plant busbar for California (30.1 MMWh at the charger electrical outlet) and 312.0 MMWh at the power plant busbar (287.1 MMWh at the outlet) for the other 47 states in the CONUS. For this case, PHEVs will use a total of 344.7 MMWh in 2030. Further discussion of PHEV impacts on electricity generation, including regional impacts, is presented in Chapter 3 on electric sector modeling.

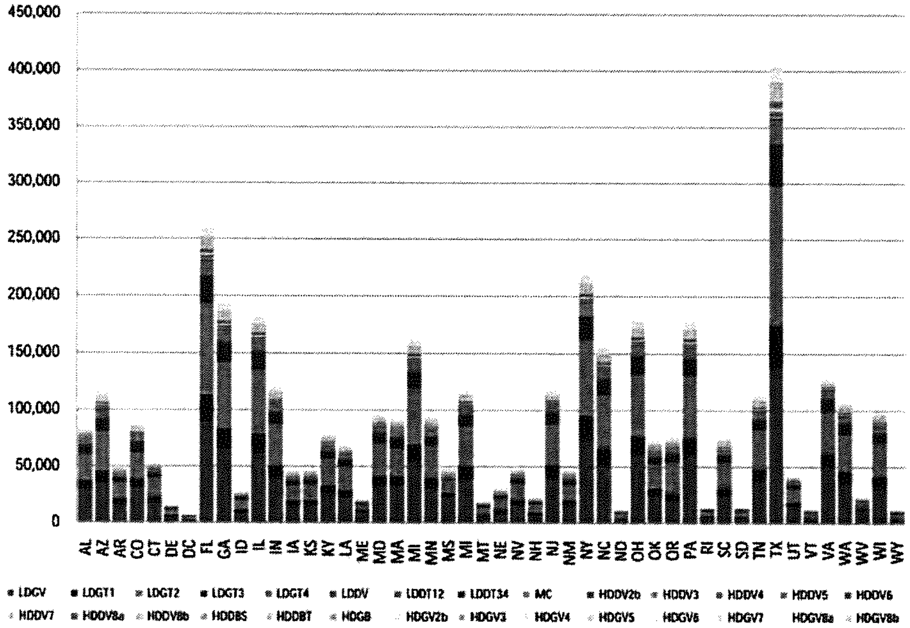

Figure 2-6
47-State Distribution of VMT by Vehicle Category (000,000 mi)

PHEV Charge Profile

An aggregated charge profile was created for the fleet of PHEVs in the model (**Figure 2-7** below). The total charge energy requirements are apportioned to each hour of the day. Conceptually, the highest charging loads occur during late night and early morning hours, with modest loads—presumably from daytime public or workplace charging occurring in the middle of the day. Hours of minimal charging correspond roughly with commute times.

This specific charge profile creates a scenario where 74% of the charging energy is delivered from 10:00 p.m. to 6:00 a.m. (nominally off-peak). The remaining 26% is provided between 6:00 a.m. to 10:00 p.m. This is simply one of many possible scenarios and represents an initial approximation of aggregate charging behavior in a fleet of PHEVs. The scenario is supported by the following assumptions:

1. PHEVs are charged primarily, but not exclusively, at home.
2. Owners are provided economic incentives to use less expensive off-peak electricity.
3. Near-term vehicles are likely to have charge onset delays built into their systems to allow battery system rest and cooling before recharge.
4. In the long term and in the presence of large PHEV fleets, utilities will likely use demand response or other programs to actively manage the charging load.

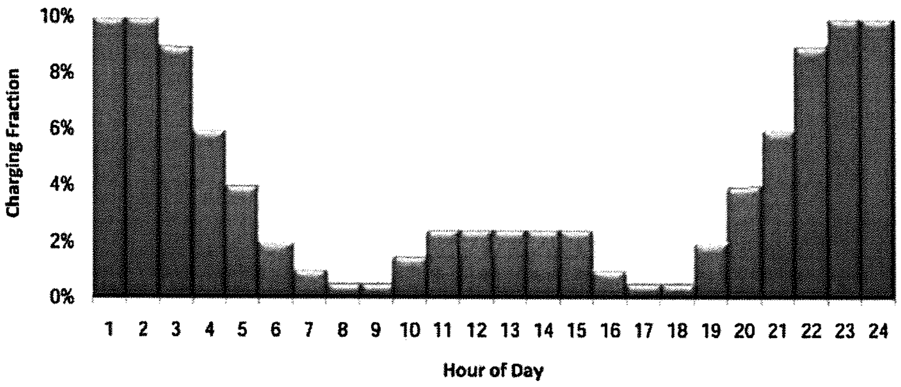

Figure 2-7
PHEV Charging Profile

Development of 2030 PHEV Scenario Emissions

2030 PHEV scenario emissions were estimated by scaling the projected base case 2030 emissions downward to account for PHEV fleet penetration. Key assumptions that were made in generating the 2030 base to 2030 PHEV case scaling factors are as follows:

1. Vehicle exhaust emissions (both running exhaust and start emissions) are reduced by the fraction of electric VMT estimated for the PHEV case.
2. Vehicle evaporative emissions are assumed to be equal between the base and PHEV cases.
3. Vehicle brake wear and tire wear emissions are assumed to be equal between the base and PHEV cases.
4. Upstream emissions associated with gasoline production, storage, and transport, including Stage I and Stage II emissions, are reduced by the fraction of gasoline vehicle electric VMT in the PHEV case.

County-level factors to scale on-road emissions from the 2030 base case to the 2030 PHEV case were calculated based on the application of the VMT reduction factors (scaling the total VMT down by the fraction of electric VMT estimated for the PHEV case) by vehicle class to county-level VMT estimates for each vehicle class. The county-level scaling factors were applied to 2030 base case on-road emissions to estimate 2030 PHEV scenario on-road emissions. **Table 2-6** shows the state-level summer season 2030 base case to PHEV case scalars; the summer and winter season scalars by county are provided in **Appendix A, Table A-1**.

The TOG emissions scalars in Table 2-6 are composite scalars, and encompass both evaporative emissions which are assumed to remain unchanged from the base to the PHEV case, and exhaust emissions which are assumed to be reduced according to estimated VMT reductions.

Table 2-6
Summer 2030 Base to 2030 PHEV Emission Scalars and Fossil Fuel VMT Reductions by State

State	TOG	CO	NOx	PM_{10}	$PM_{2.5}$	SO_2	NH_3	CO_2	VMT
Alabama	0.894	0.808	0.836	0.970	0.940	0.821	0.805	0.842	0.816
Arizona	0.920	0.809	0.843	0.971	0.941	0.825	0.807	0.848	0.819
Arkansas	0.892	0.807	0.841	0.972	0.943	0.825	0.806	0.850	0.819
California	0.957	0.862	0.930	0.933	0.903	0.866	0.839	0.867	0.846
Colorado	0.910	0.810	0.829	0.970	0.939	0.820	0.804	0.840	0.815
Connecticut	0.917	0.806	0.848	0.970	0.939	0.820	0.804	0.840	0.815
Delaware	0.907	0.807	0.852	0.971	0.942	0.824	0.806	0.849	0.818
District of Columbia	0.915	0.806	0.838	0.969	0.936	0.817	0.803	0.833	0.812
Florida	0.899	0.807	0.834	0.970	0.939	0.820	0.805	0.841	0.815
Georgia	0.902	0.807	0.845	0.971	0.940	0.822	0.805	0.845	0.817
Idaho	0.899	0.807	0.838	0.972	0.942	0.825	0.806	0.850	0.819
Illinois	0.904	0.807	0.843	0.970	0.939	0.821	0.805	0.841	0.815
Indiana	0.900	0.806	0.839	0.971	0.941	0.824	0.805	0.847	0.818
Iowa	0.890	0.804	0.843	0.972	0.943	0.825	0.806	0.850	0.819

(Continued)

Table 2-6 (Continued)
Summer 2030 Base to 2030 PHEV Emission Scalars and Fossil Fuel VMT Reductions by State

State	TOG	CO	NOx	PM_{10}	$PM_{2.5}$	SO_2	NH_3	CO_2	VMT
Kansas	0.893	0.806	0.838	0.971	0.941	0.824	0.806	0.847	0.818
Kentucky	0.899	0.807	0.842	0.971	0.942	0.824	0.806	0.848	0.818
Louisiana	0.894	0.807	0.840	0.971	0.942	0.824	0.806	0.848	0.818
Maine	0.889	0.803	0.832	0.969	0.938	0.817	0.800	0.837	0.811
Maryland	0.905	0.806	0.852	0.971	0.940	0.823	0.805	0.845	0.817
Massachusetts	0.919	0.808	0.850	0.970	0.938	0.820	0.804	0.840	0.815
Michigan	0.890	0.806	0.834	0.971	0.940	0.822	0.805	0.844	0.816
Minnesota	0.897	0.805	0.837	0.971	0.942	0.826	0.806	0.851	0.820
Mississippi	0.895	0.799	0.849	0.972	0.944	0.828	0.801	0.861	0.819
Missouri	0.898	0.807	0.842	0.971	0.941	0.823	0.805	0.845	0.817
Montana	0.887	0.805	0.839	0.972	0.943	0.827	0.806	0.853	0.821
Nebraska	0.894	0.806	0.839	0.971	0.942	0.825	0.806	0.850	0.819
Nevada	0.921	0.814	0.834	0.970	0.940	0.822	0.805	0.843	0.816
New Hampshire	0.903	0.806	0.848	0.971	0.942	0.825	0.806	0.849	0.819
New Jersey	0.925	0.808	0.862	0.970	0.939	0.819	0.804	0.839	0.814
New Mexico	0.903	0.812	0.838	0.971	0.942	0.825	0.806	0.850	0.819
New York	0.927	0.807	0.855	0.970	0.940	0.821	0.805	0.841	0.815
North Carolina	0.904	0.807	0.845	0.971	0.941	0.823	0.805	0.846	0.817
North Dakota	0.890	0.806	0.840	0.972	0.943	0.827	0.806	0.853	0.820
Ohio	0.900	0.806	0.840	0.971	0.940	0.822	0.805	0.844	0.816
Oklahoma	0.894	0.807	0.837	0.971	0.941	0.824	0.805	0.847	0.818
Oregon	0.900	0.809	0.841	0.971	0.942	0.824	0.808	0.845	0.819
Pennsylvania	0.912	0.807	0.850	0.971	0.941	0.823	0.805	0.845	0.817
Rhode Island	0.903	0.805	0.834	0.969	0.938	0.819	0.804	0.837	0.813
South Carolina	0.890	0.806	0.840	0.971	0.942	0.825	0.806	0.850	0.819
South Dakota	0.894	0.806	0.840	0.972	0.944	0.827	0.806	0.853	0.821
Tennessee	0.897	0.806	0.839	0.971	0.941	0.823	0.805	0.846	0.817
Texas	0.905	0.807	0.841	0.970	0.939	0.821	0.805	0.842	0.816
Utah	0.902	0.810	0.838	0.970	0.939	0.821	0.804	0.842	0.815
Vermont	0.899	0.806	0.845	0.972	0.942	0.826	0.806	0.851	0.819
Virginia	0.893	0.803	0.829	0.969	0.937	0.815	0.802	0.831	0.810
Washington	0.909	0.806	0.836	0.971	0.941	0.823	0.805	0.845	0.817
West Virginia	0.891	0.797	0.832	0.970	0.939	0.818	0.798	0.843	0.811

(Continued)

Table 2-6 (Continued)
Summer 2030 Base to 2030 PHEV Emission Scalars and Fossil Fuel VMT Reductions by State

State	TOG	CO	NOx	PM_{10}	$PM_{2.5}$	SO_2	NH_3	CO_2	VMT
Wisconsin	0.893	0.806	0.846	0.971	0.941	0.824	0.806	0.848	0.818
Wyoming	0.889	0.806	0.838	0.972	0.943	0.826	0.806	0.852	0.820

The fraction of TOG emissions that are evaporative for the base and PHEV cases are shown in **Table 2-7**. The PM emissions scalars are also composite scalars, including brake wear and tire wear emissions which are assumed to remain unchanged from the base to the PHEV case, and exhaust emissions which are assumed to decrease according to VMT reductions. The fraction of PM emissions that are from brake wear and tire wear for the base and PHEV case are also shown in Table 2-7.

Table 2-7
2030 TOG Evaporative and PM_{10} and $PM_{2.5}$ Brake Wear and Tire Wear Fractions

	Evaporative Fraction	Brake Wear & Tire Wear Fraction	
	TOG	PM_{10}	$PM_{2.5}$
47-States	**Summer**		
Base	40.7%	80.2%	60.3%
PHEV	43.1%	82.7%	64.1%
47-States	**Winter**		
Base	24.5%	79.8%	59.5%
PHEV	28.1%	82.2%	63.2%
California	**Summer**		
Base	58.6%	49.9%	27.4%
PHEV	61.3%	53.5%	30.4%
California	**Winter**		
Base	61.2%	49.9%	27.4%
PHEV	63.8%	53.5%	30.4%

PHEV Scenario Upstream Emissions Reductions

On-road vehicle emissions upstream sources include emissions associated with the processing, transport, and storage of gasoline. Diesel associated upstream emissions were not included for scaling as diesel fuel throughput reductions were estimated to be significantly small relative to gasoline throughput reductions because of the very low or zero penetration of PHEVs in the heavy-duty vehicle categories that account for the majority of on-road vehicle diesel fuel usage in the United States.

Emissions in the RPO inventories are identified by Source Category Code (SCC). In order to estimate which area and point source emissions were affected by projected upstream reductions, the SCCs in each inventory were evaluated based on standard descriptions to estimate whether the emissions associated with these SCCs were related to upstream gasoline throughput. If an SCC in the point and area source inventory was identified as related to upstream gasoline throughput, the emissions associated with that SCC were included for scaling in the PHEV case. A list of SCCs identified as associated with upstream gasoline emissions is presented in **Appendix A, Table A-2**. Upstream emissions by state and SCC source category are also presented in **Appendix A, Table A-3**. Reductions in gasoline vehicle VMT attributable to PHEV battery operation were estimated at 20% and 16% for the 47 non-California states and California, respectively. Individual emission reduction factors for each non-California state were not estimated as the changes in VMT reductions between non-California states was at most 1%.

Table 2-8 shows base case and PHEV case upstream emissions by state and pollutant, and the percent reduction. The majority of the upstream VOC emissions in most states are from vehicle refueling and underground storage tank filling and breathing emissions. The unexpectedly small amount of upstream VOC emissions in Idaho and Ohio appears to be due to accidental omission of emissions associated with vehicle refueling for these states in the RPO inventory. In Illinois, the magnitude of base case refueling emissions is approximately 3% of total base case on-road emissions. Therefore, if refueling emissions were not included in upstream emissions reductions in Illinois, overall emission reductions would be approximately 3% less than expected. Assuming that the relationship between on-road and refueling emissions in Idaho and Ohio is similar to the relationship between on-road and refueling emissions in Illinois, the omission of refueling emissions in Idaho and Ohio alone should not have a noticaeable impact on the overall modeling results.

Table 2-8
48-State Upstream Emissions and Percent Reductions from Base Case to PHEV Case in 2030

State	NOx			SO_2			PM_{10}			VOC		
	Base Case	PHEV Case	% Reduction	Base Case	PHEV Case	% Reduction	Base Case	PHEV Case	% Reduction	Base Case	PHEV Case	% Reduction
Alabama	1,008	808	-19.87%	418	335	-19.87%	70	56	-19.87%	10,733	8,600	-19.87%
Arizona	7.1	5.7	-19.87%	0	0	-19.87%	0	0	-19.87%	15,899	12,740	-19.87%
Arkansas	531	425	-19.87%	975	782	-19.87%	389	312	-19.87%	2,281	1,827	-19.87%
California	7,243	6,074	-16.14%	7,992	6,702	-16.14%	413	346	-16.14%	30,510	25,586	-16.14%
Colorado	643	515	-19.87%	1,106	887	-19.87%	349	280	-19.87%	16,413	13,152	-19.87%
Connecticut	3.3	2.6	-19.87%	0	0	na	0	0	na	2,601	2,084	-19.87%
Delaware	4.3	3.4	-19.87%	0	0	na	0	0	na	455	364	-19.87%
Florida	57	45	-19.87%	0.7	0.6	-19.87%	0	0	-19.87%	58,836	47,145	-19.87%
Georgia	8.6	6.9	-19.87%	0	0	-19.87%	0	0	na	20,519	16,442	-19.87%
Idaho	6.4	5.1	-19.87%	0	0	na	0	0	na	587	471	-19.87%
Illinois	2,492	1,997	-19.87%	1,425	1,142	-19.87%	386	309	-19.87%	5,508	4,414	-19.87%
Indiana	2,948	2,362	-19.87%	2,931	2,349	-19.87%	414	332	-19.87%	10,850	8,694	-19.87%
Iowa	15	12	-19.87%	0	0	-19.87%	0	0	-19.87%	8,697	6,969	-19.87%
Kansas	3,349	2,683	-19.87%	3,227	2,586	-19.87%	781	626	-19.87%	13,893	11,132	-19.87%
Kentucky	2,802	2,245	-19.87%	5,580	4,471	-19.87%	279	223	-19.87%	13,815	11,070	-19.87%
Louisiana	34,506	27,650	-19.87%	27,279	21,859	-19.87%	3,508	2,811	-19.87%	16,225	13,001	-19.87%
Maine	15.9	12.7	-19.87%	0	0	-19.87%	0	0	-19.87%	2,923	2,342	-19.87%
Maryland	14.6	11.7	-19.87%	3.5	2.8	-19.87%	0	0	-19.87%	2,795	2,240	-19.87%
Massachusetts	5.3	4.2	-19.87%	0	0	-19.87%	0	0	-19.87%	4,860	3,895	-19.87%
Michigan	246	197	-19.87%	119	95	-19.87%	8	7	-19.87%	3,519	2,820	-19.87%
Minnesota	2,732	2,189	-19.87%	4,407	3,532	-19.87%	849	680	-19.87%	23,411	18,759	-19.87%
Mississippi	1,660	1,330	-19.87%	4,389	3,517	-19.87%	425	341	-19.87%	17,971	14,400	-19.87%
Missouri	6,603	5,291	-19.87%	12	10	-19.87%	16	13	-19.87%	11,794	9,450	-19.87%
Montana	1,644	1,317	-19.87%	3,495	2,801	-19.87%	441	353	-19.87%	9,302	7,454	-19.87%

(Continued)

Table 2-8 (Continued)
48-State Upstream Emissions and Percent Reductions from Base Case to PHEV Case in 2030

State	NOx			SO_2			PM_{10}			VOC		
	Base Case	PHEV Case	% Reduction	Base Case	PHEV Case	% Reduction	Base Case	PHEV Case	% Reduction	Base Case	PHEV Case	% Reduction
Nebraska	10	8	-19.87%	2	1	-19.87%	0	0	-19.87%	8,743	7,006	-19.87%
Nevada	62	50	-19.87%	123	99	-19.87%	0	0	na	6,551	5,250	-19.87%
New Hampshire	0	0	na	0	0	na	0	0	na	1,272	1,019	-19.87%
New Jersey	2,028	1,625	-19.87%	1,177	943	-19.87%	470	376	-19.87%	17,629	14,126	-19.87%
New Mexico	842	675	-19.87%	2,302	1,845	-19.87%	238	190	-19.87%	14,353	11,501	-19.87%
New York	3.9	3.1	-19.87%	0	0	na	0	0	na	31,223	25,019	-19.87%
North Carolina	9.4	7.5	-19.87%	0	0	na	0	0	na	2,706	2,168	-19.87%
North Dakota	1,036	830	-19.87%	991	794	-19.87%	0	0	na	8,613	6,901	-19.87%
Ohio	4,014	3,216	-19.87%	3,864	3,096	-19.87%	652	522	-19.87%	339	272	-19.87%
Oklahoma	3,711	2,974	-19.87%	9,333	7,479	-19.87%	1,431	1,147	-19.87%	11,441	9,167	-19.87%
Oregon	0	0	na	0	0	na	0	0	na	16,578	13,284	-19.87%
Pennsylvania	5,900	4,727	-19.87%	6,223	4,987	-19.87%	578	463	-19.87%	4,306	3,451	-19.87%
Rhode Island	16	13	-19.87%	0	0	na	0	0	na	3,248	2,603	-19.87%
South Carolina	6.5	5.2	-19.87%	0	0	na	0	0	na	17,511	14,031	-19.87%
South Dakota	0	0	na	0	0	na	0	0	na	8,204	6,574	-19.87%
Tennessee	698	559	-19.87%	108	86	-19.87%	183	146	-19.87%	15,157	12,145	-19.87%
Texas	16,562	13,271	-19.87%	25,860	20,722	-19.87%	4,460	3,573	-19.87%	51,138	40,977	-19.87%
Utah	919	736	-19.87%	1,248	1,000	-19.87%	49	40	-19.87%	10,942	8,767	-19.87%
Vermont	1.4	1.2	-19.87%	0	0	-19.87%	0	0	-19.87%	352	282	-19.87%
Virginia	317	254	-19.87%	10	8	-19.87%	11	9	-19.87%	18,562	14,873	-19.87%
Washington	3,676	2,946	-19.87%	4,336	3,475	-19.87%	123	98	-19.87%	30,992	24,834	-19.87%
West Virginia	62	49	-19.87%	22	18	-19.87%	3	2	-19.87%	9,371	7,509	-19.87%
Wisconsin	370	296	-19.87%	647	518	-19.87%	78	62	-19.87%	3,870	3,101	-19.87%
Wyoming	200	160	-19.87%	433	347	-19.87%	2	2	-19.87%	4,243	3,400	-19.87%
US TOTAL	**108,995**	**87,608**	**-19.62%**	**120,054**	**96,498**	**-19.62%**	**16,605**	**13,321**	**-19.78%**	**601,787**	**483,349**	**-19.68%**

Transportation Sector Emissions Summary

Figure 2-8 shows the change in annual on-road NOx emissions by grid cell from the WRAP 2018 emissions inventory (EI) to the 2030 base case emissions, while **Figure 2-9** shows the change in annual on-road NOx emissions from the 2030 base case to the 2030 PHEV case. Consistent with **Table 2-3** and **Table 2-6**, emissions decreases are noted across all states in both plots. As expected, gridded NOx emission decreases are greater in major metropolitan areas compared to rural areas.

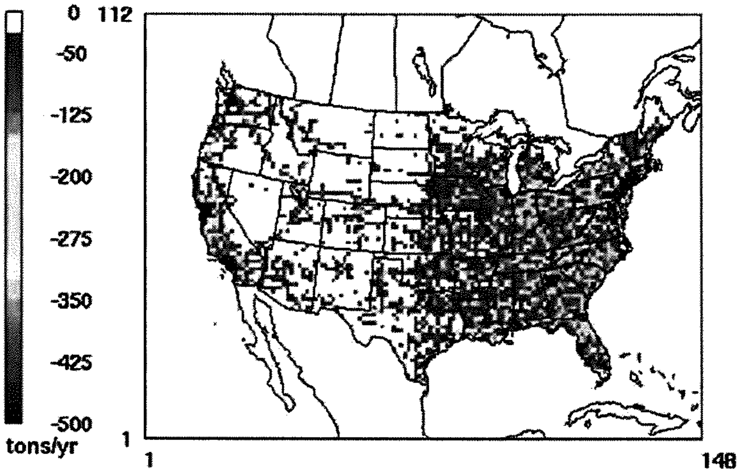

Figure 2-8
Annual Change in On-Road NOx Emissions from WRAP 2018 EI to 2030 Base Case

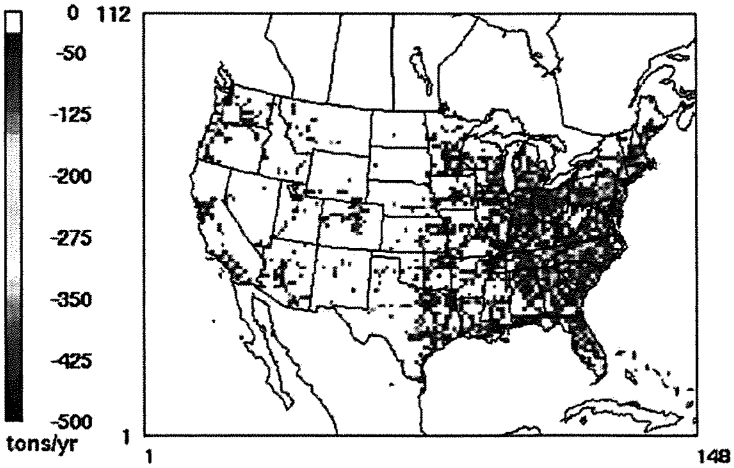

Figure 2-9
Annual Change in On-Road NOx Emissions from 2030 Base Case to 2030 PHEV Case

An alternative representation of on-road emission results are on-road emission factor changes by vehicle class from 2030 base to PHEV case emissions. On-road NMIM and EMFAC2002 modeling result emission factors for the 2030 base and PHEV cases are shown in **Table 2-9** and **Table 2-10**. The emission factors in Table 2-9 are based on NMIM/MOBILE6, and the emission factors in Table 2-10 are based on EMFAC. The denominator, VMT, for the PHEV case emission factors in Table 2-9 and Table 2-10 is combined electric and non-electric VMT.

Upstream emission factors expressed as g mi^{-1}, representing upstream emissions divided by total estimated 2030 VMT, are shown in **Table 2-11**. The magnitude of VOC and SOx upstream emission factors are significant relative to TOG and SO_2 on-road emission factors.

Table 2-9
Overall On-Road Emission Factors (g mi^{-1}) by Vehicle Class for Base Case and PHEV Case in 2030 (47 States)

Vehicle Class	TOG	CO	NOx	PM_{10}	$PM_{2.5}$	SO_2*	CO_2
Base Case - 47 State NMIM On-Road Emissions / MSAT VMT							
LDGV	0.300	8.503	0.207	0.025	0.011	0.007	368
LDGT1	0.344	8.285	0.290	0.025	0.011	0.009	479
LDGT2	0.464	9.449	0.441	0.025	0.011	0.012	625
HDGV	0.311	9.724	0.178	0.032	0.017	0.017	911
MC	2.500	16.054	1.483	0.037	0.021	0.003	177
LDDV	0.049	0.606	0.029	0.030	0.016	0.002	314
LDDT	0.108	0.340	0.114	0.029	0.015	0.004	585
HDDV	0.309	0.308	0.577	0.055	0.027	0.010	1,424
PHEV Case - 47 State NMIM On-Road Emissions / MSAT VMT							
LDGV	0.262	6.654	0.162	0.024	0.010	0.005	288
LDGT1	0.299	6.696	0.235	0.024	0.011	0.007	387
LDGT2	0.406	7.760	0.362	0.024	0.011	0.009	513
HDGV	0.287	8.180	0.150	0.030	0.016	0.014	764
MC	2.500	16.054	1.483	0.037	0.021	0.003	177
LDDV	0.040	0.499	0.024	0.028	0.014	0.002	258
LDDT	0.089	0.279	0.093	0.028	0.014	0.003	481
HDDV	0.304	0.303	0.569	0.054	0.026	0.010	1,399

Table 2-10
Overall On-Road Emission Factors (g mi^{-1}) by Vehicle Class for Base Case and PHEV Case in 2030 (California)

Vehicle Class	TOG	CO	NOx	PM_{10}	$PM_{2.5}$	SOx	CO_2
Base Case - CA EMFAC2002 On-Road missions / EMFAC2002 VMT							
LDGV	0.101	0.814	0.063	0.034	0.020	0.004	385
LDGT1	0.196	1.271	0.118	0.044	0.029	0.005	487
LDGT2	0.269	1.983	0.198	0.053	0.038	0.007	675
HDGV	0.807	3.528	1.069	0.035	0.017	0.007	766
MC	4.241	24.324	1.227	0.030	0.017	0.000	176
LDDV	0.070	0.419	1.361	na	na	na	458
LDDT	0.078	0.561	1.375	0.025	0.018	na	353
HDDV	0.246	1.327	2.337	0.125	0.091	0.018	1,925
PHEV Case - CA EMFAC2002 On-Road Emissions / EMFAC2002 VMT							
LDGV	0.095	0.680	0.053	0.032	0.018	0.003	322
LDGT1	0.186	1.053	0.097	0.040	0.025	0.004	405
LDGT2	0.255	1.690	0.169	0.048	0.033	0.006	575
HDGV	0.794	3.386	1.003	0.034	0.017	0.006	718
MC	4.241	24.324	1.227	0.030	0.017	0.000	176
LDDV	0.070	0.419	1.361	na	na	na	458
LDDT	0.078	0.561	1.375	0.025	0.018	na	353
HDDV	0.244	1.309	2.317	0.125	0.090	0.018	1,910

Table 2-11
Overall Upstream Emissions Factors (g mi^{-1}) for Base Case and PHEV Case in 2030

Region	NOx	SOx	PM_{10}	VOC
47 States (non-CA)				
Base	0.022	0.024	0.003	0.121
PHEV	0.017	0.019	0.003	0.097
California				
Base	0.014	0.016	0.001	0.060
PHEV	0.012	0.013	0.001	0.050

3

Electric Sector Modeling

Operations of the United States electric sector in 2030 were modeled in order to provide hourly electric sector emissions to be used as an input to the air quality modeling. Specifically, the model was used to project hourly electric sector emissions of sulfur dioxide (SO_2), nitrogen oxides (NOx), particulate matter ($PM_{2.5}$), elemental mercury (Hg^0), ionic mercury (Hg^{2+}) and particulate mercury (Hg^P). The hourly projected emissions were provided for the year 2030 for each of two cases. In the first case, there are no plug-in hybrid electric vehicles (PHEVs) in operation and thus there are no impacts on the electric sector. In the second case, there is a significant penetration of PHEVs in the motor vehicle fleet (See Chapter 2) resulting in increased load demand on the electrical system.

Hourly emissions estimates for 2030 were provided for power plant stacks located throughout the United States. This final output was then provided for further processing to develop gridded emission fields for air quality model simulations (see Chapter 4).

Electric Sector Modeling Methodology

The North American Electricity & Environment Model (NEEM) from CRA International[5] was used to simulate the operations of the electric sector through 2030. The NEEM model is a bottom-up representation of the electric sector that has been designed to model new capacity, retirements, environmental compliance and fuel choice at the national level. NEEM is described in further detail below, while key assumptions used in the model are discussed in the following section.

The North American Electricity & Environment (NEEM) Model

NEEM is a linear programming model that simulates a competitive electricity market for the CONUS. NEEM minimizes the present value of incremental costs to the electric sector while meeting electricity demand and complying with relevant environmental limits. NEEM was designed specifically to be able to simultaneously model least-cost compliance with all state, regional and national, seasonal and annual emissions caps for SO_2, NOx, Hg and CO_2. The least-cost outcome is the expected result in a competitive wholesale electricity market. As part of the cost minimization solution, NEEM produces forecasts of short-term and long-term decisions such as coal choices, investments in pollution control equipment and new capacity additions in a manner that minimizes the total costs to the electrical sector.

NEEM is a process-based model of U.S. electricity markets and portions of the Canadian system. The electricity market is divided into 28 individual demand regions (24 U.S. regions and 4 Canadian regions, as depicted in **Figure 3-1**) interconnected by limited transmission capabilities. Coal units (and other units of interest) are represented in detail as these are most affected by environmental regulation. All but small coal units are modeled at a unit level.[6] All non-coal generating units in the United States are also represented in the model, with some level of unit aggregation. Units are dispatched to load duration curves within each region so that all loads are met at least cost. NEEM also models the dynamics of coal supply and transportation.

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[5] CRA International developed the proprietary NEEM model, which has been used extensively in analyses for EPRI, the Edison Electric Institute and many electric power companies.

[6] Coal units greater than 200 MW are individually represented in the model. Smaller coal units are aggregated together based on region and size. We also individually represented coal units in Ohio and Indiana to provide more precise data for those particular regions. Natural-gas fired and oil-fired units in these regions were also separated from other similar units within their respective broader NEEM region.

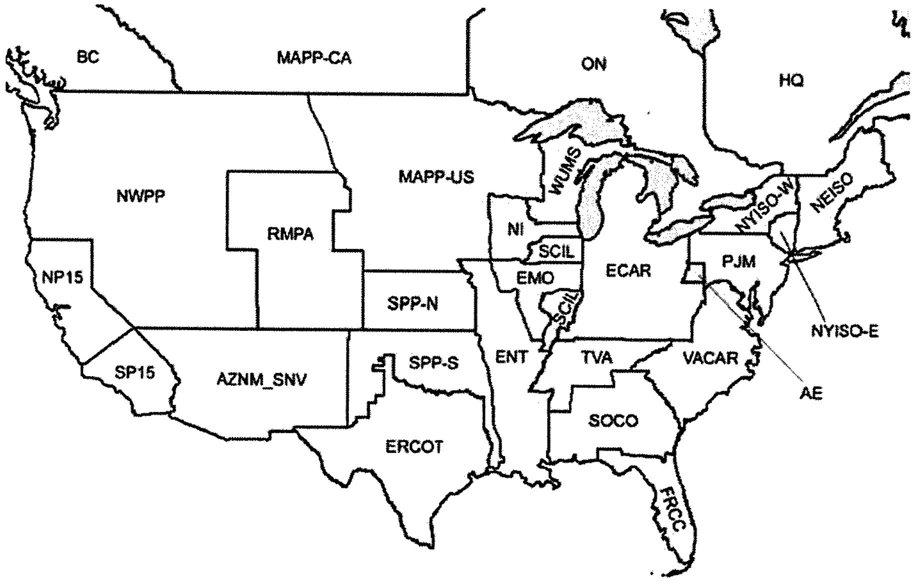

Figure 3-1
Map of NEEM Regions

A particular aspect of NEEM is the detail included for modeling the coal sector. NEEM includes coal supply curves that represent 21 coal supply regions and coal types. These coal supply regions are linked to the generation units by a coal transportation matrix with unit-specific transportation costs.

In NEEM, this means that different levels of coal use in different periods lead to different average coal prices; effectively, coal prices are an output of NEEM, not an input. This approach ensures internal consistency between allowance prices and coal prices, unlike other models in which coal prices are effectively fixed regardless of rate of consumption.

Key inputs to NEEM include: unit-level generator operating characteristics, natural gas and oil prices, electricity demand and environmental policies. Key outputs from NEEM include wholesale electricity prices by region, emission allowance prices, coal prices, unit retirements, resource additions, unit retrofits and unit-level emissions.

The load shapes used in NEEM are based upon 2002 actual hourly load profiles from EIA Form 411, and are therefore consistent with the 2002 meteorological data used in the air quality modeling. Electricity demand in NEEM is represented by load duration curves by season (summer, winter, shoulder months). Hourly demand within each season is sorted from highest to lowest and placed into load blocks. The demand within any load block is then the average hourly demand of the hours within the load block. The load blocks have been created to best represent the relative peak intensity of the energy demand. As such there are fewer hours included in peak demand load blocks and more hours in the off-peak demand load blocks. There are a total of 30 load blocks — 14 load blocks for the summer months (May through September) and eight load blocks each for the winter months (January, February and December) and the shoulder months (March, April, October and November).

Overview of Assumptions

Whenever and wherever possible, key assumptions were drawn from the Energy Information Administration's (EIA) Annual Energy Outlook 2006 (AEO 2006). These assumptions include the following:

- New generation costs and characteristics;
- Natural gas prices;
- Regional electricity demand growth rates post-2014[7]; and
- Pollution control equipment costs and characteristics.

New Generation Costs and Characteristics

NEEM includes a full suite of supply options to meet load growth including coal, natural gas, nuclear and renewable units. **Table 3-1** shows the costs and operating characteristics of these units. The relative trade-offs between capital costs, fuel costs and emissions determine the mix of new generation additions. Also, in certain regions some new generation types are not allowed (e.g., pulverized coal in California).

