Supporting Information

Variability in Measured Real-World Operational Energy Use and Emission Rates of a Plug-In Hybrid Electric Vehicle

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60 pages, 26 tables, 54 figures

Table S0 Organization and Content of the Supporting Information

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Field Study Design	Study Routes (Page S3)	• Description of the routes tested with the PHEV • Schedule of the routes driven each of the eight test days
Power Demand -- Vehicle Specific Power (VSP)	Vehicle Specific Power (VSP) Modes (Page S5)	• Definition of each VSP mode
Power Demand -- Vehicle Specific Power (VSP)	Driving Cycle (Page S6)	• Distribution of Travel Time in each VSP mode for each of the eight routes
Upstream Energy Use and Emissions for Gasoline Production	Upstream Energy Use and Emissions for Gasoline Production (Page S10)	• Comparison of upstream emission factors for gasoline production and direct tailpipe emission factors
Indirect Energy Use and Emissions for Electricity Generation	Indirect Energy Use and Emissions for Electricity Generation (Page S17)	• State-by-State and U.S. national energy mix average emission factors for electricity generation

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Charge Depleting (CD) and Charge Sustaining (CS) Modes	Charge Depleting (CD) and Charge Sustaining (CS) Modes (Page S26)	• Definitions of CD and CS modes • Tables of vehicle activity, energy economy and pollutant mass emission rates for CD and CS modes • Graphs of pollutant mass emission rates for CD mode for each State depending on varying State electricity generation mix • Graphs of energy economy and pollutant mass emission rates for CS mode for each study route
Engine On and Engine Off	Engine On and Engine Off (Page S41)	• Definitions of engine "on", "startup", "shutdown", and "off" • Graphs of pollutant mass emission rates versus VSP mode for CD mode for engine on and off • Graphs of energy use and pollutant mass emission rates versus VSP mode for CS mode for engine on and off
Cold Start and Hot Stabilized Running	Cold Start and Hot Stabilized Running (Page S52)	• Definition of cold start • Graphs of traction battery discharging, fuel use, and pollutant mass emission rates versus VSP mode for cold start and hot stabilized running • Comparison of air to fuel ratio versus VSP mode between cold start and hot stabilized running • Comparison of cycle tailpipe emission and energy use rates between cold start and hot stabilized running based on average cold start cycle

Study Routes

The 2013 Toyota Prius Plug-In Hybrid was measured on eight study routes (A, B, C, D, E, 1, 2, 3)[1, 2] in Raleigh, NC and Research Triangle Park (RTP), NC area from Jan 18th to Jan 25th, 2013.[3] Figure S1 shows these routes. Routes A, B, C are between NC state and North Raleigh. Route D is between NC State and Southeast Raleigh. Route E is within NC State. Routes 1, 2, and 3 are between North Raleigh and RTP. Route A is mostly comprised of minor and major arterials, with 18% of travel distance on a limited access road. Routes B, C and D are mostly comprised of major arterials and freeways, with 50%, 44%, and 48% of travel distance on freeways, respectively. Route E is mainly comprised of minor arterials. Routes 1 and 2 are mainly comprised of freeway driving. Route 3 is comprised of minor and major arterials. Route 3 has signalized major arterials with speed limits as high as 55 mph. Table S1 shows the travel distance and percentage of travel distance on freeways for each study route.

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[1] Graver, B. M., Frey, H. C., & Choi, H. W. (2011). In-use measurement of activity, energy use, and emissions of a plug-in hybrid electric vehicle. *Environmental Science & Technology*, *45*(20), 9044-9051.

[2] Frey, H.C., Zhang, K., and Rouphail, N.M. (2008). Fuel use and emissions comparisons for alternative routes, time of day, road grade, and vehicles based on in-use measurements. *Environmental Science & Technology*, 42(7), 2483-2489.

[3] Frey, H.C., and Graver, B.M. (2013). Grid Electrified Vehicle: Performance, Design, and Environmental Impact, Chapter 9: Real-world activity, energy use, and emissions of a plug-in hybrid electric vehicle. Nova Science Publishers, NY.