Table 3-1
New Generation Costs and Characteristics

	Capital Cost	Fixed O&M	Variable O&M	Heat Rate
	(2003$/kW)	(2003$/kW-y)	(2003$/MWh)	(Btu kWh^{-1})
Pulverized Coal	$1,430	$24.36	$4.06	8,844
Combined Cycle	$618	$10.35	$1.77	7,139
Combustion Turbine	$400	$9.32	$2.81	9,227
IGCC	$1,606	$34.22	$2.58	8,309
Nuclear	$2,398	$60.08	$0.44	10,400
Wind	$1,255	$26.81	$0.01	NA

Fuel Prices

Natural gas prices are based on AEO 2006 prices. Prices are converted from wellhead prices to Henry Hub prices based on historical conversion rates. Annual prices for each region are then calculated based on historical basis differentials with Henry Hub. Lastly, the annual prices are converted to seasonal prices based on historical seasonality by region. The Henry Hub prices are shown in **Table 3-2**.

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[7] For the period prior to 2015, electricity demand is based on the North American Electric Reliability Corporation (NERC) ES&D 2005 forecasts of demand by region. NERC ES&D forecasts of electricity demand are used by NERC in their annual long-term reliability assessments. NERC ES&D data is available at http://www.nerc.com/~esd/.

Table 3-2
Henry Hub Natural Gas Prices (2003$/MMBtu)

	2010	2015	2020	2025	2030
Henry Hub	$5.54	$4.98	$5.40	$5.99	$6.52

Coal prices are calculated within the model based on electric sector demand for coal. NEEM includes annual coal supply curves for each of the 21 coal supply regions. These curves contain quantities of coal available at a series of minemouth coal prices to form a step function supply curve. The available supply and the minemouth prices for different levels of supply are based on a model of projected production capabilities at coal mines located throughout the United States. There is a separate matrix of coal delivery costs. Coal delivery costs are plant specific and are based on historical delivery costs.

The characteristics for each coal in the model are included in **Table 3-3**.

Table 3-3
Coal Characteristics

Coal Type	Rank	SO_2	Hg	Heat Content
		(lb $MMBtu^{-1}$)	(lb $TBtu^{-1}$)	(Btu lb^{-1})
Northern Appalachian High Btu, Low Sulfur	Bituminous	2.47	12.31	12,862
Northern Appalachian High Btu, High Sulfur	Bituminous	3.95	12.54	12,900
Northern Appalachian Low Btu, Low Sulfur	Bituminous	1.72	15.98	12,097
Northern Appalachian Low Btu, High Sulfur	Bituminous	3.42	20.87	11,782
Central Appalachian Compliance	Bituminous	1.12	5.87	12,731
Central Appalachian High Btu, Non-Compliance	Bituminous	1.50	8.24	12,637
Central Appalachian Low Btu, Non-Compliance	Bituminous	1.80	9.20	12,030
Southern Appalachian	Bituminous	1.97	8.73	12,185
Illinois Basin High Sulfur	Bituminous	5.20	6.44	11,395
Illinois Basin Med Sulfur	Bituminous	2.80	6.44	11,395
Illinois Basin Low Sulfur	Bituminous	1.70	6.44	11,395
Central Basin	Bituminous	4.82	12.72	12,077
Lignite	Lignite	2.62	10.80	6,743
Montana Powder River Basin	Subbituminous	1.19	5.17	9,043
Northern Wyoming Powder River Basin	Subbituminous	0.89	7.08	8,380
Central Wyoming Powder River Basin	Subbituminous	0.75	5.42	8,562
Southern Wyoming Powder River Basin	Subbituminous	0.65	5.76	8,854
Rocky Mountain Colorado	W Bituminous	0.93	3.65	11,466
Rocky Mountain Utah	W Bituminous	1.04	4.14	11,554
Four Corners	Bituminous	1.44	4.20	9,666
Import	Bituminous	0.98	5.52	12,000

Electricity Demand Growth

Regional electricity demand is based on NERC ES&D 10-year forecasts through 2014. After 2014, growth rates from AEO 2006 are applied. These rates are shown in **Table 3-4**.

Table 3-4
Growth Rates in Electricity Demand Post-2014

AEO Region	Growth Rate
East Central Area Reliability Coordination Agreement	1.58%
Electric Reliability Council of Texas	1.78%
Mid-Atlantic Area Council	1.17%
Mid-America Interconnected Network	1.57%
Mid-Continent Area Power Pool	1.56%
Northeast Power Coordinating Council / New York	0.94%
Northeast Power Coordinating Council / New England	1.04%
Florida Reliability Coordinating Council	1.57%
Southeastern Electric Reliability Council	1.56%
Southwest Power Pool	1.04%
Western Electricity Coordinating Council / Northwest Power Pool Area	1.98%
Western Electricity Coordinating Council / Rocky Mountain Power Area and Arizona-New Mexico-Southern Nevada Power Area	2.19%
Western Electricity Coordinating Council / California	1.59%
United States	**1.54%**

Pollution Control Equipment Costs and Characteristics

Table 3-5 shows the basic costs and characteristics of flue gas desulfurization (FGD), selective catalytic reduction (SCR), selective non-catalytic reduction (SNCR), activated carbon injection (ACI) and ACI/Fabric Filter (ACI/FF) retrofits.

The model selects retrofit installations based upon economics, with the exception of planned retrofits. Planned retrofits include publicly-announced retrofits that have been identified through CRA's routine monitoring of the trade press.[8] In addition, retrofits believed to be required for units to comply with the Clean Air Visibility Rule (CAVR) are also forced into the model in 2014.

Non-forced retrofits will be added based on their respective economics. Under a cap and trade policy, the model will select retrofits that have the lowest cost per ton (per pound) removed.

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[8] Key trade press resources include Energy Central Professional (http://pro.energycentral.com) and McIlvaine's Utility Environmental Upgrade Tracking System (http://www.mcilvainecompany.com/).

Under an emission price policy, the model will select retrofits that have a cost per ton removed lower than the specified allowance price.

In addition to pollution control retrofits, coal units that do not currently have the capability to burn sub-bituminous coals can add a fuel switch "retrofit". This retrofit covers the costs of boiler modifications and coal handling equipment that would likely result from the addition of the capability of burning sub-bituminous fuels. This retrofit has a capital cost of between $90/kW and $120/kW for aggregate coal units and is $60/kW for non-aggregate coal units.

The capital costs in the table above are from AEO 2006, with the exception of the SNCR costs, which are from EPA (SNCR not listed in AEO 2006).

Table 3-5
Summary of Retrofit Costs (in 2003$)

Retrofit	Reference Size	Capital Cost	Fixed Yearly O&M	Scaling Exponent[9]	Variable O&M	% Removal
	(MW)	($/kW)	($/kW)		($/MWh)	
FGD	500	$208.94	$8.00	0.60	$1.96	98%
SCR	500	$98.15	$0.53	0.35	$0.97	90%
SNCR	500	$18.30	$0.27	0.58	$0.87	35%
ACI	250	$3.89	$0.77	0.35	$0.82	90%
ACI/FF	250	$58.31	$0.96	0.35	$0.67	90%

Environmental Regulations

All existing environmental regulations are included in NEEM[10]. These include:

- Title IV/Clean Air Interstate Rule (CAIR) for SO_2 — Title IV melds into the CAIR SO_2 program beginning in 2010 when units in the CAIR region are required to submit two allowances for every ton emitted. This increases to 2.86 allowances per ton in 2015.
- SIP Call/CAIR Ozone Season NOx — the SIP Call program for ozone season NOx compliance is modeled through 2008, after which this program is phased out in favor of the CAIR Ozone Season NOx program.
- CAIR Annual NOx — the CAIR Annual NOx program begins in 2009 for much of the Eastern United States, with a second, tighter cap in 2015.
- Clean Air Mercury Rule (CAMR) — the final CAMR rule begins in 2010, with a second, tighter cap in 2018.[11]

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[9] The scaling component is applied for both the capital and fixed costs according to the formula: Cost x (500 MW / Unit Size) ^ Scaling Exponent.

[10] No CO_2 policy is therefore included in this analysis.

[11] Our modeling assumes that all states follow the model cap-and-trade program for mercury emissions from EGUs proposed by EPA following the release of the Clean Air Mercury Rule.

Table 3-6
Emission Allowance Limits

	SO_2	NOx			Hg
	Title IV/CAIR	NOx SIP Call	CAIR Ozone Season	CAIR Annual	CAMR
Year	Million Tons	Thousand Tons	Thousand Tons	Million Tons	Tons
2006	9.44	528	-	-	-
2008	9.44	528	-	-	-
2009	9.44	-	568	1.722	-
2010	8.95	-	568	1.722	38
2015	8.95	-	485	1.268	38
2018	8.95	-	485	1.268	15
2020	8.95	-	485	1.268	15
2030	8.95	-	485	1.268	15

Table 3-6 includes a summary by program and pollutant of the annual emission allowance limits.

NEEM allows for allowance banking so emissions in a given year do not necessarily match the limits specified in the table. NEEM also includes existing renewable portfolio standards (RPS) or goals for the following states: Arizona, New Mexico, California (33% by 2030), Colorado, Texas, Iowa, Illinois, Minnesota, Connecticut, Massachusetts, Maine, Rhode Island, Vermont, Nevada, Montana, New York, Washington, DC, Delaware, Maryland, New Jersey, Pennsylvania and Wisconsin.

California-Specific Assumptions

There are a number of California-specific assumptions that were implemented in the study to address some of the unique attributes of the California electricity market.

In order to address the California Solar Initiative (also known as the Million Solar Roofs Program), installations of solar photovoltaics were added from 2007 through 2017, with total installations equal to 3,000 MW.

New transmission between the AZ_NM_SNV and SP15 NEEM regions was added to account for the addition of the Devers-Palo Verde 2 (DPV2) line.[12] This transmission line is expected to increase transmission capacity between the regions by 1,200 MW in 2015.

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[12] Inclusion of the DPV2 in the model assumptions should be interpreted only as a reflection the status of the transmission line during the electric sector modeling. The proposed line had won approval of the California Public Utilities Commission (CPUC) in January 2007. Since this analysis was completed, the Arizona Corporation Commission (ACC) rejected the application to construct this new transmission line (June 2007). Provisions of the Energy Policy Act of 2005 allow FERC to site transmission facilities in certain regions designated by the Department of Energy (DOE) as National Interest Electric Transmission (NIET) Corridors in which state regulators have "withheld" approval for more than a year. In a rulemaking issued in late 2006, FERC interpreted the word "withheld" in the statute to also mean "denied." In May 2007, DOE proposed to designate a region including the DPV2 line as a NIET corridor.

The Regional Clean Air Incentives Market (RECLAIM) program is aimed at reducing emissions from industry and electricity within the South Coast Air Quality Management District (SCAQMD). SCAQMD includes the following counties: Los Angeles, Orange, San Bernardino and Riverside. Units located in these counties were required to purchase RECLAIM credits to offset any NOx emissions. The price of the credits was based on 2006 actual prices and a CRA analysis of projected prices. In 2030, the price for a RECLAIM permit was set at $10.50 per pound (in 2003 dollars).[13]

All new units in Southern California also had to incur costs for emission reduction credits (ERCs) because the entire region is a non-attainment region and is proposed to remain so.[14] Costs for ERCs include the cost to offset emissions of NOx, PM_{10} and CO. These costs were applied to new combined cycle and combustion turbines in Southern California (no other new fossil fuel-burning plants were allowed in California in the model simulation). ERC prices were based on 2006 actual transactions.

In addition, all new natural gas-fired combined cycles and combustion turbines were assumed to include SCR and SNCR systems, respectively. The cost of such a system was included in the capital costs of the new unit.

Because of the extremely high costs of adding new generation within California, an additional generation option was included. This new generation option included building a combined cycle unit in the AZ_NM_SNV NEEM region and also building transmission to transmit that power into Southern California. The cost of this option includes a new transmission cost of $1,000,000 per mile. Limits on this option were no more than 2.5 GW every five years and none prior to 2015.

Increases in emissions in Southern California from the electricity sector also needed to be offset from reductions in other sectors as a result of New Source Review (NSR) provisions. Increases in electric sector NOx emissions were offset by a factor of 1.2 from other sectors of the economy. These reductions are included in the emissions summaries discussed in Chapter 4 and in the air quality modeling discussed in Chapter 5.

Calculation of Electric Generating Unit Emissions

NEEM determines unit-level emissions for SO_2, NOx and Hg based on each modeled unit's fuel choices, existing equipment and retrofit choices. The details for SO_2, NOx, Hg and $PM_{2.5}$ are described below.

SO_2 Emissions

SO_2 emissions in NEEM are dynamically calculated over time in response to a number of endogenous factors. Initial data that is used to calculate SO_2 emissions include the quantity and characteristics of the existing coal fleet, including capacity, existing equipment and coal types that can be burned at each unit. NEEM models existing Federal SO_2 legislation and rules including Title IV and the CAIR. These provide a cap on the level of SO_2 emissions. The model also includes an estimate of the existing bank of SO_2 allowances entering 2006 (approximately 6 million tons) and allows for additional banking or withdrawals from the bank in order to comply with the cap in the most cost efficient manner possible.

The emissions from existing coal units will change over time in response to the SO_2 allowance price projected by NEEM and the SO_2 reduction options available to each unit. Units can reduce their SO_2

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[13] At the time of the analysis, near-term trades had an average price of $4.00 per pound (http://www.aqmd.gov/reclaim/rtc_main.html). This price was estimated to increase at approximately 4 percent per year reaching a price of $10.50 in 2030.

[14] Portions of Northern California are also in non-attainment, but other areas are in attainment. New power plants were assumed to be sited in areas in attainment and thus ERC costs were not applied in Northern California.

emissions in a number of ways. First, units that do not currently have a FGD retrofit may add one. The cost of this retrofit is a function of the size of the unit and the cost parameters included in **Table 3-5**. A unit will add an FGD if the cost of installing the FGD, as measured in dollars per ton of SO_2 removed is less than the cost of purchasing allowances for that unit.[15] A second option to reduce SO_2 emissions is to change coal types. As shown in **Table 3-3**, each coal has different SO_2 contents. If a coal can be delivered to the unit then it can switch to burning that coal. For units that do not currently burn PRB coal, a capital cost would be incurred to account for the plant being able to burn PRB coals. Lastly, a unit can reduce its SO_2 emissions by generating less. If the unit does not have other options it may be pushed higher up the dispatch curve because of its SO_2 emissions costs and therefore generate less.

In addition to existing coal units, new coal units also produce SO_2 emissions. All new coal units, however, are assumed to include an FGD and therefore have an SO_2 emission rate that reflects 98% removal of inlet SO_2.

NOx Emissions

NOx emissions in NEEM are also dynamically calculated over time in response to a number of endogenous factors. Unlike SO_2, NEEM includes initial NOx emission rates for coal-, natural gas- and oil-fired plants. This information is based on third quarter 2005 NOx rates reported as part of the EPA Continuous Emissions Monitoring System (CEMS). Third quarter data is used to get a better estimate of the NOx rate when any post-combustion controls (if any are installed) are being operated since all of the third quarter is part of the summer ozone season.

NEEM includes the following NOx limits:

- SIP Call — applicable to a number of Eastern states during the ozone season (May through September);
- CAIR NOx Ozone Season — replaces the SIP Call in 2009 and applies to a different set of primarily Eastern states;
- CAIR NOx Annual — annual NOx cap that applies to a different set of primarily Eastern states; and
- RECLAIM — a program to limit NOx emissions in the South Coast Air Basin in California. This has been modeled with an estimated allowance price increasing from $4.00 per pound ($8,000 per ton) in 2006 to $10.50 per pound ($21,000 per ton) in 2030.

Similar to SO_2, there are multiple options for reducing NOx emissions on existing units. Two retrofits are available to coal units.[16] These units will install either Selective Catalytic Reduction (SCR) or Selective Non-Catalytic Reduction (SNCR) if the cost per ton of NOx removed is less than the NOx allowance price that will be faced by the unit. The costs and characteristics of SCR and SNCR are included in Table 3-5. The other means of reducing NOx emissions from existing units is to reduce the level of generation from those units.

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[15] Under CAIR, units in the CAIR region would need to purchase two allowances for each ton emitted from 2010 through 2014 and 2.86 allowances per ton emitted from 2015 onwards. Thus, if a unit were located in the CAIR region and the allowance price in 2010 were $500 per ton, the unit would add an FGD if the cost per ton removed were less than $1,000 per ton ($500 allowance price multiplied by two to account for the need for two allowances per ton emitted).

[16] Retrofits were not provided as an option for natural gas- or oil-fired units because they would be more expensive on a dollars per ton removed basis than for any of the coal units.

New units are assumed to have controls in place necessary to meet New Source Performance Standards (NSPS). For coal units, this means a NOx emission rate of 0.06 lb MMBtu^{-1}, new combined cycle units have a NOx emission rate of 0.02 lb MMBtu^{-1} and new combustion turbines have a NOx emission rate of 0.08 lb MMBtu^{-1}. Because of non-attainment throughout California, new combined cycles are assumed to have a higher capital cost that includes the cost of an SCR, which results in a lower NOx emission rate of 0.004 lb MMBtu^{-1}. There is also a higher capital cost on new combustion turbines in California to account for the installation of a SNCR resulting in a NOx emission rate of 0.04 lb MMBtu^{-1}.

Table 3-7
Hg Co-Benefits

Equipment in Place			% Removal of Inlet Hg		
PM Control	**SO_2 Control**	**NOx Control**	**Bituminous**	**PRB**	**Lignite**
Fabric Filter	Dry FGD	No SCR	85	25	10
		SCR	90	25	10
	Wet FGD	No SCR	85	75	40
		SCR	90	75	40
	No FGD	No SCR	75	65	10
		SCR	75	65	10
Cold-Side ESP	Dry FGD	No SCR	50	15	10
		SCR	85	15	10
	Wet FGD	No SCR	60	35	35
		SCR	85	35	35
	No FGD	No SCR	35	20	10
		SCR	35	20	10
Hot-Side ESP	Dry FGD	No SCR	0	0	0
		SCR	0	0	0
	Wet FGD	No SCR	55	30	30
		SCR	85	30	30
	No FGD	No SCR	20	0	0
		SCR	20	0	0
Venturi Scrubber	Dry FGD	No SCR	25	15	15
		SCR	60	15	15
	Wet FGD	No SCR	25	15	15
		SCR	60	15	15
	No FGD	No SCR	20	5	5
		SCR	20	5	5

Hg Emissions

Similar to SO_2 emissions, Hg emissions are only from coal-fired units. Hg emissions for any coal unit are a function of the coal burned and the equipment in place on the unit. While there are Hg-specific retrofits, Hg can also be removed as a co-benefit from some non-Hg controls such as FGDs and SCRs. The Hg co-benefits were provided by EPRI and used as part of comments files in response to the proposed CAMR.

ACI was a retrofit option available to all larger coal-fired units. If the unit had an existing fabric filter then ACI alone was an option. If the unit did not have a fabric filter then the ACI option available to it was more costly because it included the installation of a fabric filter.

NEEM calculates a total Hg emissions number for each unit, however, the emissions information is later speciated into its three forms: elemental, ionic and particulate. The speciation percentages are based on information prepared by EPRI and used in EPRI's comments on the proposed mercury rule.[17]

Table 3-8
Hg Speciation

Equipment in Place			**% Elemental / % Ionic / % Particulate**		
PM Control	**SO_2 Control**	**NO_x Control**	**Bituminous**	**PRB**	**Lignite**
Fabric Filter	Dry FGD	No SCR	69.7 / 29.9 / 0.5	89.6 / 10 / 0.5	94.5 / 5 / 0.5
		SCR	29.9 / 69.7 / 0.5	89.6 / 10 / 0.5	94.5 / 5 / 0.5
	Wet FGD	No SCR	42.8 / 52.3 / 5	80.8 / 14.3 / 5	80.8 / 14.3 / 5
		SCR	38 / 57 / 5	80.8 / 14.3 / 5	80.8 / 14.3 / 5
	No FGD	No SCR	5 / 94.4 / 0.6	29.8 / 69.6 / 0.6	29.8 / 69.6 / 0.6
		SCR	5 / 94.4 / 0.6	29.8 / 69.6 / 0.6	29.8 / 69.6 / 0.6
Cold-Side ESP	Dry FGD	No SCR	89.6 / 10 / 0.4	94.6 / 5 / 0.4	94.6 / 5 / 0.4
		SCR	59.8 / 39.8 / 0.4	94.6 / 5 / 0.4	94.6 / 5 / 0.4
	Wet FGD	No SCR	84.7 / 14.9 / 0.4	89.6 / 10 / 0.4	89.6 / 10 / 0.4
		SCR	59.8 / 39.8 / 0.4	89.6 / 10 / 0.4	89.6 / 10 / 0.4
	No FGD	No SCR	34.5 / 64 / 1.5	59.1 / 39.4 / 1.5	54.2 / 44.3 / 1.5
		SCR	9.9 / 88.7 / 1.5	59.1 / 39.4 / 1.5	54.2 / 44.3 / 1.5
Hot-Side ESP	Dry FGD	No SCR	39.8 / 59.8 / 0.4	79.7 / 19.9 / 0.4	79.7 / 19.9 / 0.4
		SCR	39.8 / 59.8 / 0.4	79.7 / 19.9 / 0.4	79.7 / 19.9 / 0.4
	Wet FGD	No SCR	79.4 / 19.9 / 0.7	97.3 / 2 / 0.7	94.3 / 5 / 0.7
		SCR	59.6 / 39.7 / 0.7	97.3 / 2 / 0.7	94.3 / 5 / 0.7
	No FGD	No SCR	39.5 / 59.2 / 1.3	69.1 / 29.6 / 1.3	69.1 / 29.6 / 1.3
		SCR	9.9 / 88.8 / 1.3	69.1 / 29.6 / 1.3	69.1 / 29.6 / 1.3
Venturi Scrubber	Dry FGD	No SCR	88.8 / 9.9 / 1.3	93.8 / 4.9 / 1.3	93.8 / 4.9 / 1.3
		SCR	49.4 / 49.4 / 1.3	93.8 / 4.9 / 1.3	93.8 / 4.9 / 1.3
	Wet FGD	No SCR	88.8 / 9.9 / 1.3	93.8 / 4.9 / 1.3	93.8 / 4.9 / 1.3
		SCR	49.4 / 49.4 / 1.3	93.8 / 4.9 / 1.3	93.8 / 4.9 / 1.3
	No FGD	No SCR	0 / 98.7 / 1.3	0 / 98.7 / 1.3	0 / 98.7 / 1.3
		SCR	88.8 / 9.9 / 1.3	93.8 / 4.9 / 1.3	93.8 / 4.9 / 1.3

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[17] Comments are available at http://www.epa.gov/mercury/pdfs/OAR-2002-0056-2578.pdf. Mercury speciation in the comments (Table IV-14) only included elemental and ionic mercury, so the percentages included here are slightly different.

$PM_{2.5}$ Emissions

$PM_{2.5}$ Emissions are not directly calculated in NEEM. Instead, they are calculated based on the factors that determine PM emissions such as the boiler type (wet bottom, dry bottom, cyclone), PM equipment in place (ESP, fabric filter), the type of coal burned (and its ash and sulfur content). These factors determine the emission rate, which was based on published emission rates in the AP-42. We calculated both filterable and condensable $PM_{2.5}$ emissions.

Emission factors for filterable PM are derived from AP-42[18] Table 1.1-6 (dry bottom boilers), Table 1.1-7 (wet bottom boilers) and Table 1.1-8 (cyclone furnaces). Emission factors for condensable PM are derived from AP-42 Table 1.1-5 (with and without FGD controls).

The filterable $PM_{2.5}$ emission rate is multiplied by the ash content of the coal and then multiplied by total fuel use to derive the filterable $PM_{2.5}$ emissions for each unit. The condensable $PM_{2.5}$ emission rate, which already accounts for the sulfur content of the coal (if the unit is not scrubbed) is multiplied by the total fuel use to derive the condensable $PM_{2.5}$ emissions for each unit. The filterable and condensable $PM_{2.5}$ are summed for each unit to report a total $PM_{2.5}$ emission number.

PHEV Scenario

The PHEV Scenario used identical assumptions as those described above (and used in the base case) with the exception of total electricity demand and peak demand. These data were modified to include the expected increases in each as a result of the penetration of PHEVs.

Increased Electricity Demand

Using market penetrations, vehicle miles travelled and charging characteristics of PHEVs as described in Chapter 2, annual electricity requirements from 2010 through 2030 for PHEV charging were calculated for each of the 48 states in the CONUS. Using the share of PHEV MWh by state, the electricity usage was allocated to each of the regions within the NEEM model. The daily charging schedule for the PHEVs, illustrated again in **Figure 3-2**, depicts the fraction of incremental demand in each hour of the day. For example, 10% of incremental demand is in hour 1 (from midnight to 1:00 a.m.) and an additional 10% is in hour 2 (1 a.m. to 2 a.m.). Similarly 10% of the demand also occurs in hours 23 and 24 (10 p.m. to 11 p.m. and 11 p.m. to midnight). These examples demonstrate that the bulk of the charging occurs during off-peak hours (late at night and early in the morning) requiring additional demand for electricity during these hours.

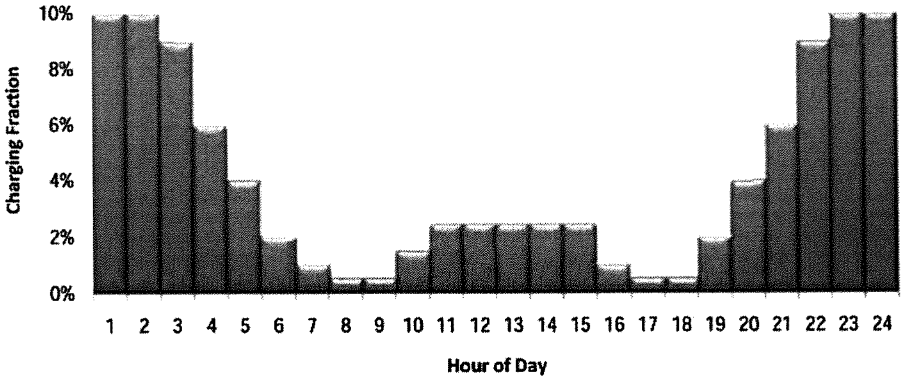

Figure 3-2
Charging Profile of Plug-In Hybrid Electric Vehicles

Using the charging profile and the total MWh of electricity to be used to charge the PHEVs we calculated the incremental electricity demand for each region, for each load block. The national increase in electricity demand in 2030 is 6%. We also calculated the increase in the projected peak demand used to compute the regional reserve margins.

Electric Sector Modeling Results

Generation and Capacity Mix

Figure 3-4 shows the national generation mix in 2030 in the base case and in the PHEV case. The base case generation mix is quite similar to the forecast for 2030 in AEO 2006. In order to provide a common frame of reference between National Energy Modeling System Electricity Market Module (NEMS EMM) regions shown in AEO 2006 and NEEM regions, Table 3-9 shows an approximate mapping of NEMS EMM regions to NEEM regions.[19] AEO 2006 also forecasts coal-fired generation (existing and new) meeting 60% of total generation, while it has nuclear meeting 16%, renewables at 9% and natural gas meeting 13%.[20] A high percentage of the demand increase from PHEVs is in off-peak hours (see Figure 3-2) and, therefore, represents primarily a need for baseload generation, such as that from large coal-fired power plants.

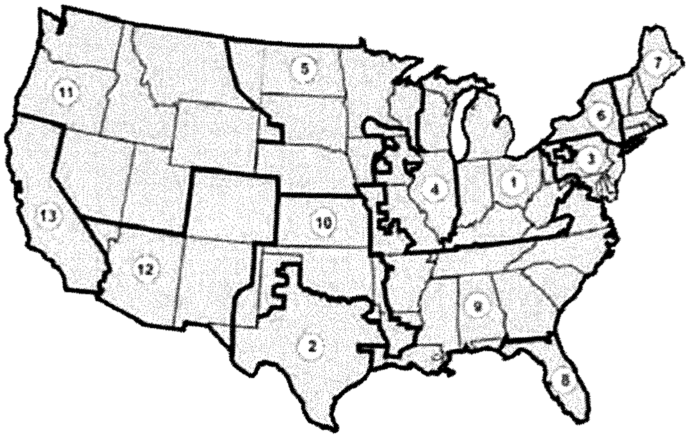

Figure 3-3
National Energy Modeling System Electricity Market Module (NEMS EMM) Regions

On a regional level, all regions increased their levels of generation except for California. This decline is offset by a large increase in the neighboring NWP region (see Table 3-10). The increased demand from California is met through lower-cost baseload generation that is imported from other states. The following figures show the generation mix within each region in both the base case and the PHEV case.

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[18] EPA has compiled emission factors for use in computing emissions inventories. Emission factors used in this study are from AP 42, Volume I, Fifth Edition for External Combustion Sources. This section of the report is available at http://www.epa.gov/ttn/chief/ap42/ch01/index.html.

[19] Individual NEMS EMM regions correspond approximately to either an individual NEEM region or a combination of NEEM regions. A key difference is that the NEMS EMM Northwest Power Pool (NWP) region includes Wyoming whereas the NEEM Northwest Power Pool (NWPP) region does not; this has been noted on Table 3-9.

[20] See *EIA's Annual Energy Outlook 2006*, Reference Case Table 8, http://www.eia.doe.gov/oiaf/archive/aeo06/excel/aeotab_8.xls.

Table 3-9
Approximate Mapping between NEMS Regions and NEEM Regions

NEMS EMM Region			**NEEM Region(s)**
13	California	CA	SP15 + NP15
1	East Central Area Reliability Coordination Agreement	ECAR	ECAR + AE
2	Electricity Reliability Council of Texas	ERCOT	ERCOT
8	Florida	FL	FRCC
3	Mid-Atlantic Area Council	MAAC	PJM
4	Mid-America Interconnected Network	MAIN	WUMS + NI + EMO + SCIL
5	Mid-Continent Area Power Pool	MAPP	MAPP-US
7	New England	NE	NEISO
11	Northwest Power Pool	NWP - Wyoming	NWPP
6	New York	NY	NYISO-W + NYISO-E
12	Rocky Mountain Power Area, AZ, NM, Southern NV	RA + Wyoming	RMPA + AZ_NM_SNV
9	Southeastern Reliability Council	SERC	ENT + TVA + SOCO + VACAR
10	Southwest Power Pool	SPP	SPP-N + SPP-S

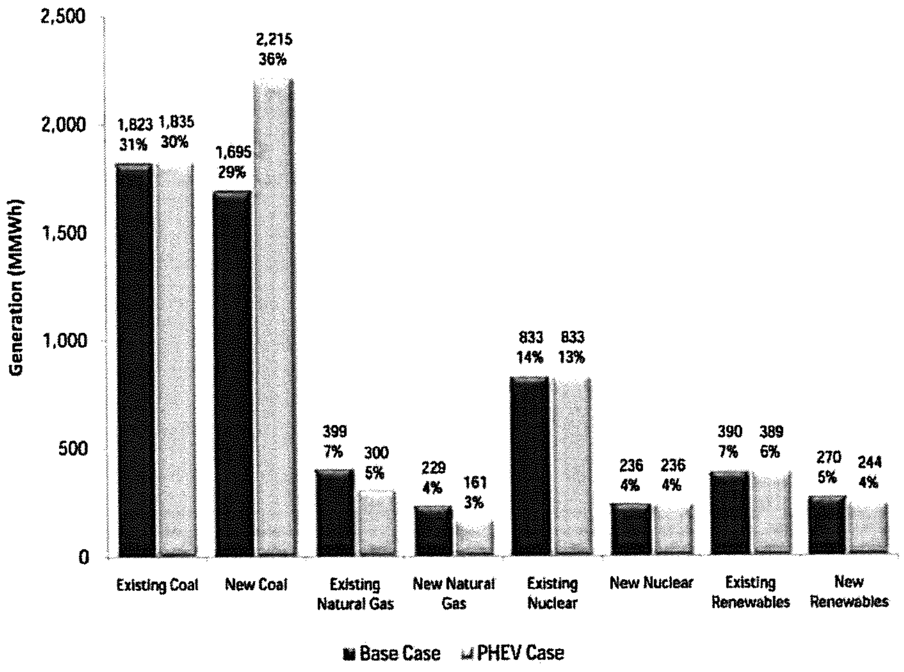

Figure 3-4
Generation Mix (% of MMWh): Base Case and PHEV Case

Table 3-10
Regional Generation Changes from Base Case to PHEV Case

NEMS EMM Region	Base Case Generation 000 MWh	Δ Generation PHEV Case 000 MWh	Percent Change
CA	315,837	-26,583	-8.4%
ECAR	864,261	14,492	1.7%
ERCOT	468,901	26,469	5.6%
FL	366,602	7,769	2.1%
MAAC	364,747	35,127	9.6%
MAIN	447,458	38,866	8.7%
MAPP	251,952	22,384	8.9%
NE	179,915	11,476	6.4%
NWP - WY	375,295	86,170	23.0%
NY	189,994	8,039	4.2%
RA + WY	468,337	14,762	3.2%
SERC	1,307,279	85,859	6.6%
SPP	274,571	13,883	5.1%
Total US	**5,875,149**	**338,713**	**5.8%**

Figure 3-5 shows further detail on the regional generation by breaking it down by generation fuel type. Another look at the NWP region (which has a significant increase in generation to offset the decline in California generation) shows that the increase is achieved through a large increase in coal-fired generation relative to the base case. The other regions with larger increases in generation also achieve these increases through increases in coal-fired generation.

Electricity demand in the United States is projected to grow by ~50% during the AQ study's time horizon (2006-2030), or about 1,931 MMWh. The additional load due to PHEVs increases gradually from negligible in 2010 to ~339 MMWh by 2030, less than 1/5 of the incremental demand projected demand increase in the base case. As a simplifying assumption in the AQ study, it was assumed that population growth and economic expansion would drive transmission expansion within the different electric sector regions of the United States.

Figure 3-6 and **Table 3-11** summarize the national and regional capacity mix in 2030 in the base case and with PHEVs. Similar to the national generation mix, the figure shows a decline in both existing and new natural gas-fired capacity and an increase in new coal-fired capacity. There is also a small decline in new renewable capacity. All of these changes are the result of an increase in baseload generation needs.

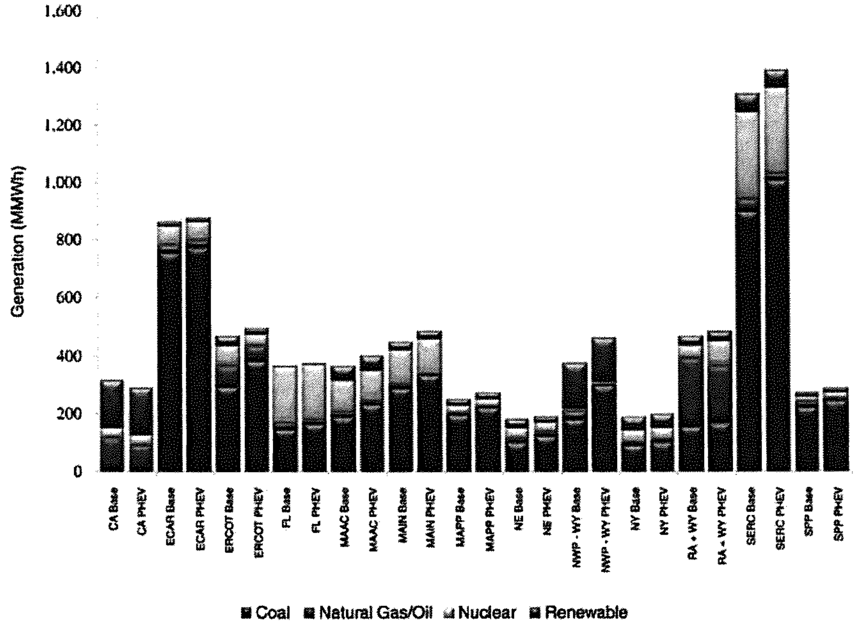

Figure 3-5
Regional Generation Mix by Fuel: Base Case and PHEV Case

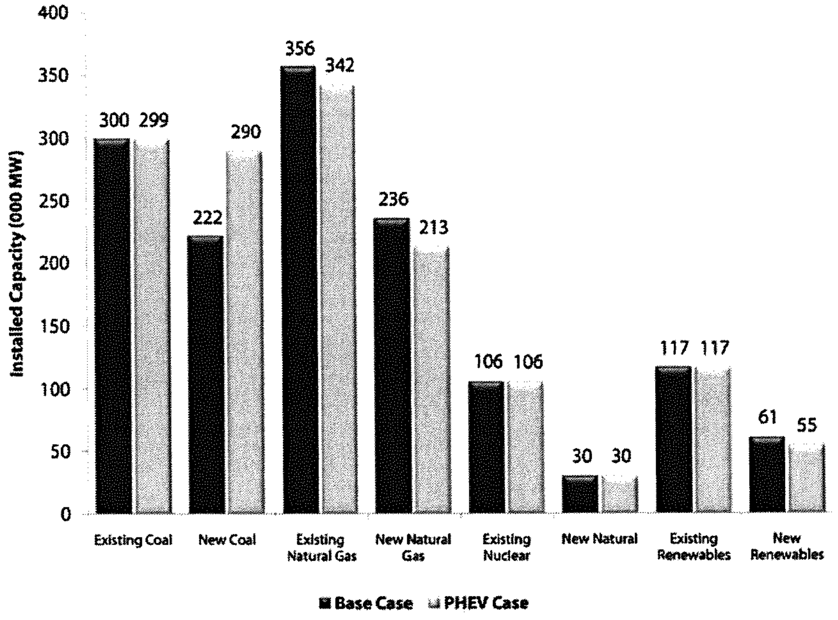

Figure 3-6
National Capacity Mix (% of MW): Base Case and PHEV Case

Table 3-11
Regional Capacity Changes from Base Case to PHEV

NEMS EMM Region	Base Case Capacity 000 MW	Δ Capacity PHEV Case 000 MW	Percent Change
CA	88	-3.1	-3.5%
NWP - WY	69	11.9	17.3%
RA + WY	130	5.0	3.9%
MAPP	56	0.7	1.3%
SPP	67	0.7	1.0%
MAIN	101	1.3	1.3%
ECAR	186	2.7	1.5%
SERC	309	3.5	1.1%
FL	124	1.0	0.8%
MAAC	98	1.1	1.1%
NY	52	0.9	1.7%
NE	46	-0.6	-1.2%
ERCOT	113	-1.1	-1.0%
Total US	**1,440**	**24.0**	**1.7%**

For each NEEM region, there is also a separate detailed regional summary of both generation and capacity in 2030 (also includes emissions). This regional summary is included in **Appendix B**.

Electric Sector Emissions Results

While the PHEV case results in a national increase in coal-fired generation this does not translate into national increases in SO_2, NOx and Hg emissions from the electric sector. Due to the national caps on emissions of SO_2, NOx and Hg, the emissions of these pollutants cannot change by more than minor amounts attributable to differences in the pattern of banked allowances. In this analysis there is no CO_2 policy, so CO_2 emissions can increase relative to the base case (similarly, no caps were applied to primary PM emissions). However, if there were to be a cap on CO_2 (or PM) emissions then the pattern seen for SO_2, NOx and Hg would also necessarily apply to CO_2 (or PM) as well.

As shown in **Table 3-12**, at a regional level, there are some increases and decreases in SO_2 emissions. However, these emissions are not directly tied to the regions with the increases in coal-fired generation. The majority of the increase in coal-fired generation comes from new plants that have state-of-the-art pollution controls. Some of this new coal-fired generation displaces older, less-efficient and higher-emitting existing coal plants resulting in reductions in SO_2 emissions within the region. The PHEV case actually has fewer retrofit installations of SO_2 pollution controls nationally because of the displacement of existing coal-fired generation by newer, more efficient coal-fired generation. Overall, SO_2 emissions decrease by approximately 16,000 tons, equivalent to 0.4% of electric sector emissions within the CONUS.

Table 3-12
Electric-Sector SO_2 Emissions by NEMS EMM Region

NEMS EMM Region	SO_2 Emissions Base Case 000 ton	% CONUS	SO_2 Emissions PHEV Case 000 ton	Δ SO_2 Emissions 000 ton
CA	0	0%	0	0
NWP - WY	117	3%	126	9
RA + WY	155	4%	130	-25
MAPP	280	7%	275	-4
SPP	358	10%	346	-13
MAIN	465	12%	446	-20
ECAR	792	21%	826	34
SERC	952	25%	936	-16
FL	57	2%	60	3
MAAC	177	5%	174	-3
NY	71	2%	71	0
NE	110	3%	126	16
ERCOT	205	5%	208	3
Total US	**3,740**	**100%**	**3,724**	**-16**

At the regional level, there are variations in NOx emissions as well (shown on Table 3-13). Many of the regions with increases in NOx emissions are not covered by either the CAIR Annual or Ozone Season NOx cap (e.g., NWP, ERCOT). For those states covered by the CAIR NOx rules, there is a small increase in the retrofit installation of NOx emission controls installed on existing coal-fired generators that is required in order to comply with the NOx caps. Overall, NOx emissions increase by approximately 59,000 tons, equivalent to 2.9% of electric sector emissions within the CONUS.

Table 3-13
Electric-Sector NOx Emissions by NEMS EMM Region

NEMS EMM Region	NOx Emissions Base Case 000 ton	% CONUS	NOx Emissions PHEV Case 000 ton	Δ NOx Emissions 000 ton
CA	4	0%	4	0
NWP - WY	169	8%	198	29
RA + WY	199	10%	198	-2
MAPP	174	9%	160	-14
SPP	235	12%	226	-9
MAIN	137	7%	138	1
ECAR	352	17%	336	-17
SERC	432	21%	463	31
FL	46	2%	52	6
MAAC	90	4%	93	4
NY	32	2%	35	3
NE	37	2%	43	7
ERCOT	127	6%	148	20
Total US	**2,035**	**100%**	**2,094**	**59**

In order to comply with the mercury cap with an increasing amount of coal generation requires additional retrofit installations of mercury control equipment by existing coal-fired generators. This is also a byproduct of the decrease in the retrofit installation of SO_2 controls, which provide co-benefits towards mercury emissions reductions. The breakdown of mercury emissions by region is provided in **Table 3-14**. Overall, mercury emissions increase by approximately 370 kg, equivalent to approximately 2.3% of electric sector emissions within the CONUS. This increase is made possible by larger reductions prior to 2030, resulting in a larger quantity of banked allowances entering 2030.

Table 3-14
Electric-Sector Hg Emissions by NEMS EMM Region

NEMS EMM Region	Hg Emissions Base Case ton	% CONUS	Hg Emissions PHEV Case ton	Δ Hg Emissions ton
CA	0.000	0%	0.001	0.001
NWP - WY	0.515	3.2%	0.681	0.165
RA + WY	0.701	4.4%	0.659	-0.041
MAPP	1.208	7.6%	1.242	0.034
SPP	1.117	7.0%	1.113	-0.005
MAIN	0.962	6.1%	1.113	0.151
ECAR	3.686	23.2%	3.231	-0.455
SERC	4.441	28.0%	4.612	0.171
FL	0.330	2.1%	0.410	0.080
MAAC	1.262	8.0%	1.297	0.035
NY	0.296	1.9%	0.328	0.032
NE	0.370	2.3%	0.453	0.084
ERCOT	0.979	6.2%	1.098	0.118
Total US	**15.868**	**100%**	**16.239**	**0.371**

As discussed above, the assumptions of this study do not include any greenhouse gas policy or emissions constraint. Since the majority of the incremental electricity load is satisfied by new coal-fired power generation, total CO_2 emissions and the CO_2 emissions intensity (ton CO_2 MWh^{-1}) from the electric sector increase.[21] If a CO_2 cap were imposed on the system, then CO_2 emissions would not be able to increase and CO_2 emissions would behave similarly to the emissions of those pollutants constrained by regulatory caps (SO_2, NOx and Hg). The results for total CO_2 emissions and CO_2 emissions intensity by region are summarized in **Table 3-15**. Overall, CO_2 emissions increase by approximately 430 million tons, equivalent to approximately 11.6% of electric sector emissions within the CONUS.

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[21] This analysis does not explore the net impacts on CO_2 emissions from the combination of the electric and transportation sectors. With respect to Volume 1 of this report, the electric sector assumptions used in this study are most similar to the high-CO_2 intensity electric sector, but with even higher total CO_2 emissions and CO_2 emissions intensity. The reader should refer to Volume 1 of this report for a detailed analysis of the impact of PHEVs on greenhouse gas emissions.

Table 3-15
Regional CO_2 Emissions by NEMS EMM Region

NEMS EMM Region	CO_2 Emissions Base Case 000 000 ton	% CONUS	Base Case CO_2 Intensity ton MWh^{-1}	CO_2 Emissions PHEV Case 000 000 ton	PHEV Case CO_2 Intensity ton MWh^{-1}	Δ CO_2 Emissions 000 000 ton	Δ CO_2 Intensity ton MWh^{-1}
CA	48	1%	0.153	37	0.129	-11	-0.024
NWP - WY	193	5%	0.514	290	0.628	97	0.114
RA + WY	256	7%	0.546	252	0.521	-4	-0.025
MAPP	203	5%	0.804	224	0.818	22	0.013
SPP	236	6%	0.859	252	0.874	16	0.015
MAIN	294	8%	0.658	333	0.685	39	0.027
ECAR	755	20%	0.873	775	0.882	20	0.009
SERC	892	24%	0.683	991	0.711	99	0.029
FL	149	4%	0.406	166	0.443	17	0.037
MAAC	193	5%	0.529	227	0.568	34	0.039
NY	84	2%	0.443	94	0.473	9	0.029
NE	95	3%	0.530	114	0.594	18	0.065
ERCOT	308	8%	0.657	382	0.770	74	0.113
Total US	**3,707**	**100%**	**0.631**	**4,136**	**0.666**	**430**	**0.035**

As the case with CO_2, the assumptions of this study do not include any caps on PM. As a result $PM_{2.5}$ emissions increase along with the increase in coal-fired generation. The breakdown of $PM_{2.5}$ emissions by region is provided in **Table 3-16**. Overall, PM emissions increase by approximately 49,000 tons equivalent to approximately 10% of electric sector emissions within the CONUS.

Table 3-16
Electric-Sector PM Emissions by NEMS EMM Regions[22]

	PM Emissions Base Case 000 ton	% CONUS	PM Emissions PHEV Case 000 ton	PM Emissions 000 ton
CA	0	0%	0	0
NWP - WY	22	4%	35	13
RA + WY	19	4%	21	1
MAPP	25	5%	28	3
SPP	28	6%	30	2
MAIN	38	8%	40	3
ECAR	122	25%	121	-1
SERC	136	28%	136	0
FL	16	3%	22	6
MAAC	29	6%	31	3
NY	10	2%	11	1
NE	11	2%	13	3
ERCOT	37	7%	52	15
Total US	**492**	**100%**	**541**	**49**

Detailed Hourly Emissions for Air Quality Modeling

The final step in the electric sector modeling was to provide hourly emissions by stack for use in the air quality modeling. A list of existing stacks contained in the emissions inventories discussed in Chapter 4 was developed. All existing electric generating units in NEEM were then mapped to a stack based on the stack's name, county and state location, and fuel source. New generating capacity built in NEEM is generic in nature (no specific location within a NEEM region). Emissions from new generating capacity were therefore allocated across existing electric generating stacks. For the air quality modeling, this is equivalent to siting new power plants where there are existing power plants. This assumption considers that a new power plant may be sited in the same vicinity as existing plants due to the ready access to fuel sources and transmission. However, the siting of a new power plant would also have to satisfy environmental considerations, such as Prevention of Significant Deterioration (PSD); depending on regional conditions, collocating facilities may or may not be desirable.

As described above, NEEM uses load blocks rather than dispatching on an hourly basis. However, each hour is associated with a particular load block. This mapping of hours to load blocks is based on 2002 hourly load data, which is consistent with the meteorological data utilized in the emissions processing (for on-road, off-road and biogenic emissions) and in driving the dynamics of the air quality model. To map the emissions to hourly emissions, the annual emissions were first parsed out to

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[22] Primary particulate matter emissions from power plants are in the fine size fraction, i.e. $PM_{2.5}$. Since $PM_{2.5}$ is a subset of PM_{10}, these emissions are included in the PM_{10} inventory. However, the air quality model size segregates emissions of coarse PM, i.e. $PM_{10-2.5}$, and fine $PM_{2.5}$ and simulates the formation of secondary particulate matter in the atmosphere. Secondary particulate matter in the atmosphere generally contributes to the fine size fraction and thereby contributes to both $PM_{2.5}$ and PM_{10}, but not $PM_{10-2.5}$.

emissions by load block by looking at the load block's share of annual generation for each generating unit. Then, using the mapping of hours to load blocks, the emissions were further allocated from load blocks to individual hours.

Summary Electric Sector Impacts of PHEVs

In summary, the addition of PHEVs as a significant transportation option adds approximately 6% to the total national electricity demand in 2030 compared to the base case with no PHEVs. Due to the charging profile that results in most of this additional demand occurring during off-peak hours (late night/early morning) there is an increase in the need for baseload generation. The addition of coal-fired generation to meet this need for more baseload generation does not result in any significant differences in annual emissions of SO_2, NOx, and Hg because of the caps on those pollutants. Therefore, any reductions in emissions of SO_2, NOx, or Hg from non-electric generating sources would result in a net national decline in these emissions. However, it does result in an appreciable increase in CO_2 and PM emissions as this analysis has not assumed any limits on CO_2 or PM emissions. These results are shown in **Figure 3-7**, **Figure 3-8**, and **Figure 3-9**.

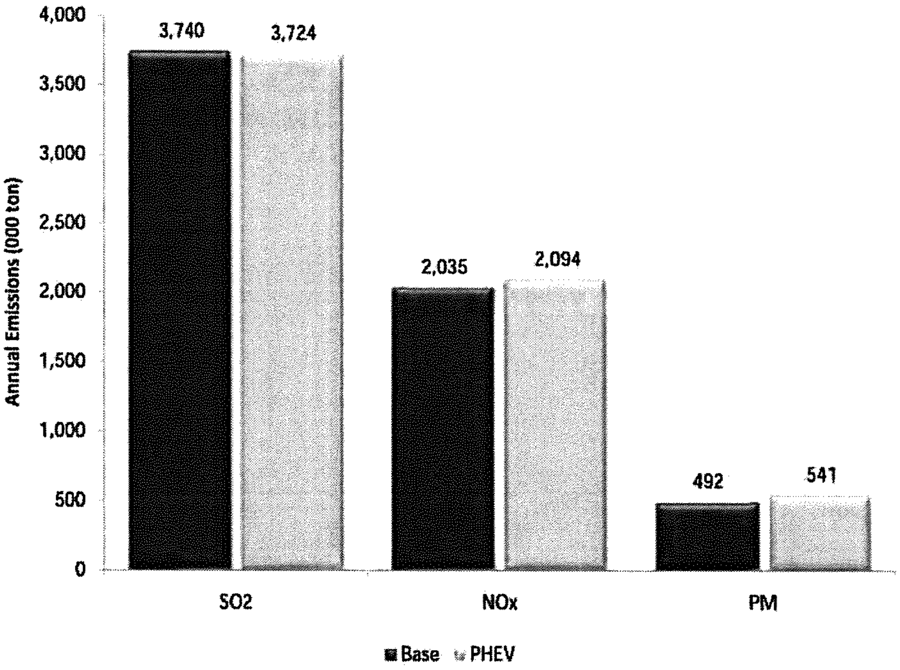

Figure 3-7
National Emissions Comparison (SO_2, NOx, PM)

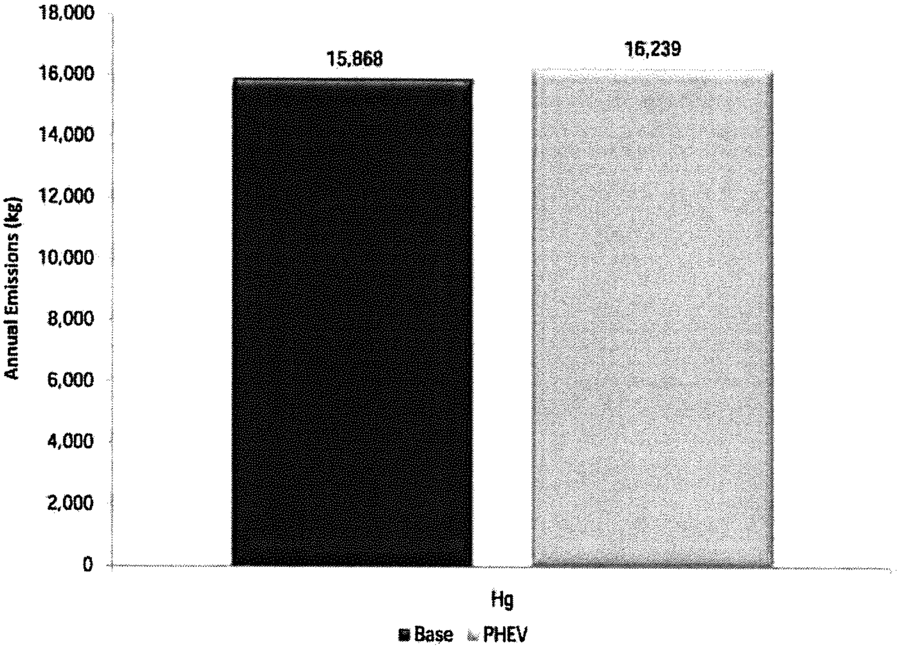

Figure 3-8
National Emissions Comparison (Hg)

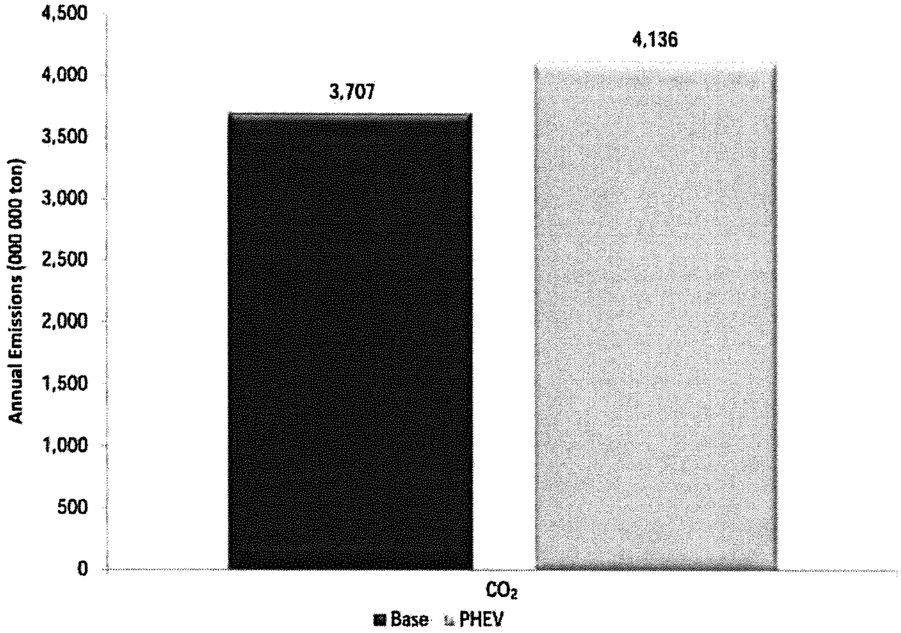

Figure 3-9
National Emissions Comparison (CO_2)

4 Emissions Processing and Results

A key component of any air quality modeling study is the emissions inventory. Spatially and temporally resolved estimates of SO_2, VOC, NOx, CO, NH_3, PM, Hg and other emissions are required for all sources including electrical generating units (EGUs), on-road mobile sources, off-road mobile sources and biogenic sources, to name a few categories. These emissions data must be formatted for input to the air quality model. Two emission inventories were prepared for a 2030 future year using the data described in Chapter 2 and Chapter 3: one for the 2030 base case scenario and another for the 2030 PHEV case scenario.

The emission inventories in the hourly, chemically speciated and gridded format needed by the Community Multiscale Air Quality (CMAQ) air quality model were prepared using the Sparse Matrix Operator Kernel Emissions (SMOKE) model. SMOKE requires emissions inventory files and ancillary data files as input data. For this work, the SMOKE input data were prepared by starting with the 2018 emission inventories prepared by the Western Regional Air Partnership (WRAP). Emissions from on-road mobile sources and EGUs were updated to reflect changes between 2018 and 2030. For all other source categories the 2030 emissions were set to the 2018 levels assuming that activity growth will be offset by technology improvement. This simplified assumption was used due to the lack of any other reliable information needed to project these emissions from 2018 to 2030. However, since the focus of this study is to quantify the impact of PHEVs on air quality, this assumption should not have any significant bearing on the results. Four source categories were modified for the PHEV scenario, namely EGU point, on-road mobile, area, and non-EGU point sources. This section describes emissions data sources and the modeling platform used in this work.

Emissions Data Sources

The emissions data for this work were from four data sources:

1. WRAP 2018 emissions database,
2. EPA's Clean Air Mercury Rule (CAMR) 2001 mercury emissions database,
3. transportation sector emissions as discussed in Chapter 2, and
4. electric sector emissions as discussed in Chapter 3.

Western Regional Air Partnership (WRAP) 2018 Emissions Inventory

The Clean Air Act (CAA) established 156 Federally-protected parks and wilderness areas (Class I areas) where visibility was determined to be a valuable environmental asset worthy of protection. To meet Sections 169A and 169B of the CAA, EPA promulgated the Regional Haze Rule (RHR). The RHR requires States to submit State Implementation Plans (SIPs) to address regional haze visibility impairment in 156 Class I areas. WRAP and its Regional Modeling Center (RMC) are responsible for performing regional air quality modeling simulations for the WRAP region to demonstrate progress in improving visibility conditions in 2018 using a five-year baseline based on visibility measurements from 2000 to 2004. The WRAP 2018 emissions were the starting point for developing the 2030 emission inventory.

The most updated WRAP emission database at the time of this work was the "2018 base b" emissions database. This database was built from the WRAP 2002 inventory by projecting the impacts of activity growth and emission controls. The point and area projection report for the 2018 base case emission inventory can be found on the WRAP website (ERG, 2006). Note that Mexican and Canadian 2018 emissions are the same as the WRAP 2002 database.[23] Some emission categories such as marine commercial shipping, area source ammonia, and biogenic emissions also are held constant from the WRAP 2002 database. Details on data collection, emission processing and quality assurance of the WRAP 2002 emission inventory can be found in Tonnesen et al. (2006).

All of the SMOKE inventory files and ancillary files are available to download at http://pah.cert.ucr.edu/aqm/308/emissions.shtml. The WRAP 2018 emissions QA plots are available at http://pah.cert.ucr.egu/aqm/308/qa_base18b36.shtml. CMAQ emission ready files by source category are also available from the WRAP RMC upon request. For this work, emissions for source categories other than area, non-EGU point, EGU point and on-road-mobile were obtained from the WRAP RMC as CMAQ model ready files.

Clean Air Mercury Rule (CAMR) 2001

The WRAP emissions database does not include mercury emissions. However, mercury emissions were estimated by EPA for the CAMR (technical information can be found at http://www.epa.gov/ttn/atw/utility/utiltoxpg.html#TECH; accessed on 04/15/2006). The 2001 CAMR data are available from EPA upon request (Peters, 2006). The basis for the 2001 mercury emissions inventory in the United States is the 1999 National Emission Inventory (NEI) for Hazardous Air Pollutants (HAPs), July 2003 version. Note that there are no mercury emissions for either the off-road or on-road mobile sources in the 1999 NEI. In addition, no mercury emissions data were available for Mexico in EPA's CAMR modeling inventories.

The CAMR 2001 mercury emissions data are provided for 3 sectors:

- IPM sector: EGU point-source facilities that were also in the April 2003 version of the 2010 Integrated Planning Model (IPM) database and matched between the 1999 NEI and the 2001 CAIR inventory.
- Non-IPM sector: All U.S. point sources not in the IPM sector and all-point source mercury emissions from Canada.
- Non-point sector: Non-point stationary sources in the U.S. and Canada. This sector includes all mercury emissions that do not have facility-specific information available.

In this chapter, only the processing of CAMR non-IPM and non-point sector emissions is described. EGU emissions were calculated as described in Chapter 3.

Source Categories

Area Sources (Non-Point Stationary Sources)

This category comprises stationary sources that are not identified as individual points and so are treated as being spread over a spatial extent (usually a county). Examples of stationary area sources include (but are not limited to) residential emissions, fires, oil and gas wells, fugitive dust, and road dust. The 2030 base case emissions were held constant at the same level as the WRAP 2018 emissions. For the 2030 PHEV scenario, emission adjustments were applied to "upstream" emissions related to gasoline refining and distribution as described in Chapter 2.

On-road Mobile Sources

This category comprises vehicular sources that operate on roadways such as light-duty gasoline vehicles and heavy-duty diesel vehicles. On-road emissions in the WRAP database are estimated from emission factors and activity data that consist of vehicle miles traveled (VMT) and vehicle speed. SMOKE computes emission factors for each CMAQ grid-cell using gridded, hourly temperature data and the output from the MOBILE6 emission factor model (U.S. EPA, 2005). The 2030 base case

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[23] Mexican and Canadian emissions were not modified for this study.

emissions were projected from 2018 and the PHEV scenario emissions were further adjusted to account for market penetration of PHEVs, as described in Chapter 2.

Off-road Mobile Sources

Off-road mobile sources include, for example, railroad locomotives, aircraft, commercial marine vessels, farm equipment, recreational boating, and lawn and garden equipment. The 2030 base case and PHEV case off-road emissions were held constant from the WRAP 2018 database. The marine shipping inventory in WRAP 2018 was estimated using the Waterway Network Ship Traffic, Energy and Environment Model (STEEM) to characterize ship traffic, estimate energy use and assess the environmental impacts of shipping (Corbett et al., 2006). Off-road emissions sources were not modified for this study, i.e. 2030 emissions were set to the 2018 levels assuming that activity growth will be offset by technology improvement.

Point Sources

These are stationary sources that are identified by point locations. Their emissions are allocated vertically through the CMAQ model layers according to stack height and plume rise. Point sources are divided into EGU sources and non-EGU sources such as refineries.

EGU emissions were estimated for the 2030 base case and PHEV case as discussed in Chapter 3. The PHEV case had higher emissions and included some new EGU facilities in Southern California. The NOx emissions from new EGUs in Southern California for the base case and PHEV case are 125 and 111 tons/year, respectively. According to the NSR program emissions introduced from new sources in non-attainment areas need to be offset. As mentioned in Chapter 3, the South Coast Air Basin (SoCAB) portion of Southern California has adopted RECLAIM program that sets a declining balance for facilities emitting NOx in the SoCAB. However, there were no new EGU sources in the SoCAB, thus, the emission offset for new EGUs was only applied to the non-RECLAIM portion of Southern California. The approach was to offset all emissions from new EGU point sources by reducing emissions from all non-EGU point sources in equal proportions. The NOx offset ratio varies with Air Pollution Control District (APCD) ranging from 1 for areas in attainment to 1.2-1.3 for areas in non-attainment for ozone. In this study, it was assumed that areas were in non-attainment and a 1.2 offset ratio was applied for the entire non-RECLAIM area.

Non-EGU emissions for the base case were offset to account for new EGUs as described above. For the PHEV case, upstream emission reductions described in Chapter 2 were applied prior to the new EGU emission offset.

Biogenic Emissions[24]

Biogenic emissions are a function of vegetation type and meteorological conditions. Land cover data characterize the types of vegetation for each CMAQ grid cell. Biogenic emissions were held constant from the WRAP 2002 database that used 2002 meteorology. Biogenic emissions were estimated using version 3 of the Biogenic Emission Landcover Database (BELD3) (EPA, 2001) and the most recent version (v0.98) of the BELD emissions factors by vegetation species (EPA, 2004).

Other Emissions

Other emission categories such as mercury from vegetation, agricultural source ammonia and the

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[24] Biogenic emissions included in this report also include natural non-biologically derived emissions except for wind-blown dust (separate category), natural fires (included in Area category) and lightning-induced NOx (not included in emissions processing).

wind-blown dust were held constant at 2018 levels from the original data sources. These three sectors fall outside of the SMOKE processing and were generated from process-based models. Emissions of gaseous mercury from vegetation were provided by EPA. The emissions were derived from a special version of the Biogenic Emissions Inventory System (BEIS) described by Lin et al. (2005). Ammonia emissions from sources including livestock, fertilizer usage, domestic sources, and wild animals were generated from a GIS-based model (Mansell, 2005). WRAP wind-blown dust emissions were developed using the WRAP windblown dust model (Mansell et al., 2006). All of these emission categories were held constant between the 2030 base case and PHEV case.

The Sparse Matrix Operator Kernel Emissions (SMOKE) MODEL

SMOKE is an emissions processor that generates hourly, gridded, speciated emissions for on-road mobile, off-road mobile, area, point, fire and biogenic source categories for input to photochemical grid models. SMOKE has been used for emissions processing in a number of regional air quality modeling applications.

Four source categories—area, non-EGU point, EGU point and mercury sources included in EPA's 2001 CAMR database—were processed using SMOKE and merged with emissions from all other source categories obtained in CMAQ-ready format. The databases required to set up and operate SMOKE are as follows:

- Area: County-level seasonal or annual area source emissions in Inventory Data Analyzer (IDA) format.
- Non-EGU: Annual non-EGU source emissions in IDA format.
- EGU: Hourly and annual stationary point source emissions in CEM and IDA format, respectively.
- Mercury: County-level seasonal or annual area source emissions in Inventory Data Analyzer (IDA) format.

SMOKE uses ancillary data to perform temporal, spatial and chemical allocation of emissions according to source category (CEP, 2004). The WRAP 2018 SMOKE configuration was used for all emissions except mercury. The CAMR 2001 SMOKE configuration was used for the mercury emissions.

Emissions Summaries

Emissions are summarized by state and major source category in the following tables. These tables were prepared from the CMAQ-ready gridded emissions by using a grid-cell to state correspondence; as a result, state totals are approximate.

Emissions from Canada, Mexico and maritime regions within the model domain are combined and reported in the row labeled "OTHER". Due to some the allocation of grid cells to individual states for summary purposes, a small amount of CONUS emissions are included in the "OTHER" classification. However, we note that the EGU category represents only EGU sources in the CONUS; consequently, the Non-EGU category represents Non-EGU sources in the CONUS and all (EGU and Non-EGU) other point sources outside of the CONUS within the model domain.

Please note that SO_2 emissions in this chapter are presented within sulfur oxide (SOx) emissions inventories. SOx emissions include SO_2, sulfur trioxide (SO_3) and sulfuric acid (H_2SO_4). For the electric sector, SOx emissions are calculated by the SMOKE model using SO_2 emissions rates determined in Chapter 3 and emission factors dependent on fuel type and control configuration of specific electric generating units.

Table 4-1 summarizes annual NOx emissions; **Table 4-2** summarizes annual SOx emissions; **Table 4-3** summarizes annual primary PM_{10} emissions; **Table 4-4** summarizes annual TOG emissions; and **Table 4-5** summarizes annual total mercury emissions.

Table 4-1
Annual NOx Emissions (ton y^{-1}) by State and Source Category

	Base Case 2030							PHEV Case 2030						
State	Area	Off-road	On-road	Non-EGU	EGU	Biogenic	Dust	Area	Off-road	On-road	Non-EGU	EGU	Biogenic	Dust
AL	38,780	42,950	34,877	85,157	31,573	15,130	0	38,780	42,950	29,203	84,957	28,046	15,130	0
AZ	29,292	47,302	38,781	19,705	64,299	27,523	0	29,292	47,302	32,728	19,703	62,203	27,523	0
AR	34,370	17,507	22,976	32,007	43,178	24,947	0	34,370	17,507	19,373	31,904	47,784	24,947	0
CA	151,859	173,734	104,531	79,848	3,129	57,484	0	151,859	173,734	96,943	79,216	2,785	57,484	0
CO	68,956	40,574	36,645	36,271	71,484	38,270	0	68,956	40,574	30,375	36,143	73,609	38,270	0
CT	13,164	14,013	9,434	8,427	3,466	625	0	13,164	14,013	8,019	8,425	3,903	625	0
DE	1,544	4,891	2,045	582	3,917	1,023	0	1,544	4,891	1,749	581	4,185	1,023	0
FL	44,955	95,092	97,309	67,588	63,655	46,587	0	44,955	95,092	81,472	67,579	68,854	46,587	0
GA	55,171	52,640	65,222	46,662	78,403	24,373	0	55,171	52,640	55,193	46,660	91,618	24,373	0
ID	82,990	17,947	9,009	10,761	68	16,799	0	82,990	17,947	7,554	10,760	10	16,799	0
IL	55,739	130,134	55,166	115,822	102,275	39,970	0	55,396	130,134	46,647	115,050	107,554	39,970	0
IN	29,200	60,478	40,045	76,443	69,090	22,557	0	29,200	60,478	33,604	76,216	67,884	22,557	0
IA	8,978	35,344	25,456	49,840	36,297	40,429	0	8,978	35,344	21,417	49,837	31,298	40,429	0
KS	71,575	22,100	20,800	90,897	90,260	74,715	0	71,561	22,100	17,438	90,442	92,347	74,715	0
KY	44,140	63,595	29,037	47,921	61,985	17,510	0	44,140	63,595	24,478	47,260	62,666	17,510	0
LA	133,514	28,190	30,685	284,707	14,931	23,207	0	133,514	28,190	25,857	277,704	16,221	23,207	0
ME	7,365	6,977	10,921	21,548	209	2,403	0	7,365	6,977	9,083	21,545	196	2,403	0
MD	23,536	27,168	22,532	28,179	33,403	3,325	0	23,536	27,168	19,074	28,176	32,585	3,325	0
MA	34,745	35,270	16,897	22,515	8,908	1,295	0	34,745	35,270	14,366	22,515	9,600	1,295	0
MI	42,218	62,213	68,393	65,647	19,411	17,399	0	42,218	62,213	57,024	65,645	17,873	17,399	0
MN	66,232	51,543	42,962	75,170	23,309	34,109	0	66,232	51,543	35,710	74,627	13,993	34,109	0
MS	10,433	54,536	17,944	59,333	19,028	17,988	0	10,433	54,536	15,282	59,314	11,327	17,988	0
MO	36,238	35,621	33,326	42,912	71,053	34,325	0	35,304	35,621	28,110	42,890	71,037	34,325	0
MT	50,738	36,697	16,637	17,855	41,876	58,128	0	50,738	36,697	13,932	17,528	47,137	58,128	0
NB	18,745	18,573	15,449	36,108	50,983	61,267	0	18,745	18,573	12,975	36,106	53,327	61,267	0
NV	15,370	22,360	11,565	11,085	19,830	14,926	0	15,370	22,360	9,654	11,072	20,239	14,926	0

(Continued)

Table 4-1 (Continued)
Annual NOx Emissions (ton y^{-1}) by State and Source Category

	Base Case 2030							PHEV Case 2030						
State	Area	Off-road	On-road	Non-EGU	EGU	Biogenic	Dust	Area	Off-road	On-road	Non-EGU	EGU	Biogenic	Dust
NH	10,588	3,907	5,176	1,617	10,652	685	0	10,588	3,907	4,373	1,617	12,758	685	0
NJ	30,897	46,619	16,785	28,090	7,699	2,000	0	30,897	46,619	14,482	27,395	8,320	2,000	0
NM	165,548	32,962	15,825	46,137	36,717	42,181	0	165,546	32,962	13,249	45,971	35,469	42,181	0
NY	87,778	69,007	46,059	48,735	28,415	9,312	0	87,778	69,007	39,424	48,730	31,647	9,312	0
NC	59,351	45,724	57,645	50,539	55,689	16,117	0	59,351	45,724	48,770	50,537	59,673	16,117	0
ND	19,524	37,230	3,695	9,537	62,031	45,603	0	19,524	37,230	3,100	9,332	67,515	45,603	0
OH	40,565	88,497	56,858	63,052	54,889	19,720	0	40,565	88,497	47,861	62,277	48,280	19,720	0
OK	149,190	16,422	28,554	99,012	79,837	58,315	0	149,190	16,422	23,932	98,067	84,306	58,315	0
OR	49,115	32,189	25,909	18,797	9,896	16,432	0	49,115	32,189	21,830	18,797	10,044	16,432	0
PA	54,215	62,315	58,722	108,719	92,137	10,185	0	54,215	62,315	50,001	107,831	92,521	10,185	0
RI	3,308	2,209	2,944	1,641	107	138	0	3,308	2,209	2,456	1,638	115	138	0
SC	26,921	34,462	30,352	59,150	40,391	11,346	0	26,921	34,462	25,553	59,149	43,768	11,346	0
SD	8,361	24,231	5,777	7,066	692	52,346	0	8,361	24,231	4,856	7,066	778	52,346	0
TN	24,022	60,488	45,493	52,659	55,006	15,104	0	24,022	60,488	38,242	52,519	64,611	15,104	0
TX	271,209	67,458	110,922	350,189	158,278	273,613	0	271,209	67,458	93,677	347,045	165,497	273,613	0
UT	31,467	28,658	18,012	21,353	62,100	12,664	0	31,467	28,658	15,104	21,168	70,968	12,664	0
VT	3,195	2,146	2,387	915	34	993	0	3,195	2,146	2,024	915	22	993	0
VA	53,606	35,811	49,772	82,381	40,003	10,284	0	53,606	35,811	41,350	82,318	38,183	10,284	0
WA	33,856	47,209	38,316	28,270	12,834	18,319	0	33,856	47,209	31,904	27,539	15,238	18,319	0
WV	12,641	22,543	11,294	38,978	71,163	3,459	0	12,641	22,543	9,404	38,978	68,376	3,459	0
WI	20,209	33,720	26,882	44,536	27,158	24,487	0	20,209	33,720	22,645	44,463	26,106	24,487	0
WY	87,961	56,778	6,935	25,438	48,257	15,383	0	87,961	56,778	5,810	25,400	52,732	15,383	0
OTHER	657,523	1,323,929	919,546	984,422	55,071	564,570	0	657,523	1,323,929	918,902	983,541	58,787	564,570	0
TOTAL	**3,070,897**	**3,371,964**	**2,462,504**	**3,604,222**	**2,035,075**	**1,939,569**	**0**	**3,069,604**	**3,371,964**	**2,226,212**	**3,584,146**	**2,093,991**	**1,939,569**	**0**

Table 4-2
Annual SOx Emissions (ton y^{-1}) by State and Source Category

	Base Case 2030							PHEV Case 2030						
State	Area	Off-road	On-road	Non-EGU	EGU	Biogenic	Dust	Area	Off-road	On-road	Non-EGU	EGU	Biogenic	Dust
AL	50,701	2,845	857	92,244	128,281	0	0	50,701	2,845	705	92,161	114,260	0	0
AZ	7,865	611	1,032	37,204	38,858	0	0	7,865	611	853	37,204	27,050	0	0
AR	29,683	935	521	21,936	83,839	0	0	29,683	935	432	21,746	89,661	0	0
CA	21,015	5,127	2,167	41,366	0	0	0	21,015	5,127	1,881	40,670	211	0	0
CO	10,107	370	744	8,434	89,257	0	0	10,107	370	612	8,214	78,485	0	0
CT	13,975	772	464	2,702	19,012	0	0	13,975	772	381	2,702	23,451	0	0
DE	1,003	926	73	1,703	1,697	0	0	1,003	926	61	1,703	2,139	0	0
FL	50,074	6,138	2,623	98,921	140,129	0	0	50,074	6,138	2,156	98,921	115,425	0	0
GA	60,248	825	1,692	45,502	175,446	0	0	60,248	825	1,395	45,502	205,148	0	0
ID	14,354	101	221	23,773	0	0	0	14,354	101	183	23,773	0	0	0
IL	15,881	10,690	1,609	144,050	335,957	0	0	15,881	10,690	1,324	143,458	343,572	0	0
IN	51,639	4,163	959	98,348	157,271	0	0	51,639	4,163	792	98,328	161,420	0	0
IA	4,928	703	487	61,701	81,982	0	0	4,928	703	403	61,701	77,828	0	0
KS	26,123	42	425	16,806	68,027	0	0	26,123	42	351	16,337	62,466	0	0
KY	42,172	6,767	720	41,622	149,272	0	0	42,172	6,767	595	40,259	156,192	0	0
LA	88,945	1,469	684	298,668	29,922	0	0	88,945	1,469	566	293,244	32,696	0	0
ME	13,539	152	1,101	26,963	3	0	0	13,539	152	901	26,963	11	0	0
MD	15,501	1,041	963	42,494	78,791	0	0	15,501	1,041	790	42,494	68,544	0	0
MA	55,722	465	2,301	19,043	57,815	0	0	55,722	465	1,888	19,043	62,287	0	0
MI	37,812	4,409	1,474	76,067	50,385	0	0	37,812	4,409	1,214	76,067	57,747	0	0
MN	18,142	541	998	36,226	27,660	0	0	18,142	541	823	35,351	27,467	0	0
MS	3,897	4,398	473	38,750	37,704	0	0	3,897	4,398	393	38,749	34,384	0	0
MO	41,866	1,504	901	72,373	183,212	0	0	41,866	1,504	743	72,370	176,758	0	0
MT	6,835	61	258	14,013	19,253	0	0	6,835	61	214	13,318	21,327	0	0
NB	10,171	34	296	31,698	87,731	0	0	10,171	34	245	31,698	86,081	0	0

(Continued)

Table 4-2 (Continued)
Annual SOx Emissions (ton y^{-1}) by State and Source Category

	Base Case 2030							PHEV Case 2030						
State	Area	Off-road	On-road	Non-EGU	EGU	Biogenic	Dust	Area	Off-road	On-road	Non-EGU	EGU	Biogenic	Dust
NV	16,028	241	381	1,909	15,923	0	0	16,028	241	313	1,885	15,214	0	0
NH	7,162	24	618	2,968	15,398	0	0	7,162	24	511	2,968	17,270	0	0
NJ	13,992	2,016	938	24,012	15,197	0	0	13,992	2,016	768	23,370	15,650	0	0
NM	18,802	107	401	23,646	14,922	0	0	18,802	107	332	23,188	13,541	0	0
NY	123,639	1,460	2,122	67,397	56,552	0	0	123,639	1,460	1,745	67,394	61,513	0	0
NC	9,483	849	1,604	60,358	85,346	0	0	9,483	849	1,324	60,358	67,367	0	0
ND	4,827	65	90	9,952	99,193	0	0	4,827	65	75	9,755	101,248	0	0
OH	17,119	7,394	1,348	99,090	76,917	0	0	17,119	7,394	1,111	98,323	82,356	0	0
OK	19,951	40	670	55,255	143,318	0	0	19,951	40	553	53,228	143,702	0	0
OR	16,620	197	571	10,676	21,623	0	0	16,620	197	471	10,676	21,855	0	0
PA	68,084	1,538	1,858	89,288	176,001	0	0	68,084	1,538	1,532	88,458	176,753	0	0
RI	4,075	40	97	1,988	0	0	0	4,075	40	79	1,988	0	0	0
SC	16,466	1,968	747	90,207	79,784	0	0	16,466	1,968	618	90,207	76,361	0	0
SD	10,456	50	133	1,746	732	0	0	10,456	50	110	1,746	741	0	0
TN	31,362	4,086	1,113	65,258	126,116	0	0	31,362	4,086	918	65,237	151,059	0	0
TX	113,617	470	3,861	304,448	299,288	0	0	113,617	470	3,179	299,316	300,207	0	0
UT	6,161	153	464	11,212	26,024	0	0	6,161	153	381	10,961	28,569	0	0
VT	4,974	22	122	1,620	0	0	0	4,974	22	101	1,620	0	0	0
VA	11,391	814	1,179	105,520	103,346	0	0	11,391	814	963	105,518	71,947	0	0
WA	11,951	367	910	40,200	6,284	0	0	11,951	367	750	39,339	7,210	0	0
WV	10,152	1,176	274	65,754	185,410	0	0	10,152	1,176	225	65,754	160,381	0	0
WI	5,821	1,336	764	82,632	73,649	0	0	5,821	1,336	631	82,503	63,717	0	0
WY	24,741	64	98	43,887	41,369	0	0	24,741	64	81	43,801	43,908	0	0
OTHER	306,846	350,807	29647	2,868,459	123697	0	0	306,846	350,807	29,664	2,866,970	166,134	0	0
TOTAL	**1,565,917**	**430,371**	**74,052**	**5,520,089**	**3,827,593**	**0**	**0**	**1,565,917**	**430,371**	**66,336**	**5,496,540**	**3,811,309**	**0**	**0**

Table 4-3
Annual Primary PM_{10} Emission (ton y^{-1}) by State and Source Category

	Base Case 2030							PHEV Case 2030						
State	Area	Off-road	On-road	Non-EGU	EGU	Biogenic	Dust	Area	Off-road	On-road	Non-EGU	EGU	Biogenic	Dust
AL	63,738	3,741	2,846	34,926	12,079	0	147,280	63,738	3,741	2,719	34,912	8,231	0	147,280
AZ	87,926	4,819	7,185	7,018	4,822	0	196,646	87,926	4,819	6,816	7,018	4,729	0	196,646
AR	65,377	2,868	1,738	14,980	6,570	0	127,941	65,377	2,868	1,663	14,905	7,737	0	127,941
CA	211,673	15,367	30,672	30,674	0	0	327,244	211,673	15,367	27,903	30,644	9	0	327,244
CO	62,178	2,895	5,210	24,485	9,355	0	268,268	62,178	2,895	4,932	24,416	10,597	0	268,268
CT	7,260	1,464	1,260	1,181	610	0	11,951	7,260	1,464	1,204	1,181	967	0	11,951
DE	1,298	347	211	436	611	0	7,046	1,298	347	203	436	811	0	7,046
FL	100,270	11,896	8,536	44,374	20,112	0	243,465	100,270	11,896	8,151	44,374	24,773	0	243,465
GA	100,662	5,568	5,513	27,022	36,907	0	246,460	100,662	5,568	5,273	27,022	37,121	0	246,460
ID	112,703	1,381	1,300	2,899	0	0	123,576	112,703	1,381	1,236	2,899	0	0	123,576
IL	20,360	9,305	5,179	37,063	26,028	0	403,489	20,318	9,305	4,950	36,965	28,992	0	403,489
IN	42,030	4,427	3,149	31,057	24,311	0	194,146	42,030	4,427	3,014	31,006	24,006	0	194,146
IA	18,805	4,302	1,499	21,182	4,490	0	751,019	18,805	4,302	1,436	21,182	4,642	0	751,019
KS	205,222	2,276	1,314	50,299	7,032	0	820,336	205,221	2,276	1,258	50,163	7,452	0	820,336
KY	26,220	3,916	2,388	20,229	16,167	0	128,755	26,220	3,916	2,287	20,163	15,327	0	128,755
LA	110,240	6,089	2,381	68,959	5,638	0	110,446	110,240	6,089	2,277	68,249	5,832	0	110,446
ME	11,425	1,269	734	7,265	0	0	35,476	11,425	1,269	698	7,265	0	0	35,476
MD	21,275	4,709	3,053	6,650	10,815	0	45,377	21,275	4,709	2,914	6,650	10,618	0	45,377
MA	23,795	3,323	2,332	5,219	1,875	0	39,141	23,795	3,323	2,224	5,219	2,028	0	39,141
MI	17,640	6,742	4,577	15,345	7,848	0	23,609	17,640	6,742	4,373	15,345	6,062	0	23,609
MN	58,320	9,690	2,828	33,283	3,592	0	531,576	58,320	9,690	2,703	33,114	3,925	0	531,576
MS	22,281	3,139	1,653	22,767	5,332	0	153,301	22,281	3,139	1,586	22,765	4,610	0	153,301
MO	49,806	7,678	2,788	19,060	13,482	0	522,299	49,747	7,678	2,667	19,059	14,678	0	522,299
MT	60,751	1,906	1,776	9,871	3,865	0	725,740	60,751	1,906	1,689	9,783	5,992	0	725,740
NB	16,859	1,990	939	15,523	7,054	0	643,135	16,859	1,990	899	15,523	8,165	0	643,135

(Continued)

Table 4-3 (Continued)
Annual Primary PM_{10} Emission (ton y^{-1}) by State and Source Category

	Base Case 2030							PHEV Case 2030						
State	Area	Off-road	On-road	Non-EGU	EGU	Biogenic	Dust	Area	Off-road	On-road	Non-EGU	EGU	Biogenic	Dust
NV	37,654	1,386	1,834	1,870	1,461	0	197,828	37,654	1,386	1,737	1,870	2,116	0	197,828
NH	11,488	687	648	1,325	3,489	0	6,646	11,488	687	620	1,325	4,299	0	6,646
NJ	12,340	4,714	2,750	8,124	2,248	0	22,550	12,340	4,714	2,627	8,021	2,571	0	22,550
NM	36,488	1,782	2,617	2,622	2,416	0	283,042	36,488	1,782	2,487	2,575	2,471	0	283,042
NY	116,320	7,012	5,807	6,816	9,064	0	129,428	116,320	7,012	5,552	6,815	10,274	0	129,428
NC	50,587	4,506	4,935	17,239	18,831	0	105,095	50,587	4,506	4,722	17,239	21,339	0	105,095
ND	7,813	2,286	528	527	10,651	0	435,947	7,813	2,286	502	527	12,941	0	435,947
OH	12,462	6,745	4,403	15,516	19,140	0	32,226	12,462	6,745	4,210	15,388	19,998	0	32,226
OK	118,182	2,908	2,060	16,800	12,977	0	502,541	118,182	2,908	1,971	16,494	14,993	0	502,541
OR	183,042	2,547	3,568	14,281	966	0	258,259	183,042	2,547	3,386	14,281	1,316	0	258,259
PA	44,005	7,757	5,403	39,125	30,999	0	130,698	44,005	7,757	5,169	39,018	32,761	0	130,698
RI	1,274	326	310	180	0	0	2,311	1,274	326	296	180	0	0	2,311
SC	38,479	3,046	2,448	20,564	12,446	0	92,364	38,479	3,046	2,345	20,564	13,429	0	92,364
SD	13,555	1,753	967	761	185	0	696,561	13,555	1,753	920	761	227	0	696,561
TN	29,261	5,005	3,609	38,188	14,991	0	113,503	29,261	5,005	3,451	38,152	13,670	0	113,503
TX	156,891	13,134	12,581	78,880	40,190	0	1,925,144	156,891	13,134	12,022	78,007	55,098	0	1,925,144
UT	44,273	1,936	2,779	13,132	6,873	0	96,003	44,273	1,936	2,632	13,122	10,720	0	96,003
VT	4,703	308	271	369	0	0	11,340	4,703	308	260	369	0	0	11,340
VA	60,171	5,015	3,683	20,529	9,892	0	62,069	60,171	5,015	3,512	20,527	10,213	0	62,069
WA	85,770	3,931	6,086	24,267	2,216	0	305,614	85,770	3,931	5,767	24,243	3,615	0	305,614
WV	12,100	1,288	865	13,186	30,427	0	13,175	12,100	1,288	826	13,186	29,390	0	13,175
WI	24,525	3,891	2,288	10,736	7,710	0	46,347	24,525	3,891	2,191	10,721	7,487	0	46,347
WY	42,681	2,388	894	27,410	8,701	0	90,283	42,681	2,388	850	27,409	12,801	0	90,283
OTHER	305,890	178,084	25,868	342554	17544	0	3,532,063	305,890	178,084	25,875	342,433	22,417	0	3,532,063
TOTAL	**2,968,068**	**383,542**	**198,261**	**1,266,768**	**492,015**	**0**	**15,918,755**	**2,967,967**	**383,542**	**189,006**	**1,263,486**	**541,449**	**0**	**15,918,755**

Table 4-4
Annual Total Organic Gas (TOG) Emissions (ton y^{-1}) by State and Source Category

	Base Case 2030							PHEV Case 2030						
State	Area	Off-road	On-road	Non-EGU	EGU	Biogenic	Dust	Area	Off-road	On-road	Non-EGU	EGU	Biogenic	Dust
AL	205,174	30,266	48,862	75,122	0	2,008,909	0	203,020	30,266	42,988	74,914	0	2,008,909	0
AZ	193,861	37,478	52,194	10,937	0	1,826,737	0	190,887	37,478	46,929	10,847	0	1,826,737	0
AR	106,146	28,140	21,517	53,705	0	1,375,367	0	105,688	28,140	18,901	53,690	0	1,375,367	0
CA	669,710	143,378	80,732	67,726	0	3,196,018	0	665,632	143,378	77,333	67,194	0	3,196,018	0
CO	216,935	27,294	44,126	147,290	0	928,567	0	216,847	27,294	39,217	143,962	0	928,567	0
CT	89,373	16,071	10,394	5,080	0	56,686	0	89,129	16,071	9,257	4,744	0	56,686	0
DE	9,651	2,382	2,819	392	0	38,155	0	9,611	2,382	2,505	386	0	38,155	0
FL	436,757	124,530	193,156	45,262	0	1,858,680	0	427,012	124,530	174,481	44,941	0	1,858,680	0
GA	318,916	37,426	102,603	75,598	0	2,200,022	0	315,568	37,426	91,296	75,404	0	2,200,022	0
ID	284,141	17,882	10,951	3,830	0	1,001,487	0	284,052	17,882	9,567	3,709	0	1,001,487	0
IL	215,751	62,310	73,568	71,757	0	570,230	0	214,865	62,310	64,712	70,833	0	570,230	0
IN	154,581	30,207	50,434	74,498	0	376,999	0	153,198	30,207	43,982	74,081	0	376,999	0
IA	118,550	34,904	35,715	55,007	0	409,274	0	117,254	34,904	30,861	54,662	0	409,274	0
KS	200,618	13,577	33,453	37,008	0	535,768	0	198,512	13,577	29,100	36,605	0	535,768	0
KY	148,409	21,041	37,886	56,863	0	685,600	0	145,958	21,041	33,134	56,558	0	685,600	0
LA	181,863	62,294	35,003	180,827	0	1,457,086	0	179,262	62,294	31,011	179,136	0	1,457,086	0
ME	54,947	20,114	11,100	7,709	0	369,397	0	54,447	20,114	9,569	7,652	0	369,397	0
MD	108,156	33,611	35,406	12,072	0	196,242	0	107,550	33,611	31,197	11,937	0	196,242	0
MA	223,383	29,252	20,040	11,947	0	104,301	0	222,376	29,252	17,966	11,866	0	104,301	0
MI	203,179	88,671	77,347	59,179	0	610,363	0	202,711	88,671	66,850	59,077	0	610,363	0
MN	210,086	139,104	48,583	48,095	0	926,210	0	205,704	139,104	42,148	47,720	0	926,210	0
MS	142,916	20,428	29,832	55,545	0	1,648,557	0	139,733	20,428	26,376	55,383	0	1,648,557	0
MO	239,648	70,743	42,355	40,648	0	1,371,797	0	237,667	70,743	37,070	40,138	0	1,371,797	0
MT	106,791	9,690	20,042	18,450	0	1,225,266	0	105,157	9,690	17,330	18,248	0	1,225,266	0
NB	78,637	11,983	21,732	12,486	0	519,472	0	77,012	11,983	18,918	12,205	0	519,472	0

(Continued)

Table 4-4 (Continued)
Annual Total Organic Gas (TOG) Emissions (ton y^{-1}) by State and Source Category

	Base Case 2030							PHEV Case 2030						
State	Area	Off-road	On-road	Non-EGU	EGU	Biogenic	Dust	Area	Off-road	On-road	Non-EGU	EGU	Biogenic	Dust
NV	66,270	14,607	18,622	3,040	0	953,728	0	65,002	14,607	16,699	2,993	0	953,728	0
NH	49,969	12,001	6,298	1,229	0	116,722	0	49,764	12,001	5,503	1,229	0	116,722	0
NJ	151,434	54,366	31,252	19,555	0	153,488	0	147,376	54,366	28,169	19,300	0	153,488	0
NM	387,402	10,461	18,652	83,803	0	1,213,909	0	384,823	10,461	16,576	83,701	0	1,213,909	0
NY	1,008,641	82,176	60,997	11,868	0	370,842	0	1,003,803	82,176	55,106	11,702	0	370,842	0
NC	205,416	43,722	89,262	77,138	0	1,331,740	0	204,770	43,722	79,120	76,981	0	1,331,740	0
ND	80,157	10,422	3,784	3,584	0	270,443	0	78,665	10,422	3,255	3,450	0	270,443	0
OH	156,852	51,607	76,555	32,197	0	374,656	0	156,655	51,607	67,060	32,059	0	374,656	0
OK	433,474	28,787	46,442	129,911	0	934,266	0	431,536	28,787	40,727	129,410	0	934,266	0
OR	752,779	26,889	31,456	41,457	0	1,394,395	0	749,687	26,889	27,892	41,407	0	1,394,395	0
PA	1,212,390	57,890	77,888	58,464	0	527,127	0	1,211,586	57,890	69,049	58,044	0	527,127	0
RI	16,573	3,382	4,745	1,933	0	14,956	0	16,108	3,382	4,164	1,903	0	14,956	0
SC	164,537	27,081	45,938	47,221	0	1,053,437	0	160,936	27,081	40,178	47,121	0	1,053,437	0
SD	50,242	10,187	5,431	3,216	0	501,757	0	48,767	10,187	4,696	3,117	0	501,757	0
TN	239,499	30,486	63,580	91,918	0	967,135	0	236,493	30,486	55,846	91,817	0	967,135	0
TX	1,337,678	108,645	169,542	245,144	0	3,469,464	0	1,329,895	108,645	152,329	242,427	0	3,469,464	0
UT	201,254	19,750	21,196	23,360	0	756,344	0	199,175	19,750	18,579	23,226	0	756,344	0
VT	26,149	6,044	3,308	1,463	0	76,198	0	26,081	6,044	2,890	1,463	0	76,198	0
VA	133,084	35,375	61,082	76,067	0	956,859	0	130,065	35,375	53,206	75,578	0	956,859	0
WA	290,730	42,716	42,141	27,118	0	789,497	0	284,923	42,716	37,354	26,773	0	789,497	0
WV	53,140	9,603	14,667	41,264	0	421,048	0	51,550	9,603	12,703	41,231	0	421,048	0
WI	144,905	54,251	33,357	48,399	0	567,920	0	144,268	54,251	28,800	48,359	0	567,920	0
WY	476,132	11,412	5,526	32,027	0	704,565	0	475,350	11,412	4,786	32,000	0	704,565	0
OTHER	5,879,585	754,367	622,748	421,788	0	27,345,266	0	5,877,024	754,367	622,594	421,211	0	27,345,266	0
TOTAL	**18,436,474**	**2,619,003**	**2,694,321**	**2,750,197**	**0**	**70,762,954**	**0**	**18,333,151**	**2,619,003**	**2,459,979**	**2,732,393**	**0**	**70,762,954**	**0**

Table 4-5
Annual Total Mercury Emissions (ton y^{-1}) by State and Source Category

	Base Case 2030			PHEV Case 2030		
State	EGU	Biogenic	Others	EGU	Biogenic	Others
AL	0.40	0.89	1.29	0.48	0.89	1.29
AZ	0.09	0.50	0.29	0.09	0.50	0.29
AR	0.47	0.91	0.81	0.53	0.91	0.81
CA	0.00	1.36	5.79	0.00	1.36	5.79
CO	0.41	0.55	0.28	0.42	0.55	0.28
CT	0.02	0.03	0.40	0.03	0.03	0.40
DE	0.05	0.03	0.01	0.03	0.03	0.01
FL	0.45	1.32	2.05	0.52	1.32	2.05
GA	0.57	1.01	1.25	0.53	1.01	1.25
ID	0.00	0.41	0.58	0.00	0.41	0.58
IL	0.89	0.87	3.58	1.02	0.87	3.58
IN	0.76	0.49	1.70	0.76	0.49	1.70
IA	0.22	0.79	0.21	0.21	0.79	0.21
KS	0.20	1.27	0.37	0.21	1.27	0.37
KY	0.49	0.59	1.93	0.43	0.59	1.93
LA	0.12	0.77	1.88	0.12	0.77	1.88
ME	0.00	0.19	0.46	0.00	0.19	0.46
MD	0.39	0.12	1.07	0.37	0.12	1.07
MA	0.09	0.06	0.85	0.10	0.06	0.85
MI	0.19	0.43	1.02	0.15	0.43	1.02
MN	0.16	0.82	1.40	0.16	0.82	1.40
MS	0.11	0.81	0.64	0.09	0.81	0.64
MO	0.34	1.10	0.19	0.32	1.10	0.19
MT	0.13	0.69	0.22	0.17	0.69	0.22
NB	0.36	0.85	0.09	0.38	0.85	0.09

(Continued)

Table 4-5 (Continued)
Annual Total Mercury Emissions (ton y^{-1}) by State and Source Category

	Base Case 2030			PHEV Case 2030		
State	EGU	Biogenic	Others	EGU	Biogenic	Others
NV	0.03	0.23	11.40	0.03	0.23	11.40
NH	0.12	0.07	0.16	0.14	0.07	0.16
NJ	0.09	0.08	1.78	0.10	0.08	1.78
NM	0.11	0.42	0.07	0.06	0.42	0.07
NY	0.27	0.35	1.71	0.31	0.35	1.71
NC	1.03	0.65	0.89	0.95	0.65	0.89
ND	0.43	0.63	0.10	0.46	0.63	0.10
OH	0.64	0.45	1.36	0.59	0.45	1.36
OK	0.64	1.04	0.38	0.66	1.04	0.38
OR	0.01	0.48	2.43	0.01	0.48	2.43
PA	1.17	0.38	2.58	1.18	0.38	2.58
RI	0.00	0.01	0.11	0.00	0.01	0.11
SC	0.44	0.44	1.07	0.45	0.44	1.07
SD	0.01	0.68	0.02	0.01	0.68	0.02
TN	0.58	0.62	1.12	0.69	0.62	1.12
TX	1.04	3.26	3.43	1.16	3.26	3.43
UT	0.16	0.22	0.78	0.20	0.22	0.78
VT	0.00	0.06	0.02	0.00	0.06	0.02
VA	0.35	0.46	0.92	0.39	0.46	0.92
WA	0.04	0.40	0.93	0.06	0.40	0.93
WV	0.88	0.26	0.10	0.75	0.26	0.10
WI	0.17	0.51	1.03	0.22	0.51	1.03
WY	0.23	0.19	0.09	0.28	0.19	0.09
OTHER	0.52	14.67	9.94	0.43	14.67	9.94
TOTAL	**15.87**	**43.42**	**70.79**	**16.24**	**43.42**	**70.79**

Table 4-6 provides an overall summary of the 2030 base case and PHEV case emissions results by source category.

Table 4-6
Overall Emissions Summary (ton y^{-1})

Domain-wide Emissions 2030 Base Case

	Area	Off-Road	On-Road	Non-EGU	EGU	Biogenic	Dust	Total
NOx	3,070,897	3,371,964	2,462,504	3,604,222	2,035,075	1,939,569	0	16,484,231
SO$_2$	1,565,917	430,371	74,052	5,520,089	3,827,593	0	0	11,418,022
PM$_{10}$	2,968,068	383,542	198,261	1,266,768	492,015	0	15,918,755	21,227,409
VOC	18,436,474	2,619,003	2,694,321	2,750,197	0	70,762,954	0	97,262,949
Hg				70.790	15.870	43.420		130.080

48-State Emissions 2030 Base Case

	Area	Off-Road	On-Road	Non-EGU	EGU	Biogenic	Dust	Total
NOx	2,413,374	2,048,034	1,542,958	2,619,801	2,035,075	1,375,000	0	11,979,172
SO$_2$	1,259,072	79,566	44,406	2,651,630	3,827,593	0	0	7,738,570
PM$_{10}$	2,662,178	205,458	172,395	924,214	492,015	0	12,386,696	16,825,409
VOC	12,556,886	1,864,636	2,071,571	2,328,409	0	43,417,686	0	62,239,188
Hg				60.840	15.870	28.750		104.940

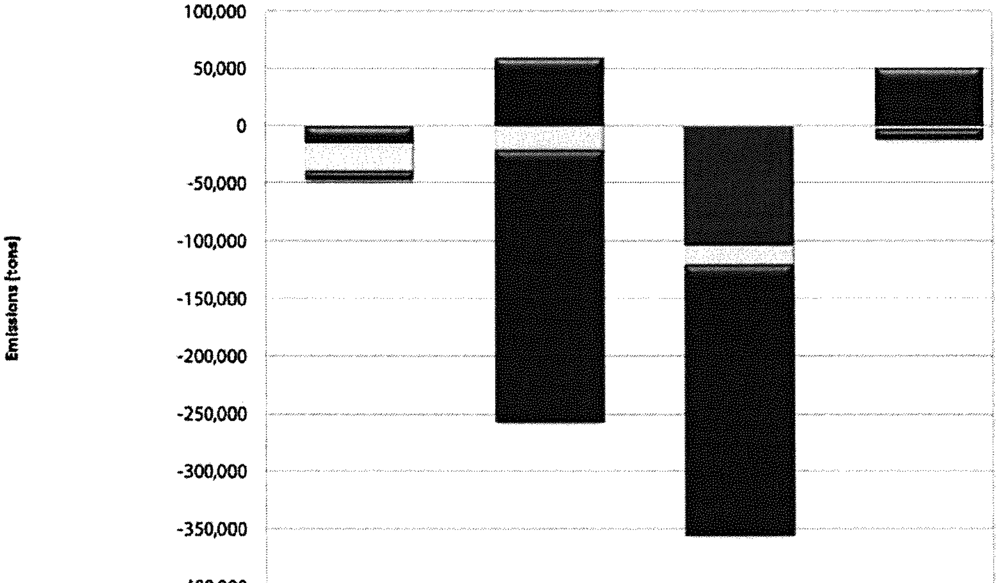
Emissions Change in PHEV Case

	Area	Off-Road	On-Road	Non-EGU	EGU	Biogenic	Dust	Total
NOx	-1,293		-236,292	-20,076	58,916			-198,745
SO$_2$	0		-7,716	-23,549	-16,284			-47,549
PM$_{10}$	-101		-9,255	-3,282	49,434			36,796
VOC	-103,323		-234,342	-17,804	0			-355,469
Hg				0	0.370			0.370

Percentage Change in PHEV Case (48-State Basis)

	Area	Off-Road	On-Road	Non-EGU	EGU	Biogenic	Dust	Total
NOx	-0.05%		-15.31%	-0.77%	2.90%			-1.66%
SO$_2$	0%		-17.38%	-0.89%	-0.44%			-0.61%
PM$_{10}$	-0.004%		-5.37%	-0.36%	10.04%			0.22%
VOC	-0.82%		-11.31%	-0.76%	0%			-0.57%
Hg					2.41%			0.35%

Figure 4-1 illustrates the impact of PHEVs on net emissions of individual species across sources categories.



	SOx	NOx	VOC	PM
■ On-Road Vehicle	-7,716	-236,292	-234,342	-9,255
▨ Refinery and Other Stationary	-23,549	-20,076	-17,804	-3,282
■ Distributed Upstream	0	-1,293	-103,323	-101
■ Power Plant	-16,284	58,916	0	49,434
Net Emissions	-47,549	-198,745	-355,469	36,796

Figure 4-1
Effect on Net Emissions in PHEV Case (ton y^{-1})

5 Air Quality Modeling Results

This chapter describes the application and results of air quality model simulations to estimate the air quality impacts of PHEVs for the year 2030. The air quality model was run for 2030 for two scenarios: a base case with no PHEVs and the PHEV case with a significant penetration of PHEVs as described in Chapter 2. The methodologies for calculating mobile sector and electric sector emissions have been described in Chapter 2 and Chapter 3, respectively; the final emissions processing necessary to prepare emissions data for the air quality simulation has been described in Chapter 4. The air quality model chosen for this work is EPA's Community Multiscale Air Quality (CMAQ) modeling system.

The first section of this chapter provides a summary description of the air quality modeling system. The subsequent sections document the modeling inputs used in this study and describe the assessment methodology for air quality results. The final section presents the air quality modeling results and discusses how PHEVs influence air quality and deposition in 2030.

Model Configuration

CMAQ is a 3-D photochemical transport and dispersion model that has an Eulerian (grid-based) formulation. The CMAQ model and supporting data are available from the Community Modeling and Analysis System (CMAS) Center (http://www.cmascenter.org). The key processes treated by CMAQ are emissions, advection and dispersion, photochemical transformation, aerosol thermodynamics and phase transfer, aqueous chemistry, and wet and dry deposition of trace species. CMAQ version 4.5.1 was chosen for this work since it was the most updated version at the time work was initiated. The model configuration is shown in **Table 5-1**. Some configuration choices were dictated by compatibility issues, for example the active sea salt chemistry in the AE4 aerosol dynamics module is incompatible with mercury chemistry dictating the selection of the AE3 aerosol dynamics module that does not have active sea-salt chemistry.

Table 5-1
Model Configuration Options for the CMAQ Model

Model Attribute	Option
Version	4.5.1 dated October 2005
Horizontal resolution	36 km
Vertical layers	19 layers
Horizontal advection	PPM
Vertical advection	Yamartino
Horizontal diffusion	Spatially varying
Vertical diffusion	Kv (eddy diffusion)
Minimum vertical diffusivity	1.0 m^2/s
Gas-phase chemistry	CB-IV
Gas-phase chemistry solver	MEBI/Hertel
Aqueous-phase chemistry	RADM
Aerosol chemistry	AE3/ISORROPIA
Dry deposition	Revised Pleim-Xiu

Modeling Domain

The CMAQ modeling grid was the 36-km RPO unified grid established by the WRAP, the Central Regional Air Planning Association (CENRAP), the Midwest Regional Planning Organization (MRPO), and the Visibility Improvement State and Tribal Association of the Southeast (VISTAS) RPOs for regional haze modeling. The RPO unified grid consists of a continental-scale Lambert-Conformal map projection based on the parameters listed in **Table 5-2**.

Table 5-2
Grid Definition for the RPO Unified Grid

Grid Parameter	Value
Projection	Lambert-Conformal
1st True Latitude	33° N
2nd True Latitude	45° N
Projection center longitude	97° W
Projection center latitude	40° N
Southwest corner origin (km)	[-2736, -2088]
Grid cells [NX x NY]	148 x 112

The CMAQ vertical structure is constrained by the vertical grid used in the MM5 meteorological modeling (described below). The MM5 model employs a terrain following coordinate system defined by pressure and was configured with 34 layers extending from the surface to a pressure altitude of 100 mb. **Table 5-3** lists the layer definitions for both MM5 and CMAQ. As is typical in large-scale model applications such as this, CMAQ employed fewer layers aloft than MM5 to reduce the computational cost of the air quality simulations. The 34 layers in MM5 were reduced to 19 layers in CMAQ as was done for the RPO unified modeling vertical structure.

Input Data

Meteorological Data

The CMAQ model requires inputs of three-dimensional gridded wind, temperature, humidity, cloud/ precipitation, and boundary layer variables. The WRAP Regional Modeling Center (RMC) has applied the MM5 meteorological model on a 36-km continental U.S. grid for the 2002 calendar year. **Table 5-4** shows the final configuration for the WRAP 36-km MM5 modeling that was used for the annual 2002 MM5 simulation to support WRAP's regional haze modeling. WRAP MM5 results exhibit reasonably good performance (Kemball-Cook et al., 2005) and therefore those meteorological fields are acceptable to use as inputs for this study.

Table 5-3
Vertical Layer Definition for MM5 Simulations (Left Five Columns), and Approach for Reducing CMAQ Layers by Collapsing Multiple MM5 Layers (Right Five Columns).

MM5 (34 layers)					CMAQ (19 layers)				
Layer	Sigma Level	Pressure (mb)	Height (m)	Depth (m)	Layer	Sigma Level	Pressure (mb)	Height (m)	Depth (m)
34	0.00	100	14662	1841	19	0.00	100	14662	6536
33	0.05	145	12822	1466					
32	0.10	190	11356	1228					
31	0.15	235	10127	1062					
30	0.20	280	9066	939					
29	0.25	325	8127	843	18	0.25	325	8127	2966
28	0.30	370	7284	767					
27	0.35	415	6517	704					
26	0.40	460	5812	652					
25	0.45	505	5160	607	17	0.45	505	5160	1712
24	0.50	550	4553	569					
23	0.55	595	3984	536					
22	0.60	640	3448	506	16	0.60	640	3448	986
21	0.65	685	2942	480					
20	0.70	730	2462	367	15	0.70	730	2462	633
19	0.74	766	2095	266					
18	0.77	793	1828	259	14	0.77	793	1828	428
17	0.80	820	1569	169					
16	0.82	838	1400	166	13	0.82	838	1400	329
15	0.84	856	1235	163					
14	0.86	874	1071	160	12	0.86	874	1071	160
13	0.88	892	911	158	11	0.88	892	911	158
12	0.90	910	753	78	10	0.90	910	753	155
11	0.91	919	675	77					
10	0.92	928	598	77	9	0.92	928	598	153
9	0.93	937	521	76					
8	0.94	946	445	76	8	0.94	946	445	76
7	0.95	955	369	75	7	0.95	955	369	75
6	0.96	964	294	74	6	0.96	964	294	74
5	0.97	973	220	74	5	0.97	973	220	74
4	0.98	982	146	37	4	0.98	982	146	37
3	0.985	986.5	109	37	3	0.985	986.5	109	37
2	0.990	991	73	36	2	0.990	991	73	36
1	0.995	995.5	36	36	1	0.995	995.5	36	36
0	1.0	1000	0	0	0	1.0	1000	0	0

Table 5-4
MM5 Configuration for the WRAP 2002 36-km Resolution MM5 Run[25]

Grid Resolution	LSM	PBL	Cumulus	Microphysics	Analysis FDDA		Obs
					3-D	Surface	FDDA
36 km	Pleim-Xiu	ACM	Betts-Miller	Reisner 2	W/T/H	W	Wind

The Meteorology-Chemistry Interface Processor (MCIP) formats MM5 data for CMAQ and provides the complete set of meteorological data required by CMAQ. WRAP processed the MM5 using the older version of MCIP (MCIP v2.3) which does not include dry deposition velocities for mercury species. The MM5 meteorological data were reprocessed using MCIP v3.0 which offers optional dry deposition velocities for 6 chlorine species and 2 mercury species.

Emissions Inputs

Emissions data are input to CMAQ in 3-D, gridded format. The emissions files were generated by SMOKE system as described in Chapter 4.

Boundary/Initial Conditions and Model Initialization

Initial and boundary conditions define the air quality at the start of the CMAQ simulation and the chemical composition of air transported within the model domain during the simulation via lateral boundaries. Initial conditions are difficult to specify in 3-D detail because of a lack of measurements. This work adopted the approach of specifying CMAQ default initial conditions (which represent clean air) followed by a 15-day initialization period, or spin-up, to eliminate any significant effects of the initial conditions. The annual simulation was divided into two periods beginning in January and July both of which were preceded by 15-day spin-up periods.

Boundary conditions determine the concentrations of gaseous and PM species that are transported into the model domain when wind flow is into the domain. The boundary conditions for this study were obtained from a global simulation performed for 2002 by Harvard University using the GEOS-CHEM model [http://www-as.harvard.edu/chemistry/trop/geos/]. The VISTAS RPO analyzed the GEOS-CHEM model output and generated day-specific 3-hourly boundary conditions for the 36-km RPO grid in the CMAQ BCON format suitable for our modeling. However, the VISTAS boundary condition files do not include mercury species. To address this issue, we extracted the mercury boundary conditions from EPA's CAMR boundary conditions for 2001 developed using the GEOS-CHEM model and merged them into the VISTAS boundary condition file.

Photolysis Table

The CMAQ system includes the JPROC processor which calculates clear-sky photolysis rates (or J-values) for a specific date. JPROC uses default values for total aerosol loading and Total Ozone Mapping Spectrometer (TOMS) satellite data for total ozone column. TOMS data are available daily from http://toms.gsfc.nasa.gov/eptoms/ep.html. The photolysis input table for our modeling was prepared by the VISTAS RPO.

Model Evaluation

WRAP previously performed CMAQ visibility modeling using the same meteorological data, initial conditions, boundary conditions and photolysis table described above for the year 2002 on a 36-km CONUS grid. The model performance evaluation found that the model satisfied many of the selected

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[25] Abbreviations: LSM = land-surface model; PBL = planetary boundary layer; FDDA = four-dimensional data assimilation; Obs = observational; PX = Pleim-Xiu; ACM = Asymmetric Convective Model; KF = Kain-Fritsch; W/T/H = wind/temperature/humidity.

performance goals for most ambient monitoring networks (Tonnesen et al., 2006). WRAP model performance evaluations maps are available at the WRAP modeling website: (http://pah.cert.ucr.edu/aqm/308/cmaq.shtml).

Assessment Methodology

The objective of the assessment is to compare air quality for two 2030 model-scenarios — the base case and the PHEV case. We employed several approaches to show comparisons of two cases:

- Spatial maps showing base case results and differences between two scenarios.
  This approach is appropriate for showing absolute ozone mixing ratios, particulate matter concentrations and deposition fluxes. For deposition fluxes, which can be highly influenced by precipitation patterns, it is also instructive to show percent changes in deposition fluxes in order to better ascertain the influence of the emissions changes.
- Spatial maps showing base case results and differences between population exposure.
  Population exposure metrics are useful to convey the information relevant to the public health effects by providing an estimate of public exposure to pollutant levels. There are different methods for calculating exposure metrics. Population exposure metrics exist that have no concentration threshold (i.e., absolute exposure), which is useful if there is no threshold for health effects. However, there may be pollution levels below which human health effects do not occur or pollution levels that cannot be attained due to limits imposed by natural or background conditions. For these reasons, calculating exposure metric above a certain ozone threshold is widely practiced. However, the selection of the threshold value is often a subject of much debate.

  Rather than choose an arbitrary threshold, we present exposure based on the design value (DV) of the pollutant of concern, i.e. the value for which the National Ambient Air Quality Standard (NAAQS) is defined. For example, the 8-hour-average ozone design value is based on the 99th percentile of observed mixing ratios which is tantamount to the 4th highest observed 8-hour-average ozone mixing ratio. This Design-Value Exposure (DVE) can be expressed as:

  $$DVE = DV\ [ppb/\mu g\ m^{-3}] \times Exposed\ Population\ [persons]$$

  with the exposure period defined inherently by the design value, e.g. 8-hour, 24-hour or annual. This study presents the DVE and the difference in DVE between the base case and PHEV case simulations.

  Population data for 2030 were developed from U.S. Census Bureau data made available as National and State population trend data for 1993-2050 [available at http://www.census.gov/population/projections/DownldFile3.xls].
  These trend data were combined with gridded 2002 population data for the 36-km RPO unified grid [available at http://www.epa.gov/ttn/chief/emch/spatial/newsurrogate.html] to calculate 2030 population for each grid cell. The ozone population exposure metric was computed for each grid cell by summing ozone concentrations for every hour in the year and multiplying this sum by grid cell population.
- Maps showing visibility impairment.
  The IMPROVE algorithm for estimating light extinction from PM data has been a useful tool for understanding haze in terms of the various PM components of aerosols. EPA adopted this algorithm as the basis for the regional haze metric for visibility impact calculations under the 1999 RHR. This work used the new IMPROVE algorithm (Pitchford et al.,

2007) which reconstructs the light-extinction coefficient (b_{ext}, expressed in units of inverse megameters, Mm^{-1}) using the following equation:

$$\begin{gathered} b_{ext} \approx \\ 2.2 \times f_S(RH) \times [\text{small sulfate}] + 4.8 \times f_L(RH) \times [\text{large sulfate}] \\ + 2.4 \times f_S(RH) \times [\text{small nitrate}] + 5.1 \times f_L(RH) \times [\text{large nitrate}] \\ + 2.8 \times [\text{small organic mass}] + 6.1 \times [\text{large organic mass}] \\ + 10 \times [\text{elemental carbon}] \\ + 1 \times [\text{fine soil}] \\ + 1.7 \times f_{SS}(RH) \times [\text{sea salt}] \\ + 0.6 \times [\text{coarse mass}] \\ + \text{Rayleigh scattering (site-specific)} \\ + 0.33 \times [NO_2\ (\text{ppb})] \end{gathered}$$

The apportionment of the total concentration of sulfate compounds into the concentrations of small and large size fractions is accomplished using the following equations:

$$\begin{gathered} [\text{large sulfate}] = [\text{total sulfate}/20] \times [\text{total sulfate}], \text{ for } [\text{total sulfate}] < 20\ \mu g/m^3 \\ [\text{large sulfate}] = [\text{total sulfate}], \text{ for } [\text{total sulfate}] \geq 20\ \mu g/m^3 \\ [\text{small sulfate}] = [\text{total sulfate}] - [\text{large sulfate}] \end{gathered}$$

The same equations are used to apportion total nitrate and total organic mass into small and large size fractions. The new algorithm contains three distinct water growth terms, designated f_S, f_L, and f_{SS} for the small and large sulfate and nitrate fractions, and for sea salt, respectively. Sea salt can be calculated as $1.8 \times [\text{chloride}]_{\text{measured}}$, however, chloride measurement is not available everyday and often is missing or invalid. Thus, we used the sea salt component from the CMAQ model for the visibility calculation.

Visibility expressed as reconstructed deciview (dv) at designated Class I areas with IMPROVE data (shown in **Figure 5-1**) are calculated. The deciview is a visibility metric based on the light-extinction

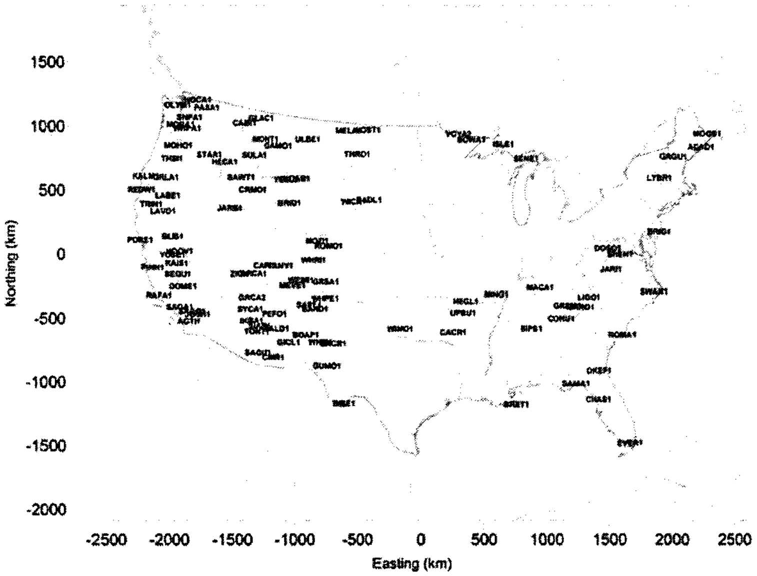


Figure 5-1
Class I Areas where IMPROVE Measurements are Available

coefficient that expresses incremental changes in perceived visibility (Pitchford and Malm, 1994). The deciview is defined by the following equation:

$$dv = 10 \ln (b_{ext}/10)$$

Air Quality Modeling Results

Ozone

Air quality modeling results for the year-2030 simulations are presented by pollutant of concern, beginning with ozone. The following figures are presented on subsequent pages, including figures representing the impact on the illustrated parameter due to the penetration of PHEVs into the vehicle fleet:

- Maps of annual 4th highest 8-hour ozone **(Figure 5-2)**, and
- Ozone population exposure maps based on the design value (**Figure 5-3**).

The annual maximum 8-hour ozone may be susceptible to model artifacts and so we focus on the annual 4th highest 8-hour ozone (Figure 5-2, top). The base case modeled annual 4th highest 8-hour ozone shows high values (above 90 ppb) in several western locations such as Central California and Colorado. High ozone concentrations (above 100 ppb) also occur over water bodies close to major urban/industrial areas near the Great Lakes, Gulf Coast and the Northeast Seaboard, where emissions are transported over water and confined to a shallow boundary layer. The current level of the ozone standard (0.08 ppm for the 4th highest 8-hour ozone, averaged over 3 years) is exceeded over large areas of several western states including California, Nevada, Utah, Colorado, Arizona and New Mexico. Upon inspection of the model results, much of this western ozone is associated with wildfire emissions high in organic particulate matter. These wildfire emissions also contain high levels of NOx which reacts to form ozone.

Ozone benefits related to PHEVs estimated to occur (Figure 5-2, bottom) across wide areas of the Eastern United States and near major urban areas. These are modest reductions, mostly less than 1 ppb. Larger ozone reductions, up to 2 ppb, are estimated to occur along the northern border of Kentucky reflecting net reductions in NOx emissions along the Ohio River which are partly due to changes in electricity generation for the PHEV scenario. Ozone increases (less than 1 ppb) are restricted to a few areas where major power plants are located such as Eastern Texas, Western Georgia, Utah, Montana, and Western North Dakota.

The DVE for ozone (in units of ppb x person) is presented in Figure 5-3. The ozone exposure results based on the ozone design value are consistent with current air quality management practices in the United States that aim to reduce exposure to high ozone concentrations, and these results show that PHEVs reduce exposure in essentially all major urban areas.

Ozone mixing ratio and exposure results are summarized numerically at the end of this chapter.

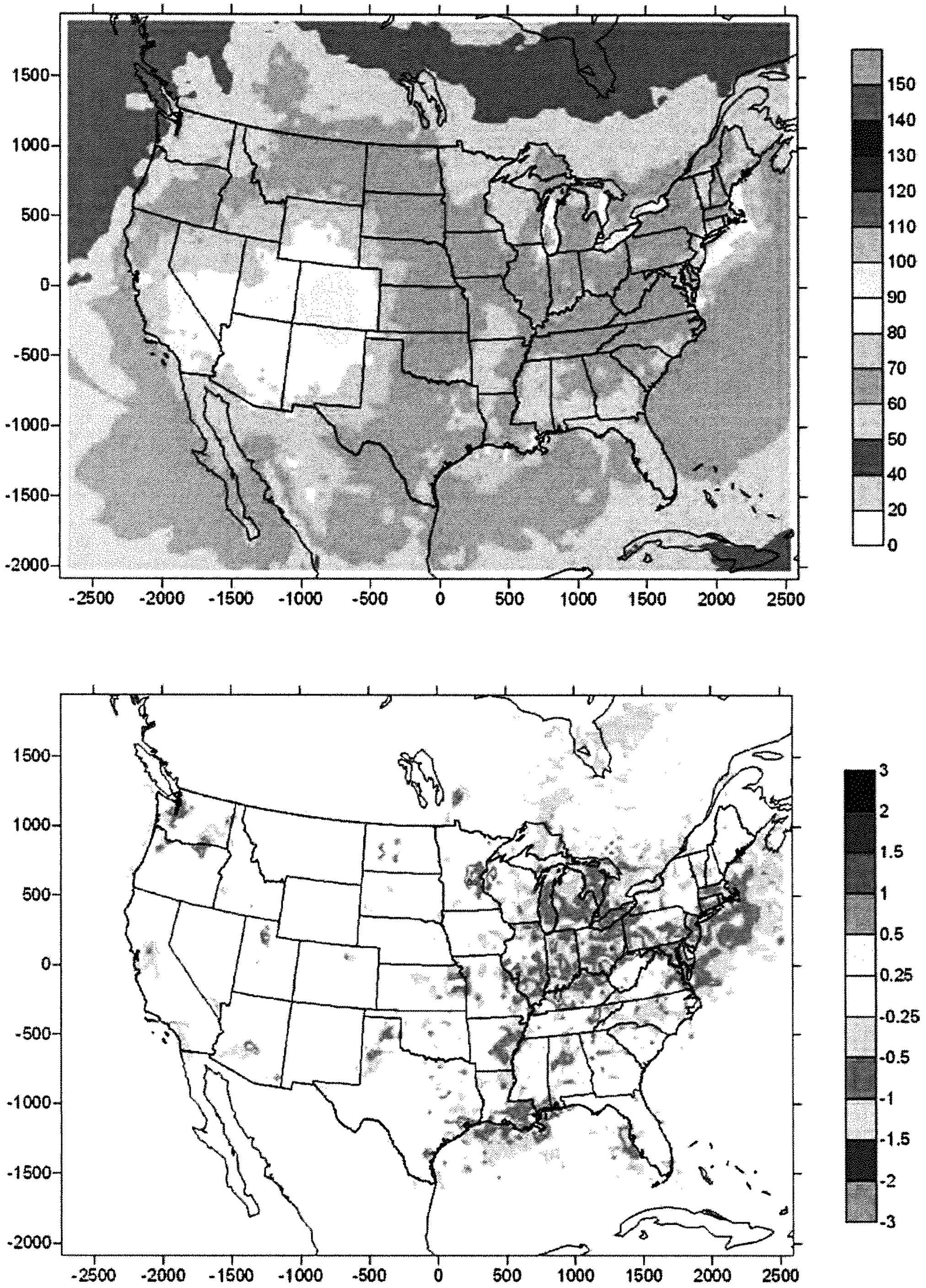


Figure 5-2
Annual 4th Highest 8-Hour-Ozone (ppb) for Base Case (top) and Difference between PHEV Case and Base Case

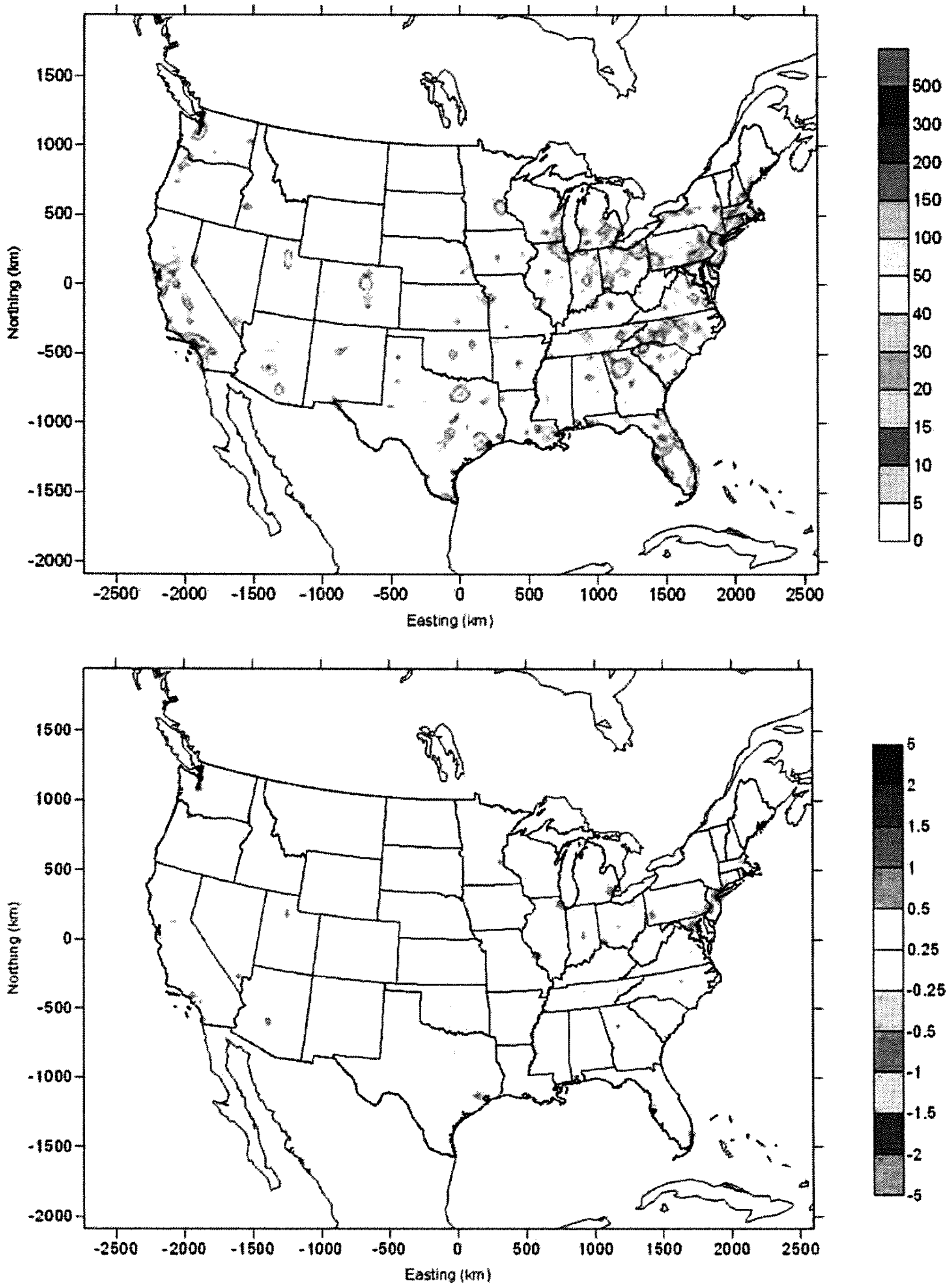


Figure 5-3
Ozone Design-Value Exposure Based on the 4th Highest 8-Hour-Average Ozone (000,000 ppb × person) for Base Case (top) and Difference between PHEV

Particulate Matter

Particulate matter results are presented for both $PM_{2.5}$ (representing fine particulate matter) and PM_{10} (representing the sum of fine and coarse particulate matter). Although there is no longer an annual average standards for PM_{10}, this section presents results for daily design-value relevant measures (98^{th} percentile of all daily concentrations) and annual average concentrations (which only hold design value relevance for $PM_{2.5}$ at present) for both measures of ambient particles. On subsequent pages, the following figures are presented:

- Maps of annual 8^{th} highest 24-hour average $PM_{2.5}$ and PM_{10} (**Figure 5-4** and **Figure 5-5**, respectively)
- Maps of annual average $PM_{2.5}$ and PM_{10} (**Figure 5-6** and **Figure 5-7**, respectively)
- PM exposure maps based on the design value for the daily NAAQS for $PM_{2.5}$ and PM_{10} (**Figure 5-8 and Figure 5-9**, respectively)
- PM exposure maps based on the annual average for $PM_{2.5}$ and PM_{10} (**Figure 5-10** and **Figure 5-11**, respectively)

The base case 8^{th} highest 24-hour average concentrations of fine $PM_{2.5}$ and PM_{10} (Figure 5-4 and Figure 5-5) show the highest peak values occurring in the Western United States but more uniformly high values occurring in the Eastern United States. The causes of the high modeled PM concentrations may be inferred from the chemical composition of the PM and the seasonal distributions (shown in Appendix C). Some peaks in the Western United States occur in urban areas, such as Portland and Seattle (characterized by high nitrate and organic carbon) whereas others are associated with wildfire emissions (indicated by high primary organic carbon). Many areas of high PM in the Western United States are associated with high primary organic carbon from wildfire emissions that are included in the emissions inventory for both the Base Case and PHEV Case modeling. An area of increased primary organic carbon over the Western Gulf of Mexico results from fire emissions in Mexico introduced via the CMAQ boundary conditions. High particulate matter concentrations in the Eastern United States have large sulfate and nitrate with additional contributions from primary organic PM in the south.

PHEVs reduce the 8^{th} highest 24-hour average PM concentrations (Figure 5-4 and Figure 5-5) across the Eastern United States, in California and in the Pacific Northwest due mainly to reductions in $PM_{2.5}$. These reductions are modest (generally less than 0.5 $\mu g\ m^{-3}$) but they are consistent. Annual average concentrations of $PM_{2.5}$ and PM_{10} (Figure 5-6 and Figure 5-7) show a similar pattern of widespread, modest reductions due to PHEVs.

The daily design-value exposures for $PM_{2.5}$ and PM_{10} (in units of $\mu g\ m^{-3}$ x person) are presented in Figure 5-8 and Figure 5-9, respectively; the daily design-value exposures for $PM_{2.5}$ and PM_{10} (in units of $\mu g\ m^{-3}$ x person) are presented in Figure 5-10 and Figure 5-11, respectively. These results mimic the ozone results illustrating that the penetration of PHEVs reduces exposures to PM in essentially all major urban areas.

PM concentration and exposure results are summarized numerically at the end of this chapter.

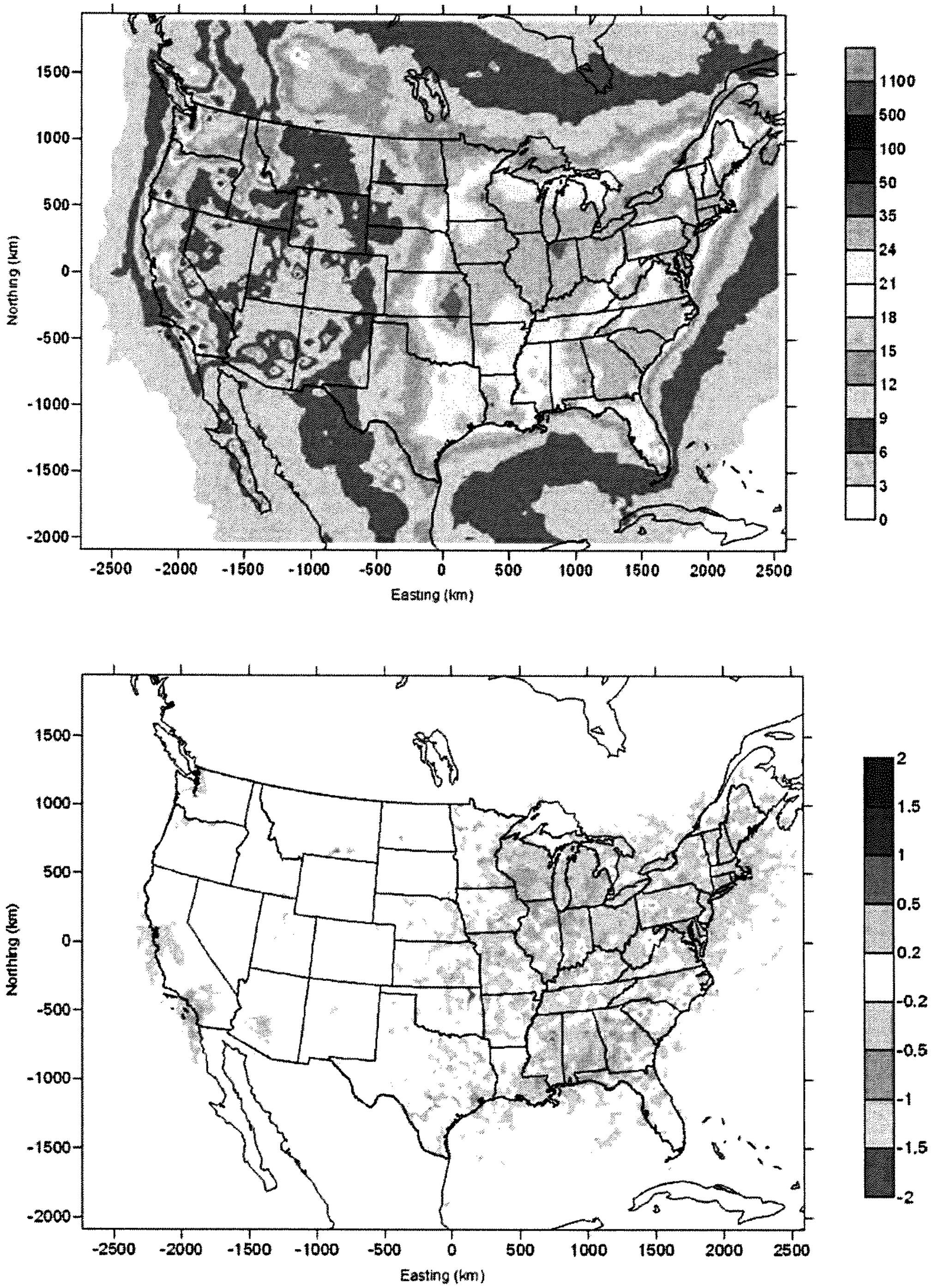


Figure 5-4
Annual 8th Highest 24-Hour Average Concentrations ($\mu g\ m^{-3}$) of $PM_{2.5}$ (top) and Difference between PHEV Case and Base Case (bottom)

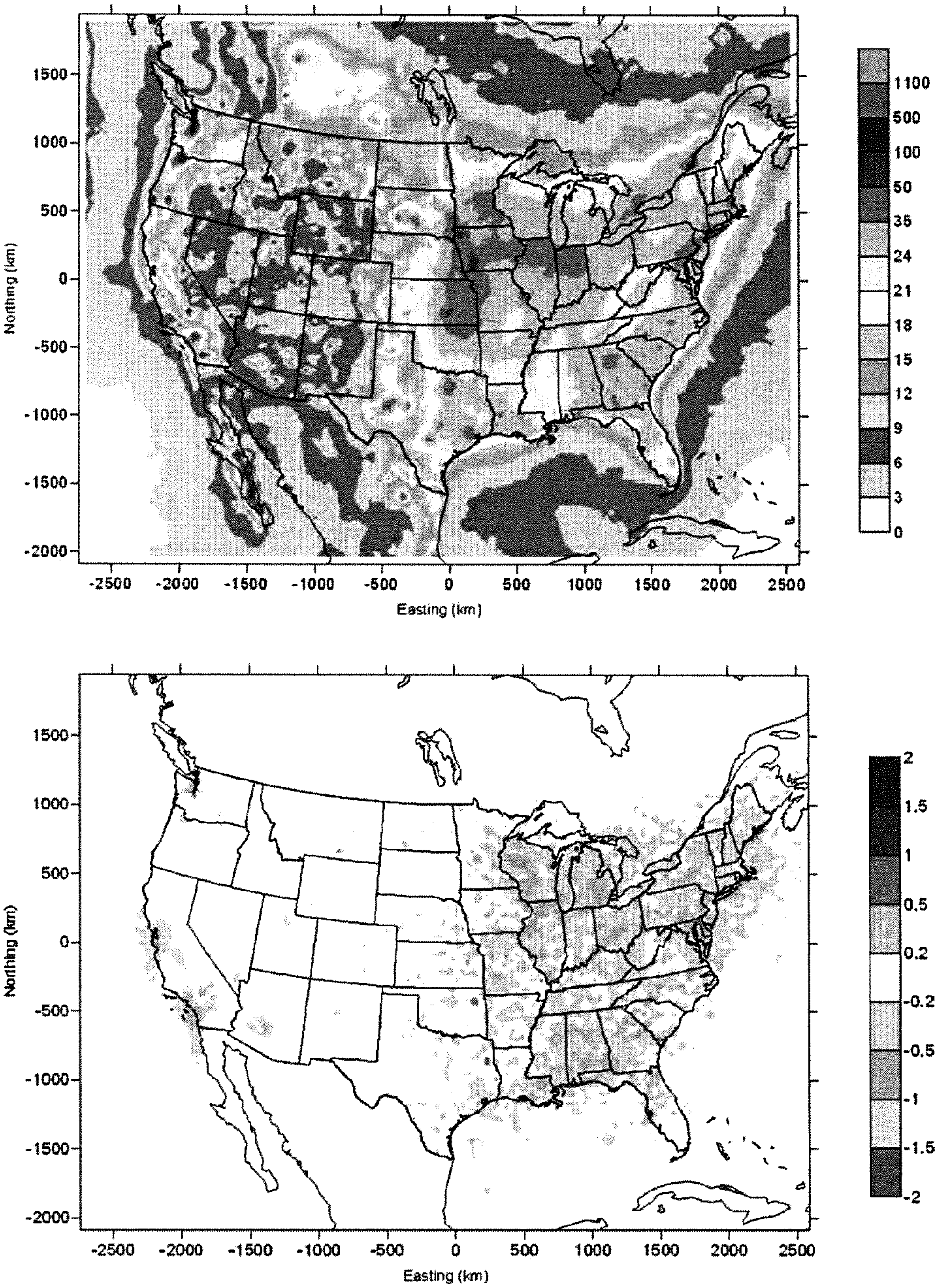


Figure 5-5
Annual 8th Highest 24-Hour Average Concentrations ($\mu g\ m^{-3}$) of PM_{10} (top) and Difference between PHEV Case and Base Case (bottom)

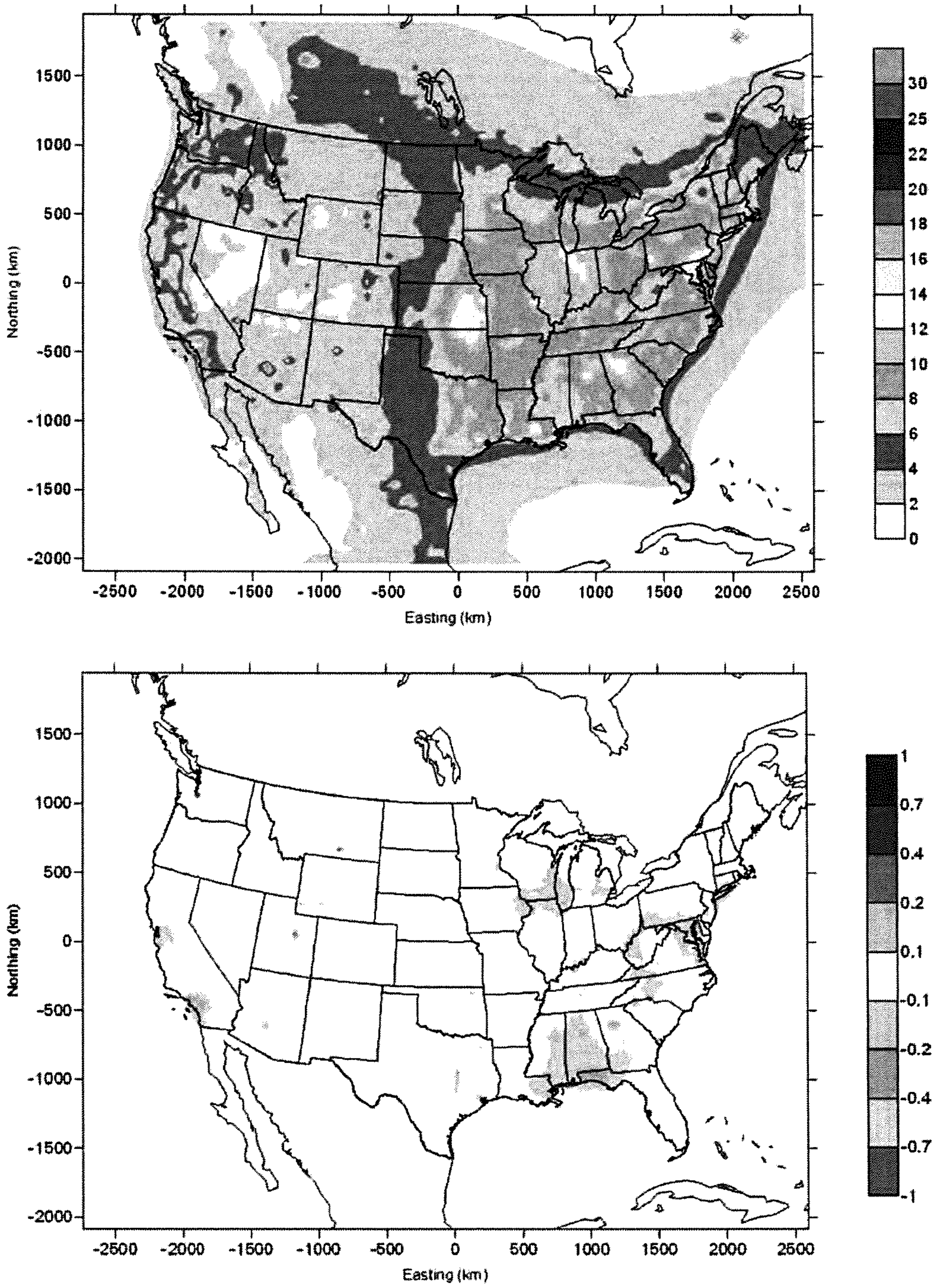


Figure 5-6
Annual Average Concentrations (μg m^{-3}) of $PM_{2.5}$ (top) and Difference between PHEV Case and Base Case (bottom)

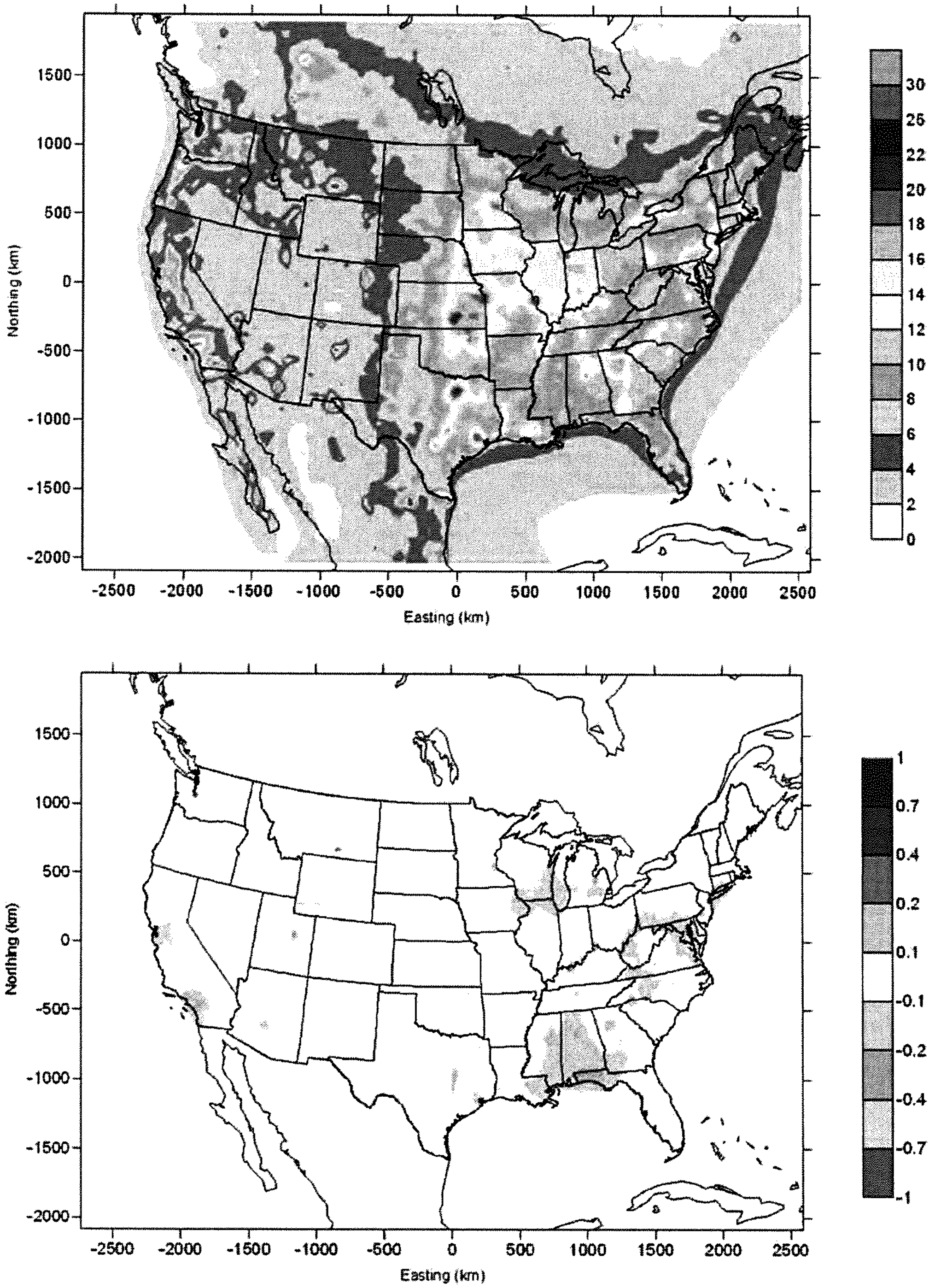


Figure 5-7
Annual Average Concentrations (μg m^{-3}) of PM_{10} (top) and Difference between PHEV Case and Base Case (bottom)

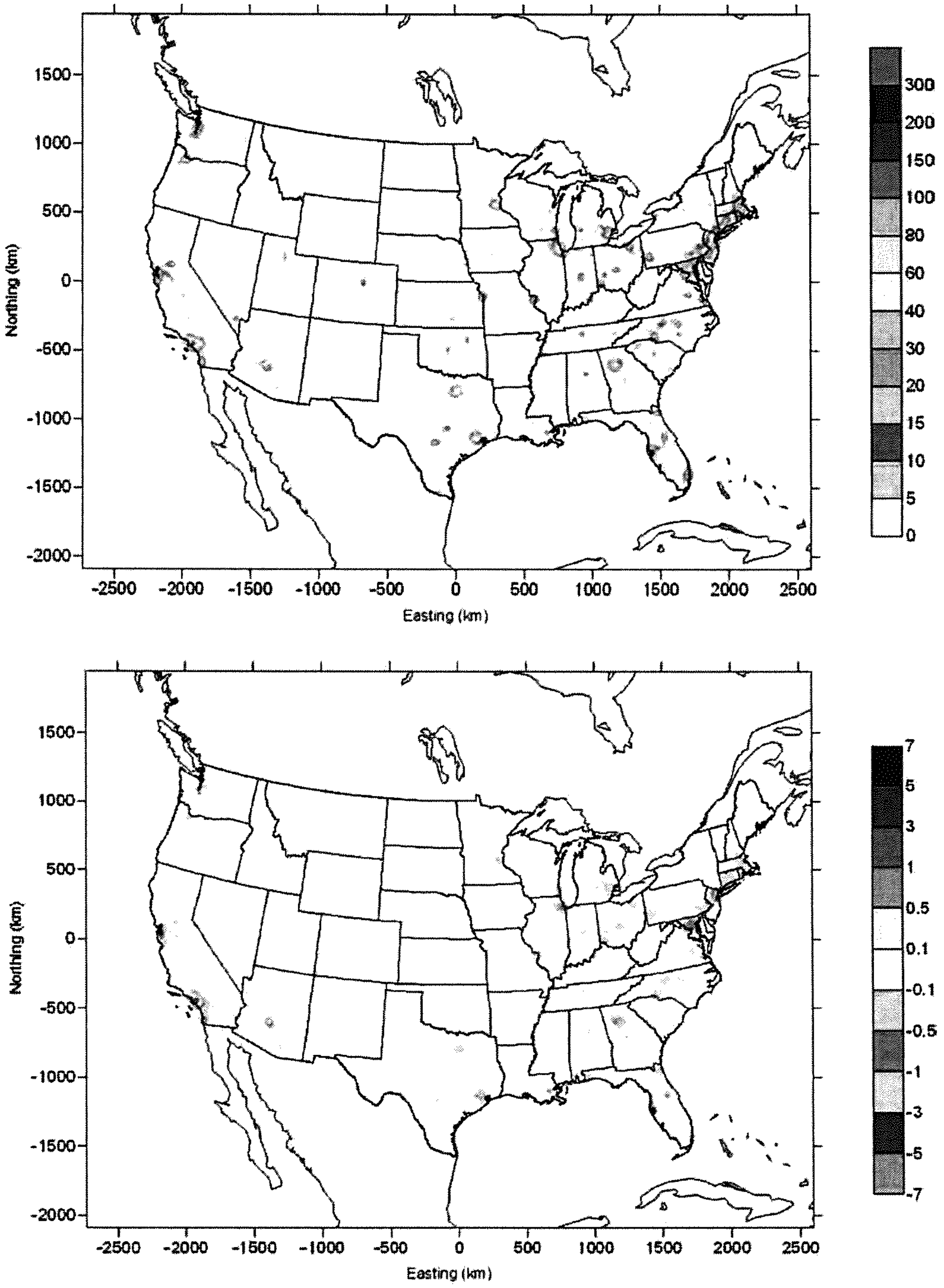


Figure 5-8
Daily $PM_{2.5}$ Design-Value Exposure Based on the 8th Highest 24-Hour-Average $PM_{2.5}$ Concentration (000,000 µg m^{-3} x person) for Base Case (top) and Difference between PHEV Case and Base Case (bottom)

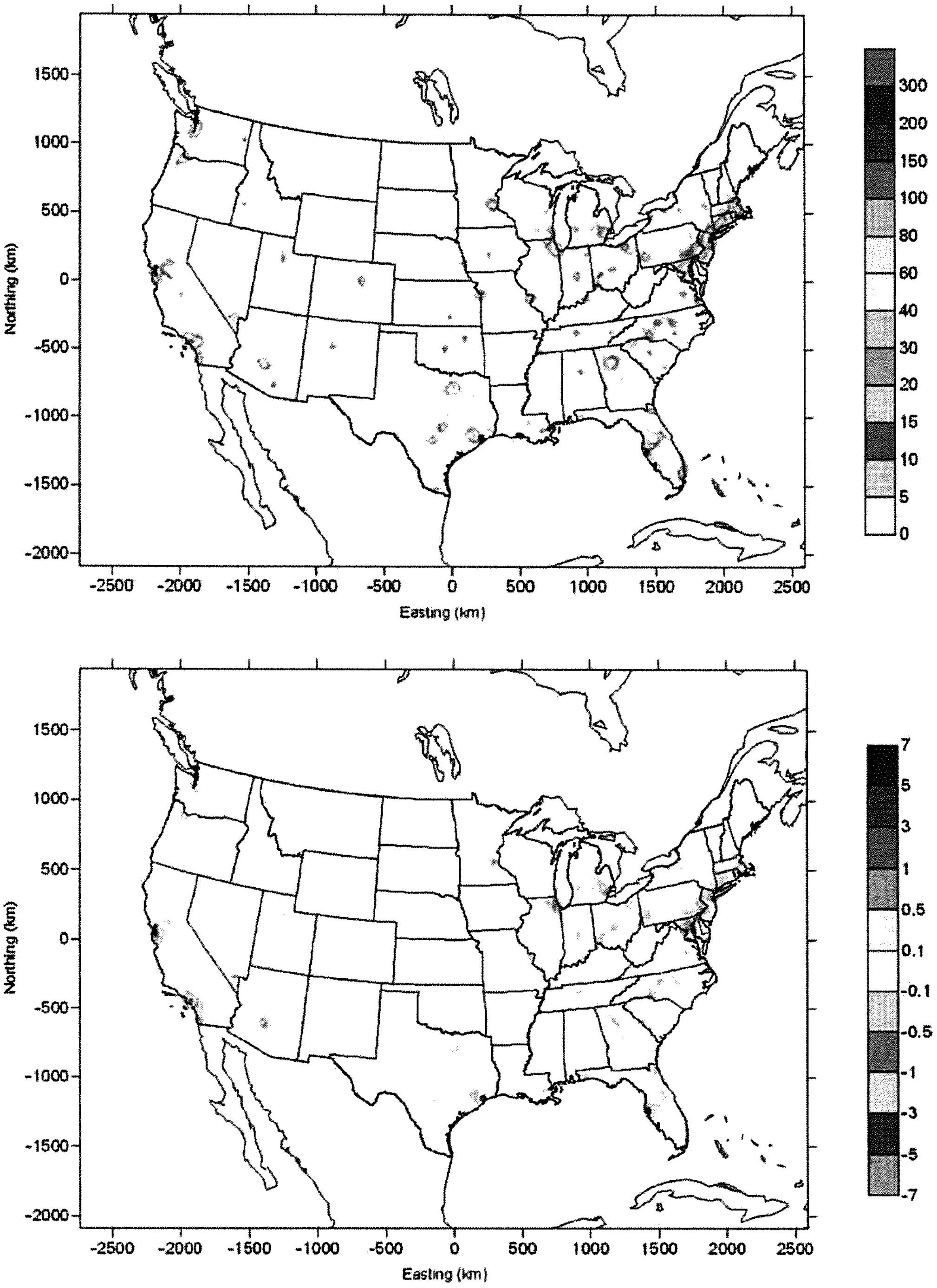


Figure 5-9
Daily PM$_{10}$ Design-Value Exposure Based on the 8th Highest 24-Hour-Average PM$_{10}$ Concentration (000,000 µg m^{-3} x person) for BaseCase (top) and Difference Between PHEV Case and Base Case (bottom)

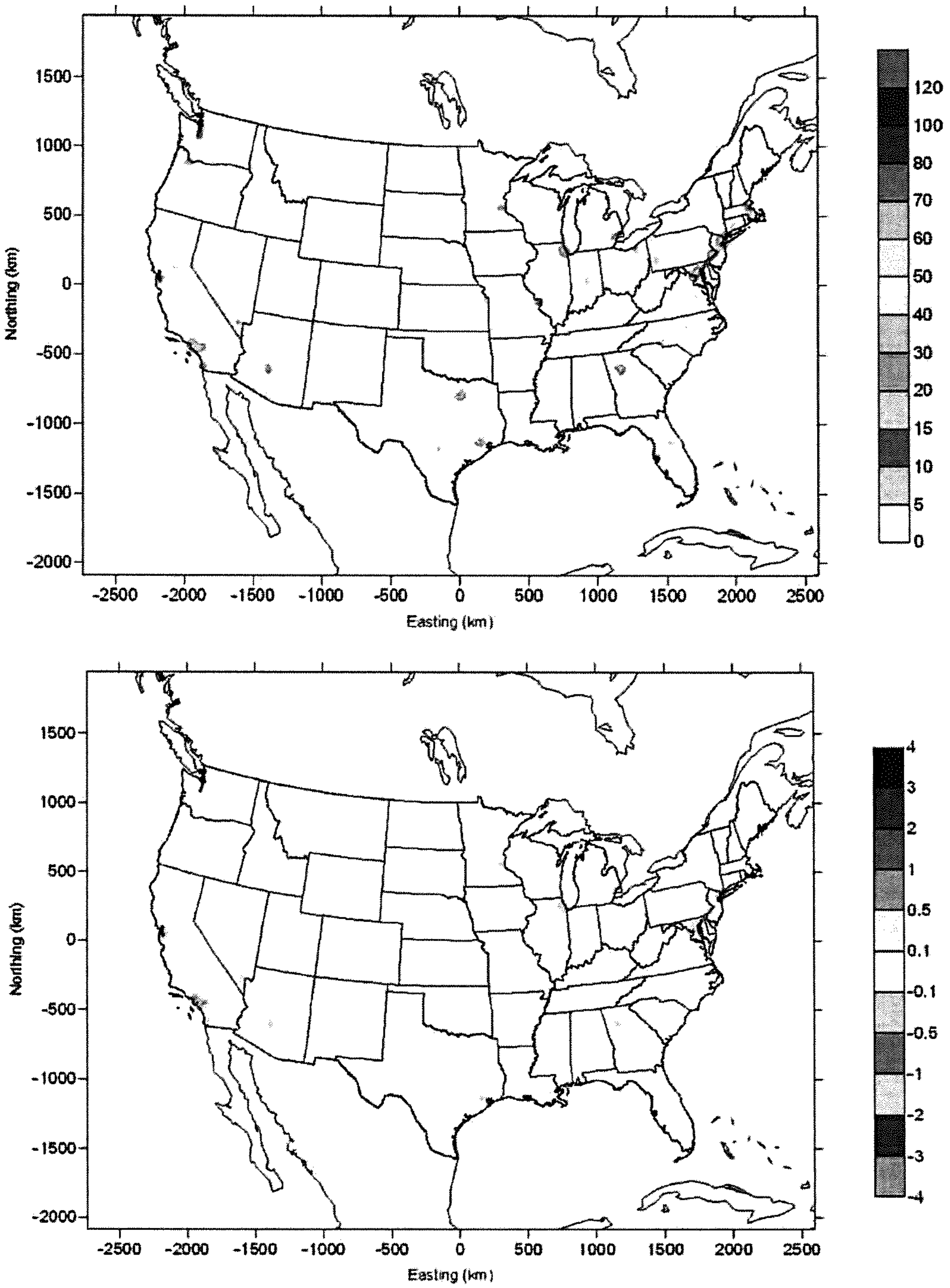


Figure 5-10
Annual $PM_{2.5}$ Design-Value Exposure Based on the Annual Average $PM_{2.5}$ Concentration (000,000 μg m^{-3} × person) for Base Case (top) and Difference Between PHEV Case and Base Case (bottom)

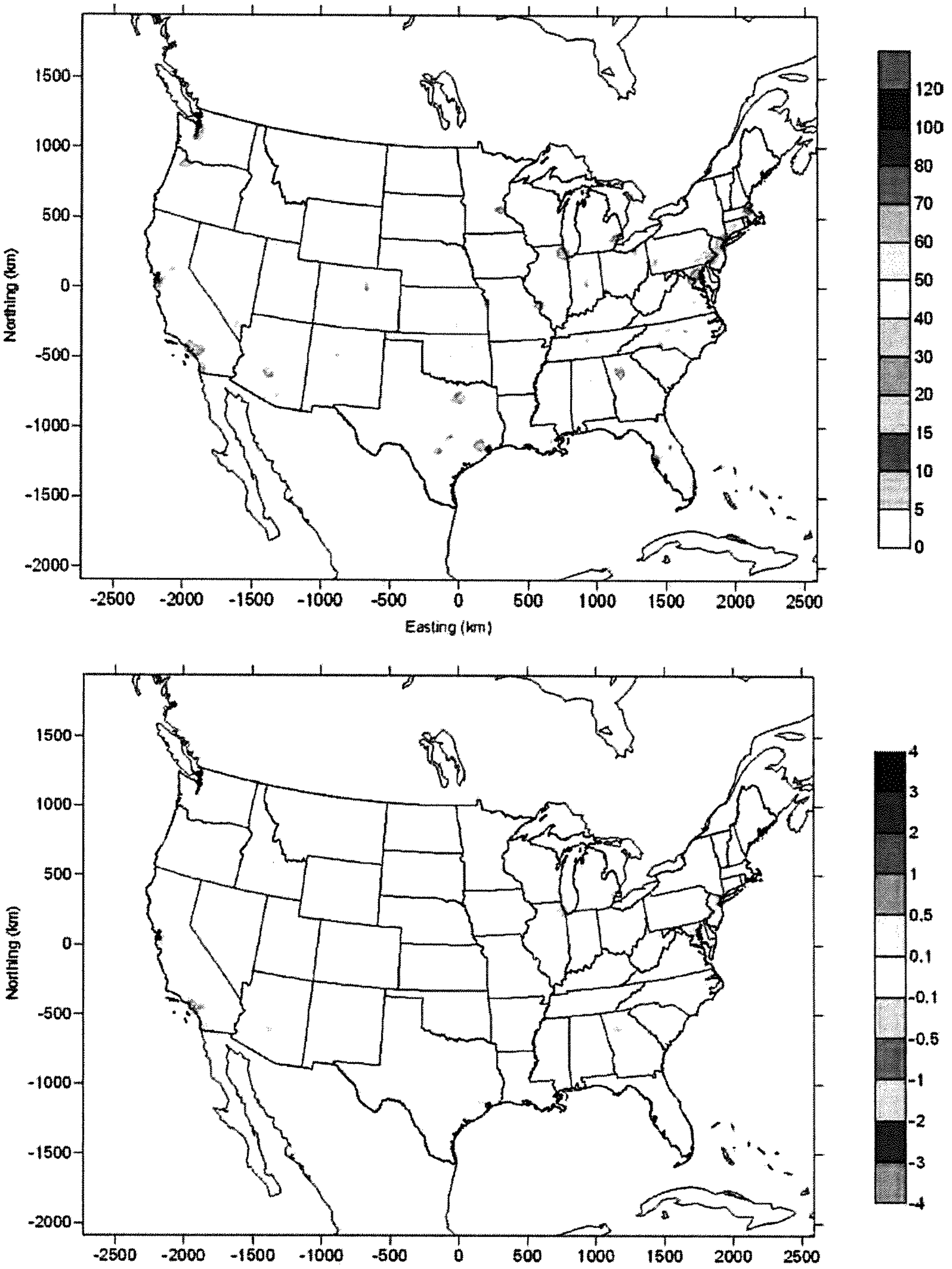


Figure 5-11
Annual PM_{10} Exposure Based on the Annual Average PM_{10} Concentration (000,000 µg m^{-3} × person) for Base Case (top) and Difference Between PHEV Case and Base Case (bottom)

Sulfate, Nitrate, and Total Nitrogen Deposition

Figures illustrating deposition results for sulfate, nitrate and total nitrogen are presented on the following pages, including:

- Maps of annual sulfate and nitrate and nitrogen deposition (**Figure 5-12** and **Figure 5-13**, respectively), and maps of annual total nitrogen deposition (**Figure 5-14**).

Base case annual sulfate and nitrate deposition maps (Figure 5-12, top and Figure 5-13, top; respectively) show that sulfate and nitrate deposition occurs mainly in the Eastern United States. Sulfate deposition (i.e., combined particulate sulfate, sulfuric acid and sulfur dioxide) is high along the Ohio River valley where many power plants are located. Nitrate deposition (i.e., combined particulate nitrate and nitric acid) shows a similar distribution with the addition of some high deposition in urban areas. Total nitrogen deposition (i.e., combined nitrate and ammonia/ammonium) is dominated by reduced nitrogen (ammonia and ammonium) and is high in agricultural lands such as the Midwestern United States. Quarterly results (shown in Appendix C for sulfate, nitrate and total nitrogen) show that the sulfate and nitrate deposition is highest in the 2nd and 3rd quarters of the year.

PHEVs increase sulfate deposition (Figure 5-12, center) in parts of the Eastern United States, including Kentucky, Tennessee, Ohio, Illinois, and Michigan, where power plant SO_2 emissions are higher in the PHEV case than the base case. However, these increases are generally less than 1% of the base case deposition and only increase up to 2% of base case deposition flux in limited areas near power plants. It is important to note that the air quality model configuration used in this study did not use a sub-grid scale treatment to explicitly simulate the unique chemistry and transport dynamics of power-plant plumes, i.e. use a plume-in-grid treatment. Studies have shown that plume-in-grid treatments are more appropriate to modeling large industrial plumes, such as those from power plants (Karamchandani et al., 2006; Lohman et al., 2006; Seigneur et al., 2006; Vijayaraghavan et al., 2006). In addition, plume-in-grid treatments provide more realistic estimates of impacts near large point sources.

Figure 5-13 (center) shows that PHEVs reduce nitrate acid deposition in much of the Eastern United States including the Ohio River valley. Several factors can contribute to lower nitrate deposition with PHEVs, with lower mobile source NOx emissions reducing the amount of nitrate formed and deposited being the chief factor. Changes in electricity generation reduce NOx emissions in some locations (e.g., some parts of the Ohio River valley) and increase NOx emissions elsewhere (e.g., Texas, Georgia and North Dakota). However, these NOx emissions do not lead to increases of nitrate deposition above 0.5% at any location of the United States.

Total nitrogen includes the deposition of oxidized nitrogen (e.g., nitric acid and nitrate) and reduced nitrogen (e.g., ammonia and ammonium). Nitrogen can adversely influence water quality by making toxic metals more available for uptake by biological systems. In addition, nitrogen increases the nutrient content of ecosystems; excess nutrient loads can lead to potential adverse impacts on vegetation, eutrophication of water bodies leading to hypoxic conditions that can devastate ecosystems. Since the nitrogen deposition is dominated by reduced nitrogen (ammonia and ammonium associated with nitrate and sulfate particles), it follows that lower nitrogen deposition with PHEVs (Figure 5-14) throughout the Eastern United States and near major urban areas results from lower mobile source NH_3 emissions with PHEVs.

All deposition results are summarized numerically at the end of this chapter.

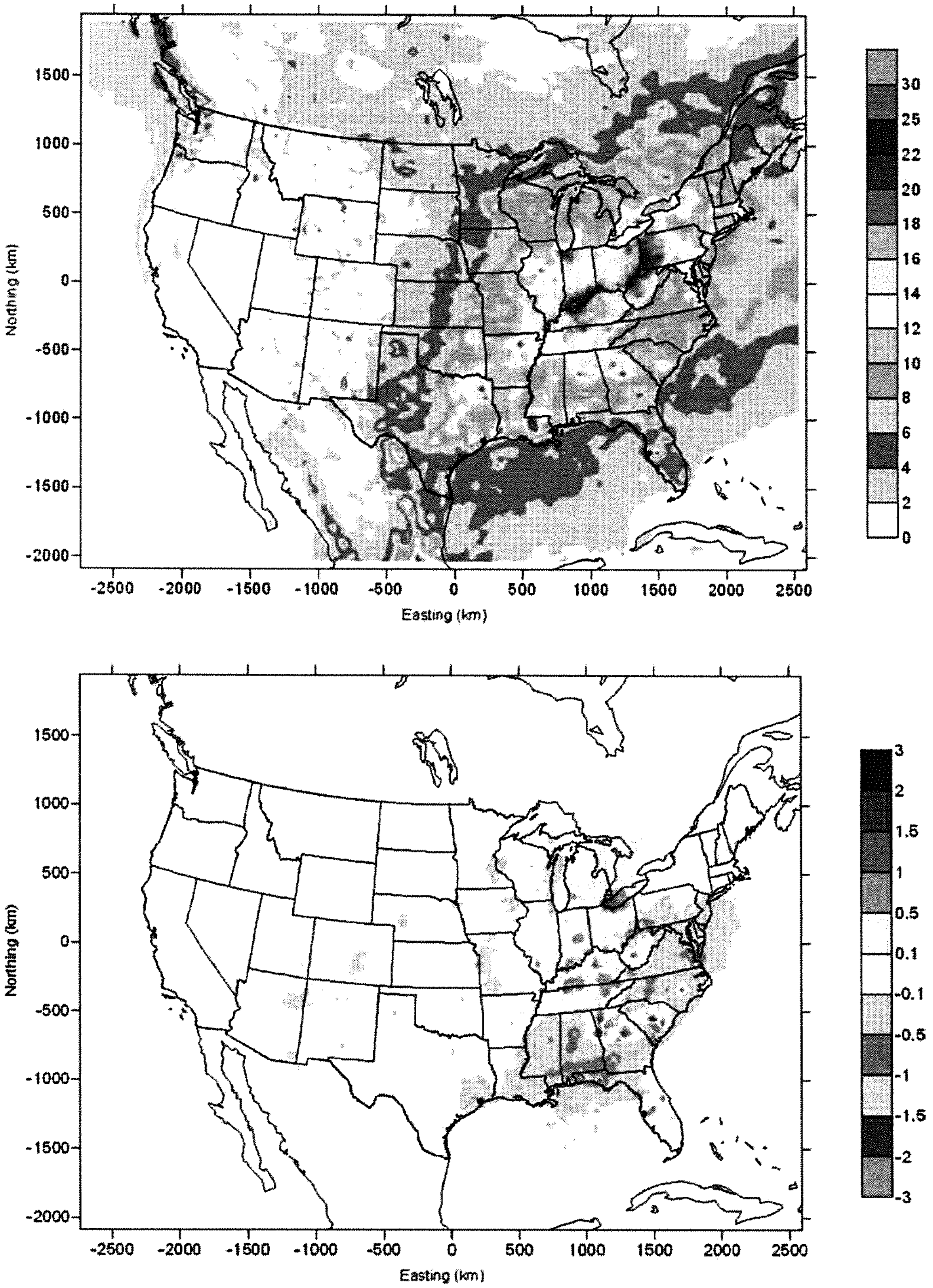


Figure 5-12
Annual Deposition (kg Ha^{-1}) of Sulfate for 2030 Base Case (top), Difference between PHEV Case and Base Case, and (c) Percentage Difference between PHEV Case and Base Case

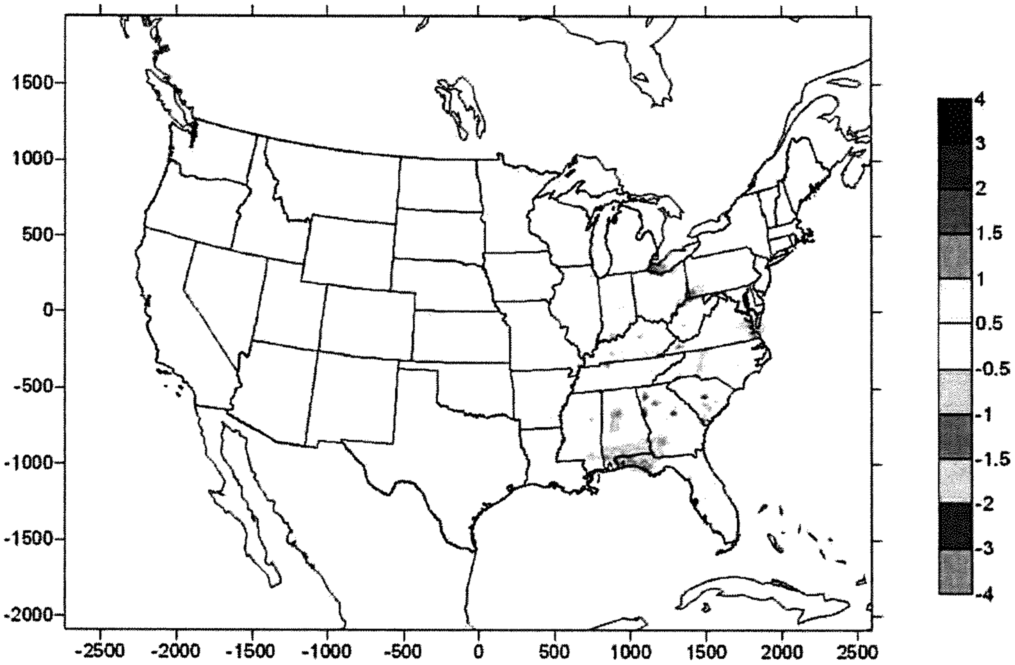


Figure 5-12 (Continued)
Annual Deposition (kg Ha-1) of Sulfate for 2030 Base Case (top), Difference between PHEV Case and Base Case, and (c) Percentage Difference between PHEV Case and Base Case

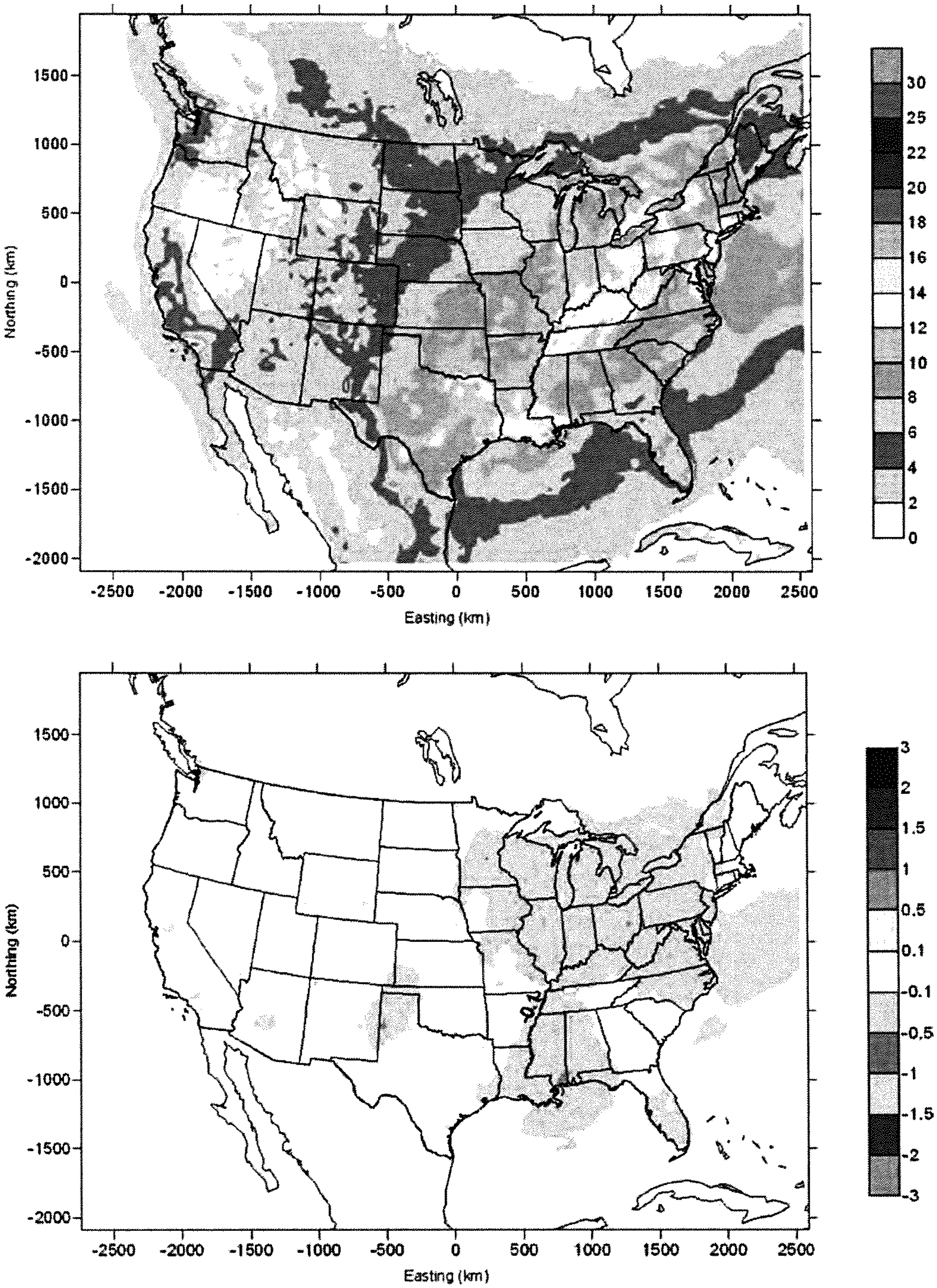


Figure 5-13
Annual Deposition (kg Ha⁻¹) of Nitrate for 2030 Base Case (top), Difference between PHEV Case and Base Case, and (c) Percentage Difference between PHEV Case and Base Case

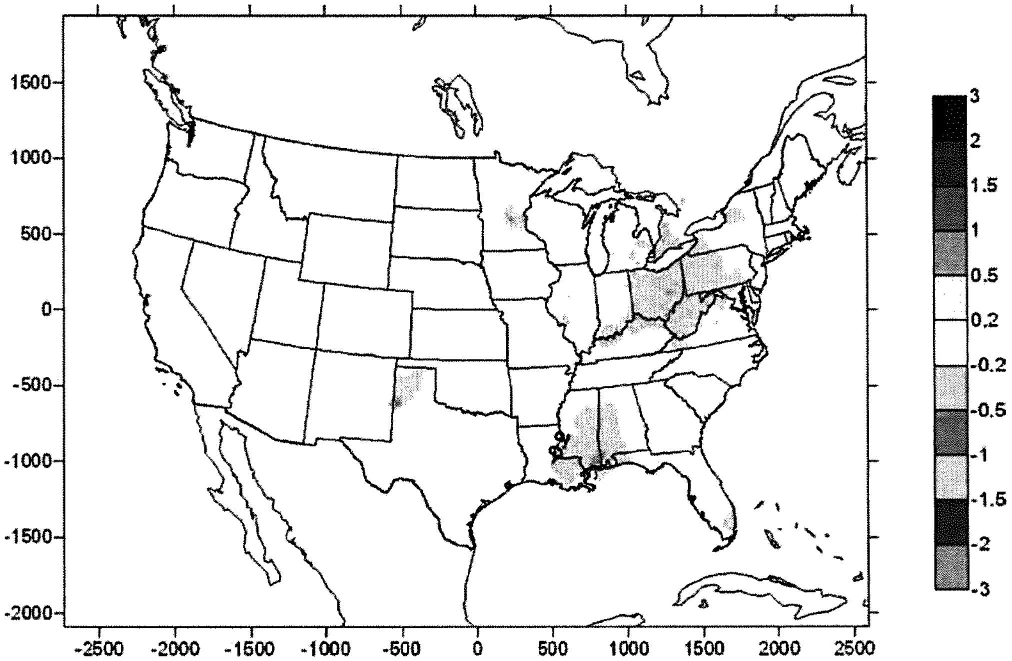


Figure 5-13 (Continued)
Annual Deposition (kg Ha^{-1}) of Nitrate for 2030 Base Case (top), Difference between PHEV Case and Base Case, and (c) Percentage Difference between PHEV Case and Base Case

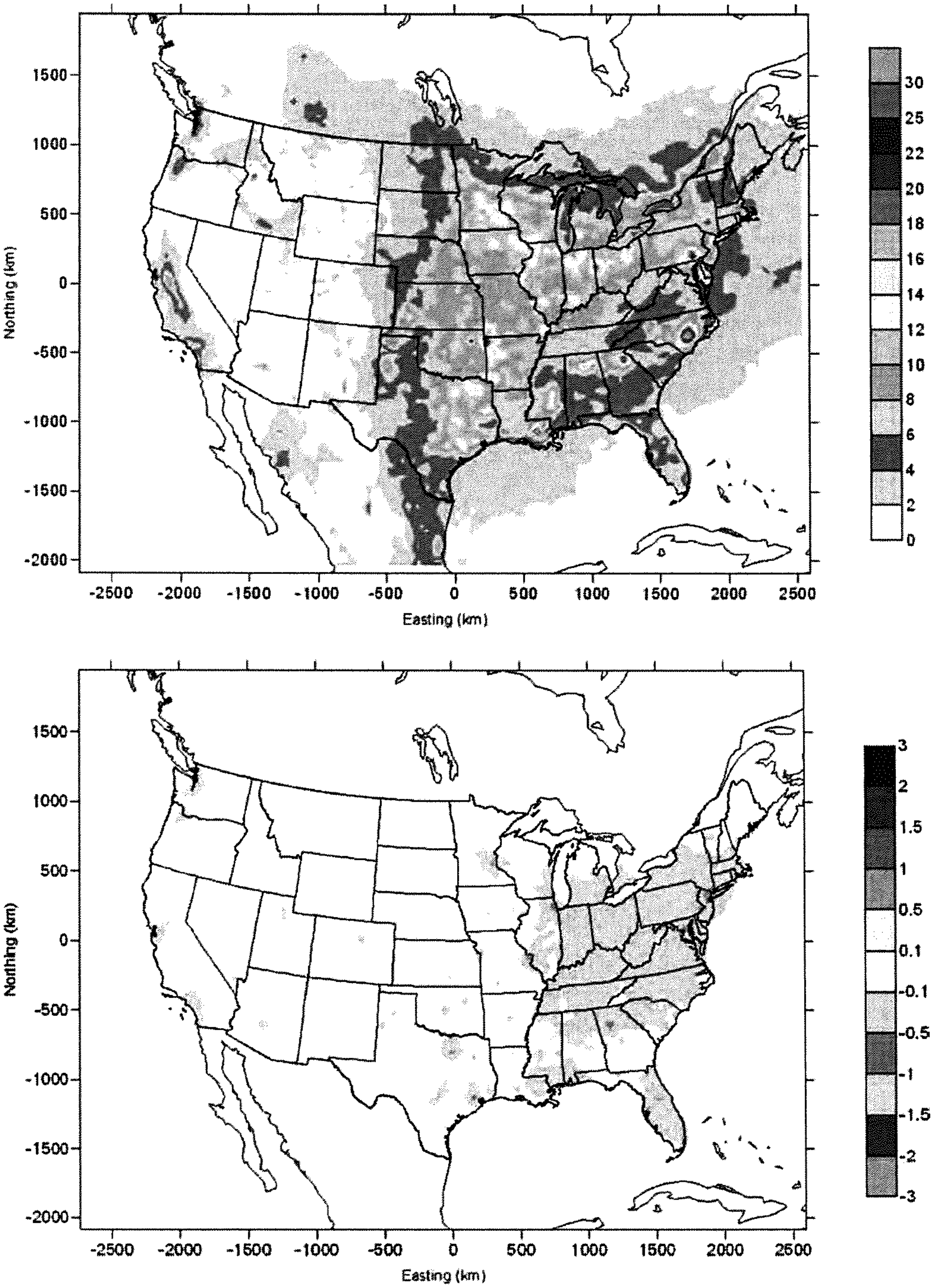


Figure 5-14
Annual Deposition (kg N Ha^{-1}) of Total Nitrogen for 2030 Base Case (top), Difference between PHEV Case and Base Case, and (c) Percentage Difference between PHEV Case and Base Case

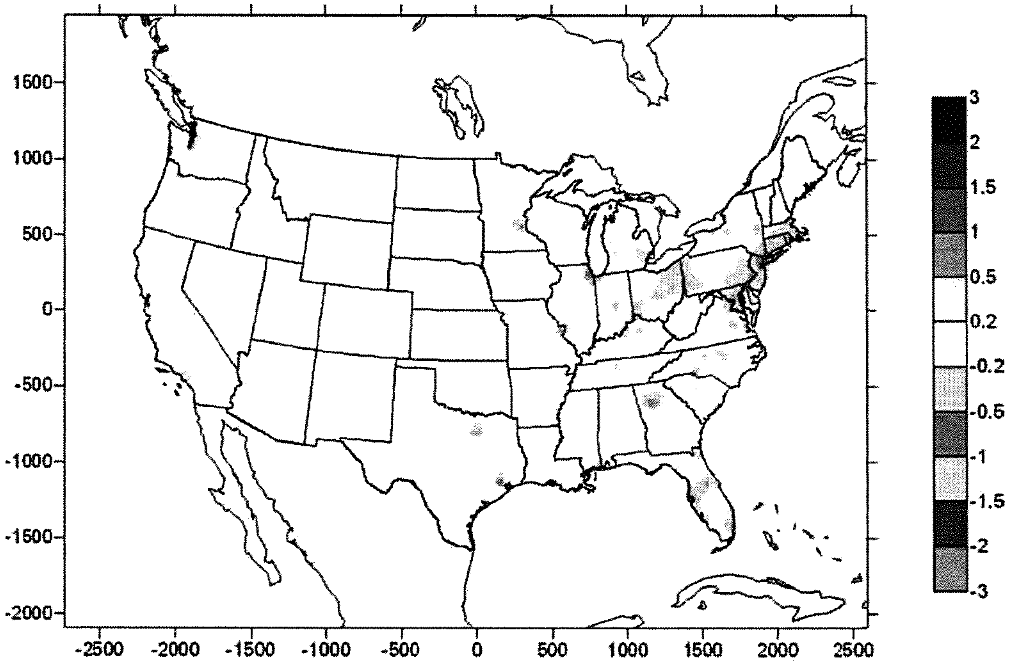


Figure 5-14 (Continued)
Annual Deposition (kg N Ha^{-1}) of Total Nitrogen for 2030 Base Case (top), Difference between PHEV Case and Base Case, and (c) Percentage Difference between PHEV Case and Base Case

Mercury Deposition

Base case mercury deposition (**Figure 5-15**) for 2030 was compared to EPA's 2018 Clean Air Mercury Rule (CAMR) modeling results and was found to be qualitatively and quantitatively similar. High mercury (Hg) deposition was found along the West Coast and in the Southern and Eastern United States. A substantial fraction of the Hg deposition is attributable to the boundary conditions: for example, most of the Hg deposition along the West Coast of the United States, Canada and Mexico is in high rainfall areas influenced by air flow from the Pacific Ocean. Hg deposition in the Eastern United States includes influences by coal-fired power plant emissions and emissions in urban areas. Quarterly results show that Hg deposition is highest in the 2nd and 3rd quarters.

There are decreases and increases in Hg deposition due to PHEVs, with decreases being more widespread (Figure 5-15). Hg deposition is reduced along the Ohio River valley due to changes in electricity generation. Hg deposition is increased in parts of Tennessee, Texas and Florida where coal-fired power plants are located, but these areas are small and represent a change of only a few percent above the base case results. Similar to the sulfate deposition results, a lack of plume-in-grid treatment in the air quality model could lead to such erroneous results. The penetration of PHEVs produces essentially no changes in Hg deposition in the Western United States.

Overall, despite a minor increase associated with EGU mercury emissions, mercury deposition is lowered in the United States due to the decreased oxidation of the total elemental mercury pool to oxidized mercury species which are prone to deposit more readily. These results are discussed in more detail in the summary section of this chapter.

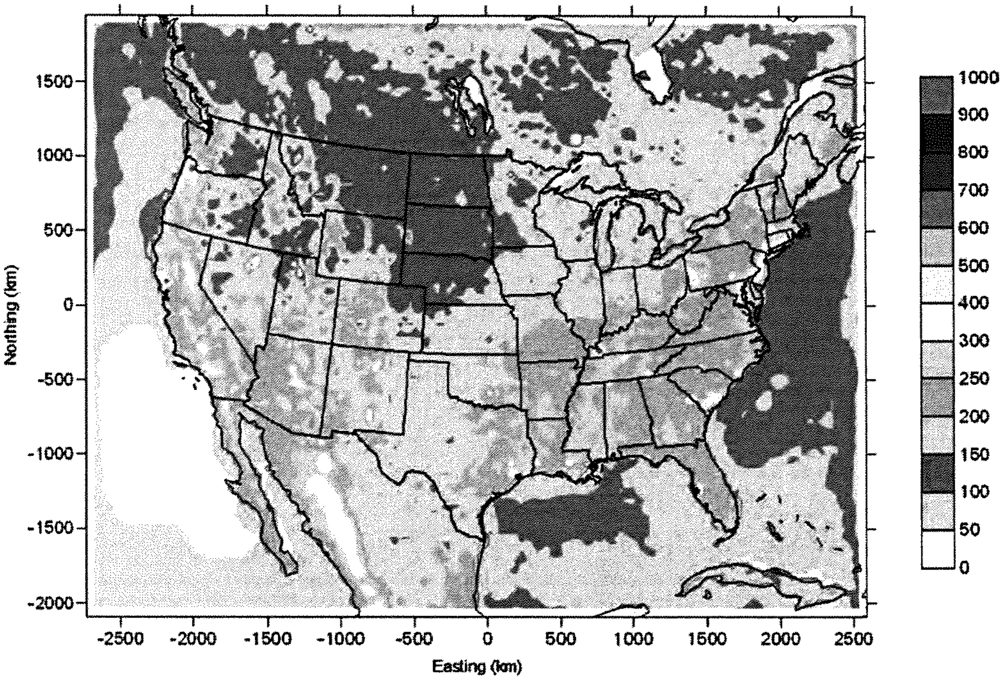


Figure 5-15
Annual Deposition (mg Ha^{-1}) of Mercury for 2030 Base Case (top), Difference between PHEV Case and Base Case, and (c) Percentage Difference between PHEV Case and Base Case

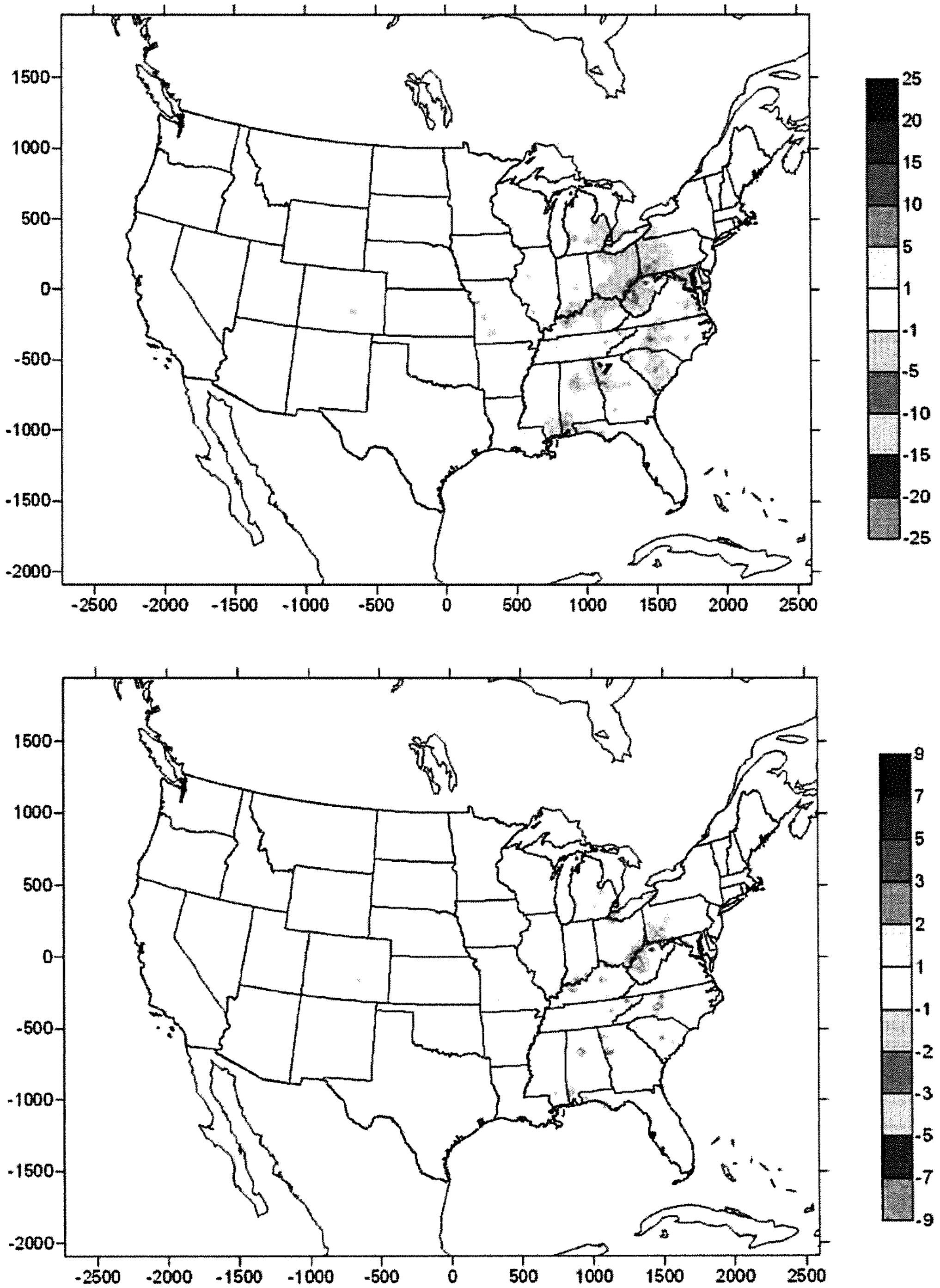


Figure 5-15 (Continued)
Annual Deposition (mg Ha^{-1}) of Mercury for 2030 Base Case (top), Difference between PHEV Case and Base Case, and (c) Percentage Difference between PHEV Case and Base Case

Visibility

Figure 5-16 (top) shows that visibility at Class I areas (represented as 98th percentile impact in deciviews) generally is degraded more in the Eastern United States than the Western United States. The color and size of the circles in the figure indicate the extent of visibility degradation. From the PM results discussed above, visibility degradation in the Eastern United States is due primarily to sulfate and nitrate aerosol and contributions from organic compounds. In the Western United States, fires impact visibility and there are several sites along the West Coast where visibility is degraded by nitrate impacts.

PHEVs result in widespread visibility improvements (Figure 5-16, bottom). Circles with grey color indicate negligible change in visibility, whereas pink, blue, and green indicate increasingly improving visibility conditions. The visibility improvements are not substantial in the Northern and Central U.S. but are considerable in the Eastern U.S. (e.g., the Appalachians) and California, specifically in southern California where there are 0.4 to 0.5 deciview improvements. Only the Mingo Class I area in Missouri exhibits any notable visibility degradation (shown in red) due to PHEVs.

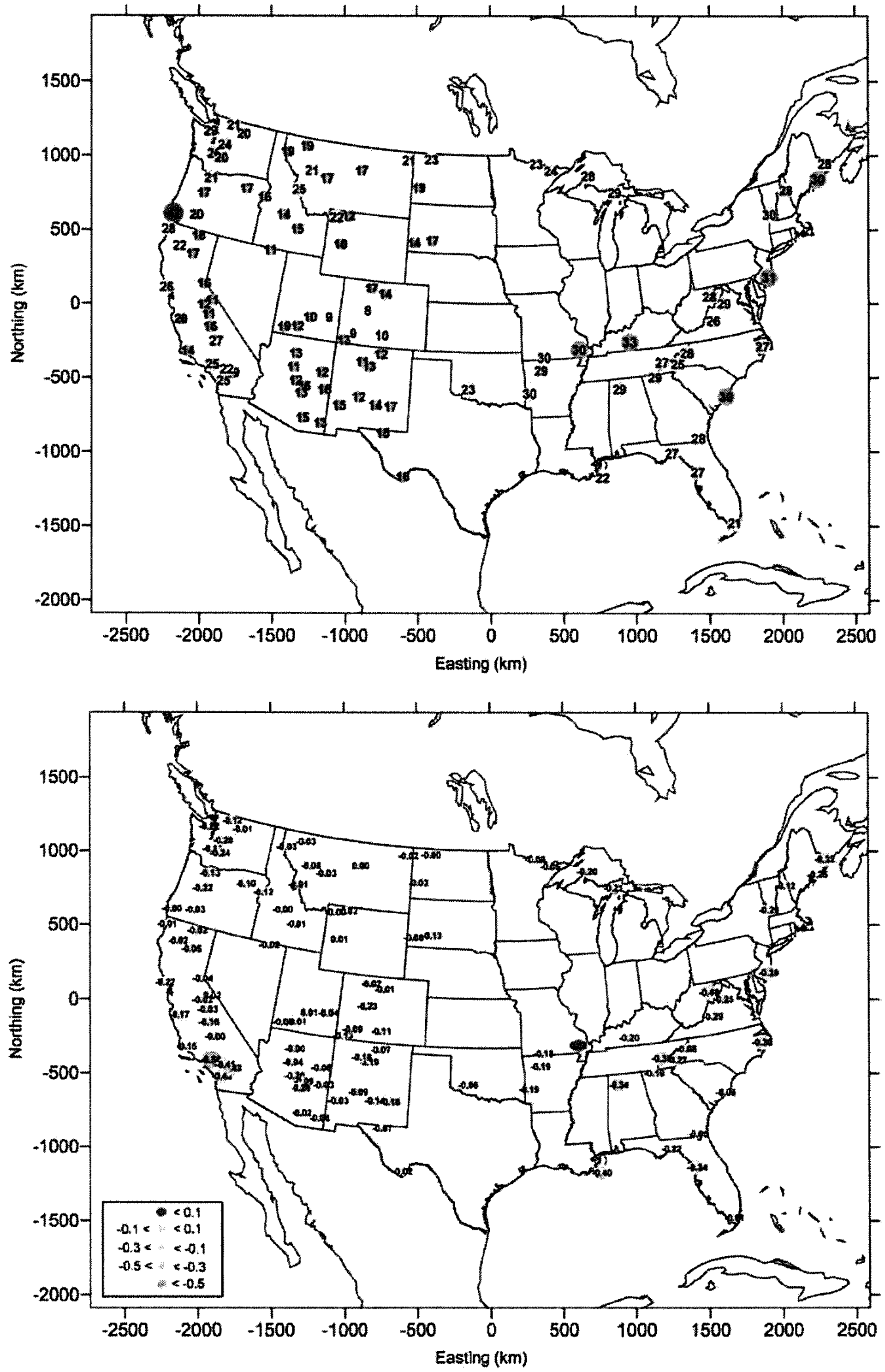


Figure 5-16
98th Percentile Visibility Degradation (dv) at Class I areas for 2030 Base Case (top) and Difference between PHEV and Base Case (bottom)

Air Quality Modeling Summary

Results discussed in the above section show both regions of air pollution benefit and disbenefit. The combined benefit across the continental United States can provide insights on the overall net direction of PHEV impacts. This section presents the net benefit metrics which take into account exposed area coverage and exposed population. The formulations used in this analysis (shown in **Table 5-5** and **Table 5-6**) are:

- Exposed area coverage (km^2) and percentage of the coverage (%) derived from the number of benefit/disbenefit grid cells multiplied by cell size (36 km by 36 km), and
- Exposed population (persons) and percentage of the population (%) derived from the number of people in benefit/disbenefit grid cells

The ambient pollutant summary (Table 5-5) shows:

- Difference in Design Value Exposure (DVE) for pollutants, and
- Mean difference in DVE of a pollutant expressed as:

  Mean ΔDVE = [Difference in DVE for pollutant] / [Exposed Population]

These metrics are applied to the 4th highest 8-hour ozone, the 8th highest 24-hour $PM_{2.5}$ and PM_{10}, and the annual 24-hour average $PM_{2.5}$ and PM_{10}.

The deposition summary (Table 5-6) shows:

- Difference in deposition mass, and
- Mean deposition flux expressed as:

  Mean ΔFlux = [Total deposition Mass] / [Exposed Area Coverage]

These metrics are applied to the total deposition of sulfate, nitrate, total nitrogen and mercury.

The benefit/disbenefit over appropriate thresholds for each pollutant is also shown in the right side of Table 5-5 and Table 5-6. The difference between the two scenarios is taken to be insignificant (except for perceiving the tendency of the model in this numerical regime) when its absolute value is lower than the chosen threshold value and is excluded from the calculation.

Ozone metrics with and without threshold of 0.25 ppbv both suggest clear benefits from PHEVs. 92% and 61% of the population benefit from PHEVs with and without considering the threshold, respectively. The net ozone population exposure metric magnifies ozone health benefit due to the decreased exposure to high ozone levels in most urban areas.

Table 5-5
Ambient Pollutant Summary (Shown with and without Threshold)

Metric	Disbenefits	Benefits	Metric	Disbenefits	Benefits
Δ O_3 (8-Hour) Threshold = 0			**Δ O_3 (8-Hour) Threshold = 0.25 ppb**		
Area (km^2)	922,752	7,380,720	Area (km^2)	93,312	2,129,328
% Area CONUS	11%	89%	% Area CONUS	1%	26%
Population (persons)	29,542,045	331,708,340	Population (persons)	5,086,919	220,136,705
% Population CONUS	8%	92%	% Population CONUS	1%	61%
Δ DVE (ppb)	5,340,147	158,521,472	Δ DVE (ppb)	2,645,187	145,343,088
Mean Δ DVE (ppb)	0.18	0.48	Mean Δ DVE (ppb)	0.52	0.66
Δ $PM_{2.5}$ (Daily) Threshold = 0			**Δ $PM_{2.5}$ (Daily) threshold = 0.1 $\mu g\ m^{-3}$**		
Area (km^2)	1,579,824	6,724,944	Area (km^2)	519,696	3,851,712
% Area CONUS	19%	81%	% Area CONUS	6%	46%
Population (persons)	26,847,949	334,402,730	Population (persons)	12,094,076	296,337,362
% Population CONUS	7%	93%	% Population CONUS	3%	82%
Δ DVE ($\mu g\ m^{-3}$)	4,513,934	135,394,912	Δ DVE ($\mu g\ m^{-3}$)	4,130,585	133,571,072
Mean Δ DVE ($\mu g\ m^{-3}$)	0.17	0.40	Mean Δ DVE ($\mu g\ m^{-3}$)	0.34	0.45
Δ PM_{10} (Daily) Threshold = 0			**Δ PM_{10} (Daily) Threshold = 0.1 $\mu g\ m^{-3}$**		
Area (km^2)	1,588,896	6,715,872	Area (km^2)	417,312	3,840,048
% Area CONUS	19%	81%	% Area CONUS	5%	46%
Population (persons)	25,649,816	335,600,863	Population (persons)	10,914,660	291,771,347
% Population CONUS	7%	93%	% Population CONUS	3%	81%
Δ DVE ($\mu g\ m^{-3}$)	3,814,279	130,524,824	Δ DVE ($\mu g\ m^{-3}$)	3,251,979	128,462,880
Mean Δ DVE ($\mu g\ m^{-3}$)	0.15	0.39	Mean Δ DVE ($\mu g\ m^{-3}$)	0.30	0.44
Δ $PM_{2.5}$ (Annual) Threshold = 0			**Δ $PM_{2.5}$ (Annual) threshold = 0.1 $\mu g\ m^{-3}$**		
Area (km^2)	1,931,040	6,373,728	Area (km^2)	38,880	645,408
% Area CONUS	23%	77%	% Area CONUS	0%	8%
Population (persons)	31,269,291	329,981,388	Population (persons)	2,203,469	136,187,374
% Population CONUS	9%	91%	% Population CONUS	1%	38%
Δ DVE	1,481,269	34,401,896	Δ DVE	805,776	24,662,818
Mean Δ DVE	0.05	0.10	Mean Δ DVE	0.37	0.18
Δ PM_{10} (Annual) Threshold = 0			**Δ PM_{10} (Annual) Threshold = 0.1 $\mu g\ m^{-3}$**		
Area (km^2)	1,916,784	6,387,984	Area (km^2)	38,880	664,848
% Area CONUS	23%	77%	% Area CONUS	0%	8%
Population (persons)	29,263,261	331,987,418	Population (persons)	2,203,469	140,881,055
% Population CONUS	8%	92%	% Population CONUS	1%	39%
Δ DVE	1,449,884	35,434,996	Δ DVE	803,517	25,890,716
Mean Δ DVE	0.05	0.11	Mean Δ DVE	0.36	0.18

Table 5-6
Deposition Summary (Note: Units of Total N deposition are in Kg of Nitrogen; Units of Hg Depositio are in mg of Hg)

Metric	Disbenefits	Benefits	Net Impact	Metric	Disbenefits	Benefits
Δ Sulfate Deposition Threshold = 0				**Δ Sulfate Deposition Threshold = 0.1 kg Ha^{-1}**		
Area (km^2)	2,292,624	6,012,144		Area (km^2)	659,664	1,277,856
% Area CONUS	28%	72%		% Area CONUS	8%	15%
Δ Deposition Mass (kg)	27,773,280	53,887,680	26,114,400	Δ Deposition Mass (kg)	23,211,360	41,472,000
Mean Δ Flux (kg Ha^{-1})	0.12	0.09		Mean Δ Flux (kg Ha^{-1})	0.35	0.32
Δ Nitrate Deposition Threshold = 0				**Δ Nitrate Deposition Threshold = 0.1 kg Ha^{-1}**		
Area (km^2)	1,161,216	7,143,552		Area (km^2)	107,568	2,554,416
% Area CONUS	14%	86%		% Area CONUS	1%	31%
Δ Deposition Mass (kg)	4,976,640	66,484,800	61,508,160	Δ Deposition Mass (kg)	1,581,120	45,489,600
Mean Δ Flux (kg Ha^{-1})	0.04	0.09		Mean Δ Flux (kg Ha^{-1})	0.15	0.18
Δ Total N Deposition Threshold = 0				**Δ Total N Deposition Threshold = 0.1 kg N Ha^{-1}**		
Area (km^2)	393,984	7,910,784		Area (km^2)	0	1,846,800
% Area CONUS	5%	95%		% Area CONUS	0%	22%
Total deposition mass (kg N)	233,280	55,196,640	54,963,360	Δ Deposition Mass (kg N)	0	32,412,960
Mean flux (kg Ha^{-1})	0.01	0.07		Mean Δ Flux (kg Ha^{-1})	0	0.18
Δ Total Hg Deposition Threshold = 0				**Δ Total Hg Deposition Threshold = 5 mg Ha^{-1}**		
Area (km^2)	2,431,296	5,873,472		Area (km^2)	71,280	561,168
% Area CONUS	29%	71%		% Area CONUS	1%	7%
Δ Deposition Mass (mg)	48,405,600	236,571,840	188,166,240	Δ Deposition Mass (mg)	19,712,160	146,370,240

PHEVs reduce high 24-hour average $PM_{2.5}$ and PM_{10} concentrations over a widespread area. With a threshold applied, over 80% of people benefit from PM reduction whereas only 3% of people experience increased higher PM. Annual average $PM_{2.5}$ and PM_{10} show similar patterns of widespread reductions. PM disbenefits are sparse and do not appear in densely populated areas.

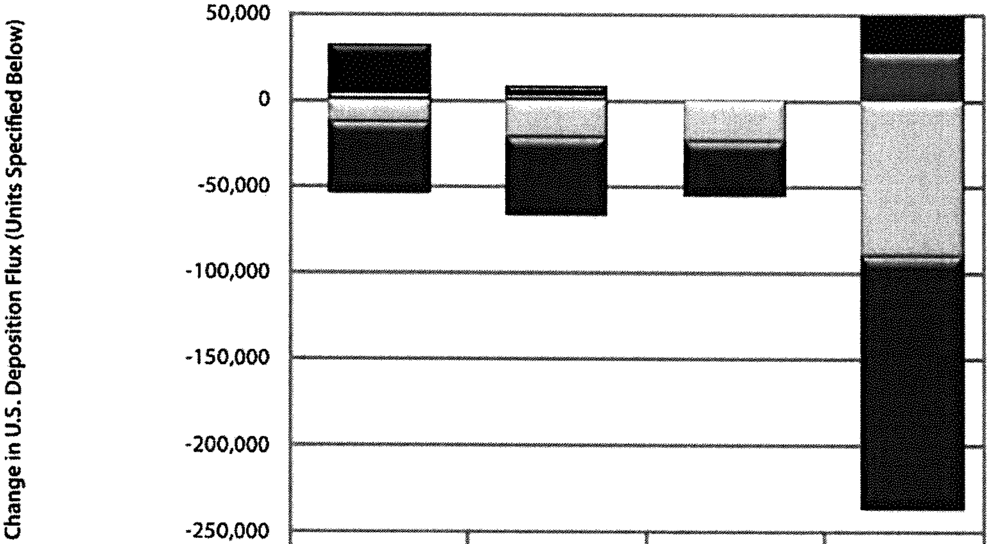
Particulate matter concentrations in ambient air are a combination of particles directly emitted by sources (primary PM) and particles formed due to chemical processes in the atmosphere (secondary PM). Primary emissions of particulate matter (PM) increase by 10% with the use of PHEVs due primarily to the large growth in coal generation assumed in the study (see Chapter 3 and Chapter 4). However, particulate matter concentrations decrease in most regions due to significant reductions in VOC and NOx emissions from the transportation sector leading to less secondary PM.

PHEVs increase sulfate deposition in many parts of the U.S, but the total continental sulfate deposition decreases. The net impact on nitrate and nitrogen deposition is also an overall reduction in total continental deposition and benefits are more widespread than disbenefits. Note that with a threshold, PHEVs do not introduce any disbenefit at all in nitrogen deposition.

PHEVs reduce the net impact of mercury deposition. With no threshold applied, the net benefit to mercury deposition is 188 kg (126 kg with a threshold) despite an increase of EGU mercury emissions of 370 kg. Mercury deposition is influenced by both emissions and atmospheric chemistry as well. Chemical reactions cycle mercury from its elemental form to oxidized forms that can deposit more readily in rain or by contact with the Earth's surface. The lower levels of atmospheric ozone in the PHEV scenario cause more of the mercury to remain in the elemental form and thereby decrease the amount deposited on the surface.

Mercury emissions increase by 2.4% with increased generation needs to meet PHEV charging loads. The study assumes that mercury is constrained by a cap-and-trade program, with the option for using banked allowances, proposed by EPA during the execution of the study. The electric sector modeling indicates that utilities take advantage of the banking provision to realize early reductions in mercury that result in greater mercury emissions at the end of the study timeframe (2030). As a result, PHEVs do not increase the U.S. contribution to the global mercury budget over the long term. Moreover, PHEVs serve to enhance the benefit of early banking by allowing the oxidant pool to have further decreased by the time these banked allowances are emitted.

Figure 5-17 shows a summary of deposition results, including the net change in U.S. deposition flux for the pollutants of interest.



	Sulfate (ton)	Nitrate (ton)	Nitrogen (ton N)	Mercury (g)
■ Benefit above Threshold	-41,472	-45,490	-32,413	-146,370
□ Benefit below Threshold	-12,416	-20,995	-22,784	-90,202
■ Disbenefit above Threshold	27,769	4,973	233	48,377
▨ Disbenefit below Threshold	4,562	3,396	233	28,693
Net Benefit	-26,114	-61,508	-54,963	-188,166

Figure 5-17
Deposition Summary

6 Summary

The objective of this study is to evaluate the impact of plug-in hybrid electric vehicles (PHEVs) on key air quality parameters for a future-year scenario with substantial penetration of PHEVs in the U.S. light-duty vehicle fleet (passenger cars and light-trucks). In order to meet this objective, a suite of computational modeling tools are used to compare two scenarios:

- A base case scenario assuming no PHEV in the vehicle fleet, and
- A PHEV case scenario assuming a high penetration of PHEVs in the vehicle fleet (approximately 40% of on-road vehicles and 50% of new vehicle sales in 2030).

In contrast to other studies that have attempted to evaluate the environmental impacts of PHEVs, the analysis presented in this report integrates the most advanced transportation, electric sector and atmospheric models using an unprecedented level of detail. The key characteristics that differentiate this study from other analyses are:

- This study simulates evolution of the electric sector from present day to 2030 for the two scenarios evaluated.
- For each year in the PHEV Case, this study evaluates the impact on the electric sector (capacity and generation) due to the incremental load from PHEVs as the technology increasingly penetrates the vehicle fleet.
- This study calculates emissions from the electric sector assuming compliance with all current federal air quality regulations on electricity generation and their associated levels of enforcement from present day to 2030.

This study translates the changes in emissions from both the transportation and electric sector to meaningful metrics of ambient levels, exposure and deposition.

The methodology of the study, presented in detail in Chapter 1, reflected the following activities:

- Define general energy assumptions for the study based on the U.S. Department of Energy's 2006 Annual Energy Outlook (AEO 2006), the California Energy Commission's 2005 Integrated Energy Policy Report (IEPR) and other key input such as Renewable Portfolio Standards throughout the United States.
- Transportation modeling to estimate growth in vehicle miles travelled (VMT) and emissions in the base case and PHEV case, including any changes in upstream emissions, and to determine incremental electricity load for PHEV Case.
- Electric sector modeling to estimate the evolution of the electric sector and corresponding emissions for the base case and PHEV case.
- Integration of transportation and electric sector emissions into a format compatible with air quality models.

An air quality model was used to simulate the air quality impacts of PHEVs in 2030. EPA's Community Multiscale Air Quality (CMAQ) modeling system was used to simulate both scenarios and air quality impacts were evaluated for ozone mixing ratios, particulate matter concentrations nutrient (sulfate, nitrate and total nitrogen) deposition, mercury deposition, and visibility.

The results of the analysis indentify the potential that PHEVs offer for widespread air quality benefits for multiple pollutants (including ozone, particulate matter and deposition rates for sulfur, nitrogen and mercury) in the United States. Some pollutants show regions of disbenefit as well; however, population-exposure and deposition-flux calculations show that the overwhelming majority of the population and land area of the United States experience benefits due to the penetration of the PHEVs in the vehicle fleet.

Important Caveats

It is important to consider several important caveats regarding the study methodology:

1. In order to remain consistent with the AEO 2006, this study did not include any CO_2 or greenhouse gas policies in the analysis of generation options for new capacity builds in the study timeframe. Volume 1 of this study describes at the impact of different CO_2 intensity futures for the electric power sector; lowering the CO_2 intensity of the electricity portfolio has the potential to also lower emissions of other pollutants, but the extent of this effect has not been evaluated explicitly in this study.

   The scenario explored in this study represents an appropriate framework from an air quality perspective at this time. Determining the air quality impacts of PHEVs under national CO_2 or greenhouse gas policies or constraints would necessitate defining specific details, including, but not limited to, the nature of the policy and whether one uniform policy applies across different economic sectors or whether different policies apply to individual economic sectors (or groupings of economic sectors). This study does not seek to define potential CO_2 policies. Notwithstanding, technologies implemented to satisfy a greenhouse gas policy on the electric sector are expected to lower air quality criteria emissions from the sector and result in a concomitant improvement to air quality from the adoption of PHEVs.

2. New power-plants built to satisfy new demand, both in the base case and the PHEV case, have been assumed to be located where current generation facilities exist. Due to the inherent uncertainty in predicting the siting of new power plants, this is a necesary simplification that can have consequences in the air quality model due to the superposition of emissions. It is important to note that any new power plant sitings will need to address Prevention of Significant Deterioration (PSD) and New Source Review (NSR) requirements in their permits and operate in such fashion to address any future air quality regulations that may be enacted in the study timeframe.

3. The air quality model configuration used in this study did not include a module for explicit treatment of the chemistry and transport dynamics of large industrial plumes, such as those from power plants. Sea-salt chemistry, which influences atmospheric composition in coastal areas, was also not included due to compatibility issues with mercury chemistry.

Emissions Summary

The following figures summarize the impact of PHEVs on emissions of several pollutants that influence air quality.[26] These figures are separated into four main categories of emissions (EGU, On-Road, Non-Road and All Other) and include past emissions of these pollutants for additional perspective.

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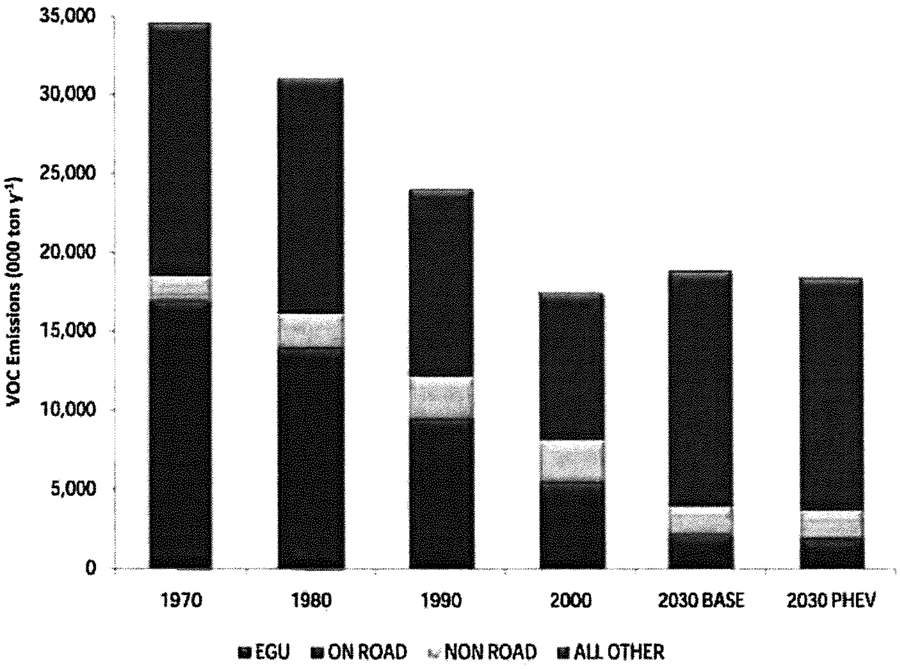
[26] Emissions in 2030 do not include any improvements for NON-ROAD and ALL OTHER categories beyond those estimated to be in place by 2018 according to the inventories developed by the Regional Haze Rule Regional Planning Organizations as this was outside the scope of the study.

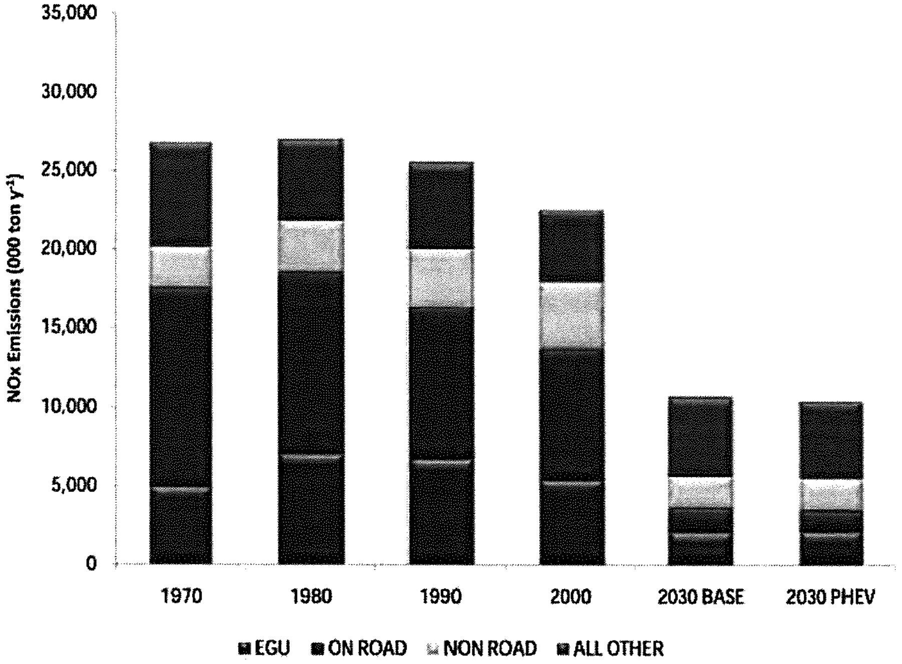
Figure 6-1 shows that total VOC emissions in 2030 are approximately 50% of 1970 values; PHEVs contribute to additional VOC emission reductions of approximately 338,000 tons.



SOURCE	1970	1980	1990	2000	2030 BASE	2030 PHEV	Δ 2030 (PHEV-BASE)	
EGU	30	45	47	62	–	–	0	
ON ROAD	16,910	13,869	9,388	5,325	2,072	1,837	-234	
NON ROAD	1,616	2,662	2,662	2,644	1,865	1,865	0	
ALL OTHER	16,103	15,000	12,011	9,481	14,885	14,782	-103	
							-338	**NET**

Figure 6-1
VOC Emissions (000 ton y^{-1})

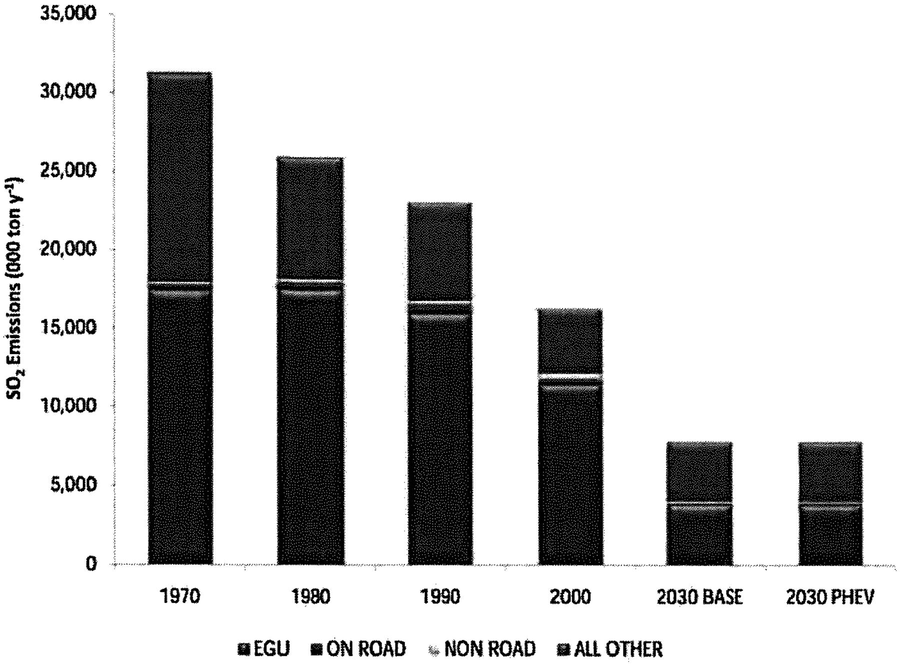
Figure 6-2 shows that total NOx emissions in 2030 are approximately 40% of 1970 values. PHEVs contribute to additional NOx emission reductions of approximately 179,000 tons.



	1970	1980	1990	2000	2030 BASE	2030 PHEV	Δ 2030 (PHEV-BASE)	
EGU	4,900	7,024	6,663	5,330	2,035	2,094	59	
ON ROAD	12,624	11,493	9,592	8,394	1,543	1,307	-236	
NON ROAD	2,652	3,353	3,781	4,167	2,048	2,048	0	
ALL OTHER	6,706	5,210	5,493	4,708	5,033	5,032	-1	
							-179	**NET**

Figure 6-2
NOx Emissions (000 ton y^{-1})

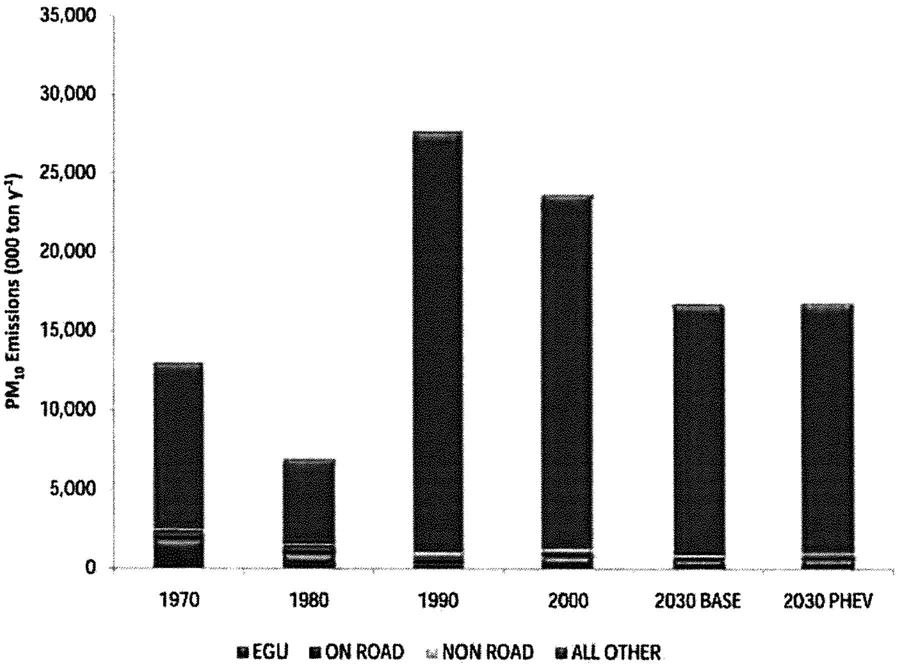
Figure 6-3 shows that total SO_2 emissions in 2030 are approximately 25% of 1970 values. PHEVs contribute to additional SO_2 emission reductions of approximately 24,000 tons.



	1970	1980	1990	2000	2030 BASE	2030 PHEV	Δ 2030 (PHEV-BASE)	
EGU	17,398	17,469	15,909	11,396	3,828	3,811	-16	
ON ROAD	273	394	503	260	44	37	-8	
NON ROAD	278	323	371	437	80	80	0	
ALL OTHER	13,269	7,739	6,293	4,254	3,911	3,911	0	
							-24	**NET**

Figure 6-3
SO_2 Emissions (000 ton y^{-1})

Figure 6-4 shows historical estimates of PM_{10} emissions and projections for the 2030 Base Case and 2030 PHEV Case. In order to best interpret Figure 6-4, it is important to understand how EPA has changed their methodology for estimating PM emissions over time. In 1990, EPA added fugitive dust, non-combustion agriculture/forestry emissions (e.g., crop- and livestock-related emissions) and agricultural fire emissions into the PM_{10} inventory. The definition for "fugitive dust" includes paved roads, unpaved roads and construction, although EPA at the moment does not estimate construction emissions for the inventory. Since 1970, the PM_{10} inventory has included combustion emissions associated with structural fires (e.g., the burning house), prescribed burns, and wildfires.



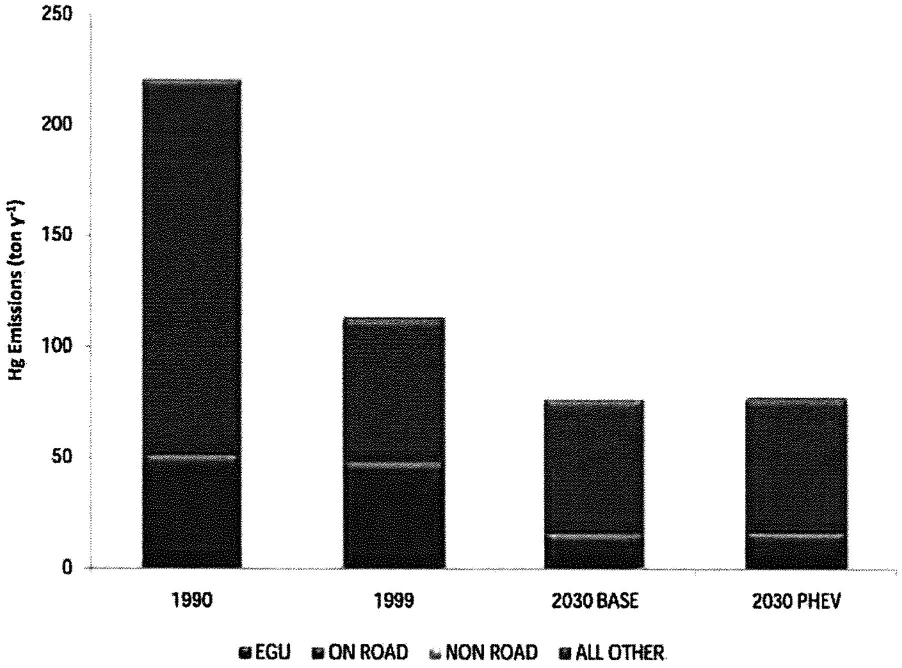
EGU	1,775	879	295	687	492	541	-49	
ON ROAD	480	432	385	230	172	163	-9	
NON ROAD	164	257	328	322	205	205	0	
ALL OTHER	10,603	5,445	26,742	22,508	15,973	15,972	-1	
							39	**NET**

Figure 6-4
PM_{10} Emissions (000 ton y^{-1})

In 2000, EPA changed the regulatory definition of **primary PM** for electricity generating units. Before 2000, the definition was specific to PM captured in filters under stack conditions; this is known as **filterable PM**. Since 2000, EPA has included the mass of particles formed when stack gases are cooled and diluted according to EPA specifications into the PM_{10} inventory for electric generating units; this is known as **condensable PM**. This is a physical definition (as in that condensation represents a phase change from a gas to a liquid or solid) and is different from **secondary PM** which is particulate matter that forms due to chemical reactions of gases in the atmosphere.

In the PHEV Case, primary emissions of particulate matter increase from electric generating units increased by 10% with the use of PHEVs since emissions of these species are regulated by performance standards (mass per unit of electricity generated) instead of regulatory caps (annual limit of emission allowances for entire sector regardless of total amount of electricity generated). However, as shown in Chapter 5 and in the next section, increases in PM emissions from the electric sector are more than offset by significant reductions in VOC and NOx emissions from the transportation sector leading to less secondary particulate matter.

Figure 6-5 shows that total Hg emissions in 2030 are approximately 35% of 1990 values, the first year of reliable estimates from EPA on man-made mercury emissions. Hg emissions increase by 370 kg in the PHEV Case. However, as shown in Chapter 5 and in the next section, PHEVs reduce the net impact of mercury deposition.



	1990	1999	2030 BASE	2030 PHEV	Δ 2030 (PHEV-BASE)	
EGU	51.05	47.91	15.87	16.24	0.37	
ON ROAD	–	–	–	–	0.00	
NON ROAD	–	–	–	–	0.00	
ALL OTHER	170.02	64.71	60.84	60.84	0.00	
					0.37	**NET**

Figure 6-5
Hg Emissions (ton y^{-1})

Summary of Air Quality Impacts

The air quality impacts of a large penetration of PHEVs are summarized in the following sections.

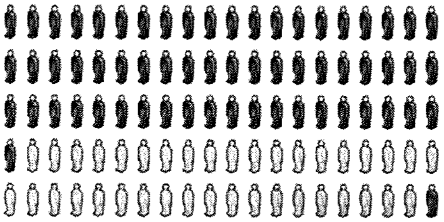
Ozone and Particulate Matter

- **PHEVs reduce ozone across the Eastern U.S. and in major urban areas.** Although the ozone reductions are modest, commonly less than 1 ppb with some regions of higher ozone reductions, population exposure calculations (based on a design-value relevant calculation) show that PHEVs reduce exposure to ozone in major urban areas. Ozone increases, also commonly less than 1 ppb, are restricted to a few areas where major power plants are located such as Eastern Texas, Western Georgia, Utah, Montana, and Western North Dakota. These increases may be attributed to greater emissions from power plants in close proximity to biogenic emission sources.
- **PHEVs reduce high 24-hour average PM concentrations** across the Eastern U.S., in California and in the Pacific Northwest due mainly to reductions in $PM_{2.5}$. These reductions are generally less than 0.5 $\mu g\ m^{-3}$ but they are consistent. Annual average $PM_{2.5}$ and PM_{10} show similar patterns of widespread, small reductions. There are some areas where PHEVs increase 24-hour and annual average $PM_{2.5}$ such as Eastern Texas and Oklahoma due to an increase in power-plant emissions.
- **Primary emissions of particulate matter (PM) increase by 10% with the use of PHEVs** due primarily to the large growth in coal generation assumed in the study.
- **In most regions, particulate matter concentrations decrease due to significant reductions in VOC and NOx emissions from the transportation sector leading to less secondary PM.** In general, increases in PM emissions from the electric sector are more than offset by significant reductions in VOC and NOx emissions from the transportation sector leading to less secondary particulate matter.
- **On a population weighted basis, the improvements in ambient air quality for ozone and particulate matter are small but numerically significant** for most of the country.

Table 6-1 provides a pictorial and numerical summary of the exposure results.

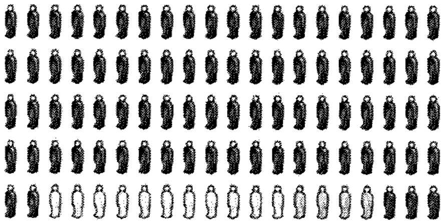
Table 6-1
Summary of Exposure Results

Ozone



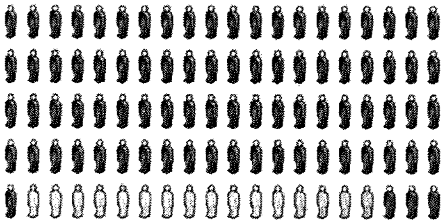
		% Population
■	Disbenefit (above Threshold)	1
▒	Disbenefit (below Threshold)	7
□	Benefit (below Threshold)	31
▓	Benefit (above Threshold)	61

Daily $PM_{2.5}$



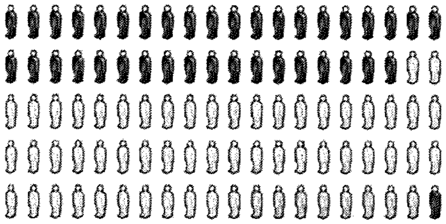
		% Population
■	Disbenefit (above Threshold)	3
▒	Disbenefit (below Threshold)	4
□	Benefit (below Threshold)	11
▓	Benefit (above Threshold)	82

Daily PM_{10}



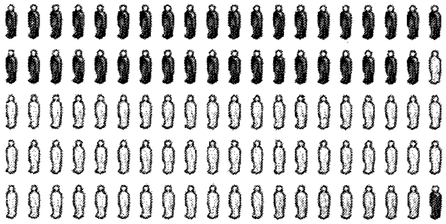
		% Population
■	Disbenefit (above Threshold)	3
▒	Disbenefit (below Threshold)	4
□	Benefit (below Threshold)	12
▓	Benefit (above Threshold)	81

Annual $PM_{2.5}$



		% Population
■	Disbenefit (above Threshold)	1
▒	Disbenefit (below Threshold)	8
□	Benefit (below Threshold)	53
▓	Benefit (above Threshold)	38

Annual PM_{10}



		% Population
■	Disbenefit (above Threshold)	1
▒	Disbenefit (below Threshold)	7
□	Benefit (below Threshold)	53
▓	Benefit (above Threshold)	39

Acid, Nutrient and Mercury Deposition

- **Changes in power-plant operations and building of new power plants change the sulfate deposition patterns in many parts of the Eastern United States.** However, the net impact of PHEVs over the entire continental United States is that of decreased sulfate deposition.
- **PHEVs reduce nitrate acid deposition in much of the Eastern United States** including the Ohio River valley. Total nitrogen deposition is reduced with PHEVs throughout the Eastern United States and near all major urban areas due to lower mobile source ammonia emissions with PHEVs.
- **There are shifts in the patterns of mercury deposition due to PHEVs,** with decreases being more widespread. Overall, despite a minor increase associated with EGU mercury emissions, mercury deposition is decreased in the U.S. Mercury deposition is influenced by both emissions and atmospheric chemistry as well. Chemical reactions cycle mercury from its elemental form to oxidized forms that can deposit more readily in rain or by contact with the Earth's surface. The lower levels of atmospheric ozone in the PHEV scenario cause more of the mercury to remain in the elemental form and thereby decrease the amount deposited on the surface.
- **Mercury emissions increase by 2.4% with increased generation needs to meet PHEV charging loads**. The study assumes that mercury is constrained by a cap-and-trade program, with the option for using banked allowances, proposed by EPA during the execution of the study. The electric sector modeling indicates that utilities take advantage of the banking provision to realize early reductions in mercury that result in greater mercury emissions at the end of the study timeframe (2030). As a result, PHEVs do not increase the U.S. contribution to the global mercury budget over the long term. Moreover, PHEVs serve to enhance the benefit of early banking by allowing the oxidant pool to have further decreased by the time these banked allowances are emitted.

Table 6-2 provides a pictorial and numerical summary of the deposition results.

Visibility

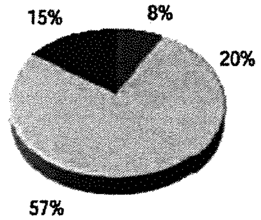
- **Visibility is improved by PHEVs at Class I areas throughout the United States.** The visibility improvements are not substantial in the Northern and Central United States but are considerable in the Eastern United States (e.g., the Appalachians) and California, especially Southern California.

Table 6-2
Summary of Deposition Results

Affected Portion of CONUS Land Area

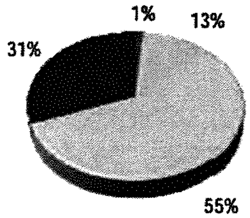
Deposition Load Changes in CONUS

Sulfate



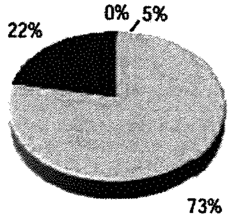
		Sulfate (ton)
■	Disbenefit (above Threshold)	23,211
▒	Disbenefit (below Threshold)	4,562
□	Benefit (below Threshold)	-12,416
▨	Benefit (above Threshold)	-41,472

Nitrate



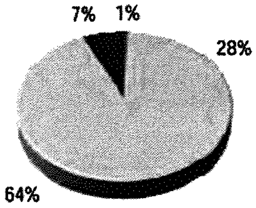
		Nitrate (ton)
■	Disbenefit (above Threshold)	1,581
▒	Disbenefit (below Threshold)	3,396
□	Benefit (below Threshold)	-20,995
▨	Benefit (above Threshold)	-45,490

Nitrogen



		Nitrogen (ton N)
■	Disbenefit (above Threshold)	0
▒	Disbenefit (below Threshold)	233
□	Benefit (below Threshold)	-22,784
▨	Benefit (above Threshold)	-32,413

Mercury



		Mercury (g)
■	Disbenefit (above Threshold)	19,712
▒	Disbenefit (below Threshold)	28,693
□	Benefit (below Threshold)	-90,202
▨	Benefit (above Threshold)	-146,370

Conclusion

In the most comprehensive environmental assessment of electric transportation to date, the Electric Power Research Institute (EPRI) and the Natural Resources Defense Council (NRDC) are examining the greenhouse gas emissions and air quality impacts of plug-in hybrid electric vehicles.

Because of the significant reduction in emissions from gasoline and diesel fuel use and because caps are in place for some conventional pollutants for the electric power sector, the study finds that in many regions deployment of PHEVs would reduce exposures to ozone and particulate matter, and reduce deposition rates for acids, nutrients, and mercury.

On the other hand, because of assuming no further controls beyond existing regulations for the power sector, ozone levels would increase locally in some areas. Similarly, the direct emissions of particulate matter and mercury would increase somewhat and some regions and populations would experience marginal increases in exposures to those pollutants. However, as explained in the key findings, PHEVs do not increase the U.S. contribution to the global mercury budget over the long term.

The air quality study is not meant to project carbon dioxide (CO_2) emissions and does not include any climate-change policies or greenhouse gas emissions constraints. As explained earlier, it is based on the U.S. Department of Energy's 2006 Annual Electric Outlook. A separate report modeled both the transportation and electricity sectors out to 2050 in order to analyze greenhouse gas emissions.

The key results of the air quality study are summarized below:

- **In most regions of the United States, PHEVs result in small but significant improvements in ambient air quality** and reduction in deposition of various pollutants such as acids, nutrients and mercury.
- **On a population weighted basis, the improvements in ambient air quality are small but numerically significant** for most of the country.
- **The emissions of gaseous criteria pollutants (NOx and SO_2) are constrained nationally by regulatory caps.** As a result, changes in total emissions of these pollutants due PHEVs reflect slight differences in allowance banking during the study's time horizon.
- **Considering the electric and transportation sector together, total emissions of VOC, NOx and SO_2 from the electric sector and transportation sector decrease due to PHEVs.** Ozone levels decreased for most regions, but increased in some local areas. When assuming a minimum detection limit of 0.25 parts per billion, modeling estimates that 61% of the population would see decreased ozone levels and 1% of the population would see increased ozone levels.
- **Mercury emissions increase by 2.4% with increased generation needs to meet PHEV charging loads.** The study assumes that mercury is constrained by a cap-and-trade program, with the option for using banked allowances, proposed by EPA during the execution of the study. The electric sector modeling indicates that utilities take advantage of the banking provision to realize early reductions in mercury that result in greater mercury emissions at the end of the study timeframe (2030).
- **Primary emissions of particulate matter (PM) increase by 10% with the use of PHEVs due primarily to the large growth in coal generation assumed in the study.**
- **In most regions, particulate matter concentrations decrease due to significant reductions in VOC and NOx emissions from the transportation sector leading to less secondary PM.**

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B2011
Unbilled KWH

		Residential Non-lighting	Residential Lighting	Small Commercial Non-lighting	Large Commercial Non-lighting	Commercial Lighting	Industrial Non-lighting	Industrial Lighting	** Street Lighting	Total Retail
2011	Jan	(3,410,040)	(12,880)	(169,108)	(1,850,944)	(63,254)	(261,855)	(508)	-	(5,768,589)
2011	Feb	(41,052,200)	(175,154)	(2,107,126)	(23,628,262)	(861,139)	(3,350,088)	(6,905)	-	(71,180,874)
2011	Mar	16,286,820	83,086	881,454	10,923,344	409,521	1,608,823	3,274	-	30,196,322
2011	Apr	15,164,125	83,993	879,773	11,626,327	414,566	1,735,303	3,308	-	29,907,395
2011	May	69,569,570	330,601	4,046,615	52,343,294	1,634,316	7,277,959	13,017	-	135,215,372
2011	Jun	28,039,434	96,873	1,471,855	17,788,510	479,468	2,277,762	3,813	-	50,157,715
2011	Jul	10,375,735	30,730	515,236	6,002,069	152,331	820,441	1,209	-	17,897,751
2011	Aug	(7,143,921)	(20,668)	(352,505)	(4,107,120)	(102,546)	(521,367)	(813)	-	(12,248,940)
2011	Sep	(55,617,549)	(174,598)	(2,863,469)	(33,916,735)	(867,315)	(4,171,049)	(6,863)	-	(97,617,578)
2011	Oct	(35,443,345)	(141,220)	(1,950,308)	(24,080,853)	(702,719)	(3,452,011)	(5,549)	-	(65,776,005)
2011	Nov	(10,334,931)	(52,830)	(595,932)	(7,753,519)	(263,066)	(1,035,542)	(2,075)	-	(20,037,895)
2011	Dec	22,379,467	101,896	1,170,233	14,264,269	508,126	1,991,400	4,000	-	40,419,391
	Annual Total	8,813,165	149,829	926,718	17,610,380	738,289	2,919,776	5,908	-	31,164,065
2012	Jan	(3,751,404)	(13,608)	(185,383)	(2,015,507)	(67,928)	(276,986)	(534)	-	(6,311,350)
2012	Feb	(44,832,839)	(177,734)	(2,292,157)	(25,545,799)	(888,080)	(3,443,270)	(6,972)	-	(77,186,851)
2012	Mar	16,906,920	82,505	909,506	11,164,185	413,337	1,598,484	3,235	-	31,078,172
2012	Apr	15,768,684	83,534	908,478	11,885,207	419,077	1,726,702	3,274	-	30,794,956
2012	May	72,297,509	331,009	4,191,682	53,749,467	1,663,263	7,296,259	12,968	-	139,542,157
2012	Jun	29,042,502	97,651	1,526,441	18,347,847	491,285	2,299,384	3,824	-	51,808,934
2012	Jul	10,923,159	31,571	543,325	6,304,923	159,086	843,620	1,236	-	18,806,920
2012	Aug	(7,102,830)	(20,047)	(350,796)	(4,070,697)	(101,108)	(505,957)	(784)	-	(12,152,219)
2012	Sep	(57,099,522)	(174,650)	(2,936,563)	(34,619,790)	(881,938)	(4,173,998)	(6,831)	-	(99,893,292)
2012	Oct	(36,669,330)	(141,788)	(2,010,657)	(24,680,466)	(717,224)	(3,466,387)	(5,543)	-	(67,691,395)
2012	Nov	(10,794,030)	(53,232)	(618,121)	(7,986,212)	(269,461)	(1,040,634)	(2,080)	-	(20,763,770)
2012	Dec	23,218,613	102,352	1,209,322	14,640,910	518,850	1,996,061	3,998	-	41,690,106
	Annual Total	7,907,432	147,563	895,077	17,174,068	739,159	2,853,278	5,791	-	29,722,368
2013	Jan	(3,814,715)	(13,437)	(186,868)	(2,037,100)	(68,189)	(272,161)	(525)	-	(6,392,995)
2013	Feb	(44,322,983)	(175,982)	(2,244,282)	(25,057,966)	(894,091)	(3,352,686)	(6,869)	-	(76,054,859)
2013	Mar	17,493,806	82,274	929,569	11,429,579	419,030	1,586,195	3,210	-	31,943,663
2013	Apr	16,346,154	83,097	927,513	12,147,540	423,818	1,709,307	3,241	-	31,640,670
2013	May	75,036,579	330,352	4,285,793	55,100,647	1,687,578	7,246,607	12,878	-	143,700,434
2013	Jun	26,411,187	85,944	1,558,317	18,823,795	499,163	2,286,958	3,803	-	49,669,167
2013	Jul	10,065,294	28,234	555,570	6,485,906	162,117	844,915	1,233	-	18,143,269
2013	Aug	(7,323,500)	(20,061)	(358,188)	(4,182,623)	(102,867)	(506,325)	(781)	-	(12,494,345)
2013	Sep	(58,978,419)	(174,861)	(3,001,794)	(35,606,721)	(897,747)	(4,177,711)	(6,805)	-	(102,844,058)
2013	Oct	(38,013,814)	(141,865)	(2,058,854)	(25,413,009)	(729,587)	(3,465,140)	(5,519)	-	(69,827,788)
2013	Nov	(11,349,893)	(53,636)	(640,104)	(8,305,837)	(276,041)	(1,048,898)	(2,086)	-	(21,676,495)
2013	Dec	23,980,395	101,444	1,232,555	15,007,674	522,841	1,979,179	3,943	-	42,828,031
	Annual Total	5,530,091	131,503	999,227	18,391,885	746,025	2,830,240	5,723	-	28,634,694
2014	Jan	(4,157,537)	(14,122)	(201,286)	(2,211,344)	(72,863)	(285,916)	(549)	-	(6,943,617)
2014	Feb	(46,091,832)	(176,389)	(2,303,368)	(25,905,895)	(911,177)	(3,361,393)	(6,850)	-	(78,756,904)
2014	Mar	18,046,845	81,529	944,104	11,672,627	422,188	1,572,762	3,165	-	32,743,220
2014	Apr	16,896,825	82,407	942,109	12,395,995	427,340	1,694,860	3,198	-	32,442,734
2014	May	77,711,278	329,699	4,367,836	56,456,941	1,712,480	7,234,404	12,788	-	147,825,426
2014	Jun	30,915,744	97,643	1,586,498	19,292,773	507,815	2,288,587	3,786	-	54,692,846
2014	Jul	11,699,016	31,956	569,923	6,700,993	166,459	849,075	1,238	-	20,018,660
2014	Aug	(7,392,650)	(19,739)	(357,782)	(4,207,712)	(102,920)	(495,773)	(765)	-	(12,577,341)
2014	Sep	(60,483,984)	(174,813)	(3,045,327)	(36,368,183)	(912,619)	(4,156,327)	(6,769)	-	(105,148,022)
2014	Oct	(38,976,160)	(141,591)	(2,086,007)	(25,910,383)	(740,442)	(3,441,586)	(5,481)	-	(71,301,650)
2014	Nov	(11,622,744)	(53,349)	(647,099)	(8,439,111)	(279,199)	(1,038,215)	(2,064)	-	(22,081,781)
2014	Dec	24,739,083	101,936	1,257,658	15,394,735	534,246	1,979,111	3,942	-	44,010,711
	Annual Total	11,283,884	145,167	1,027,259	18,871,436	751,308	2,839,589	5,639	-	34,924,282

** An unbilled adjustment is not applied to the Street Lighting class.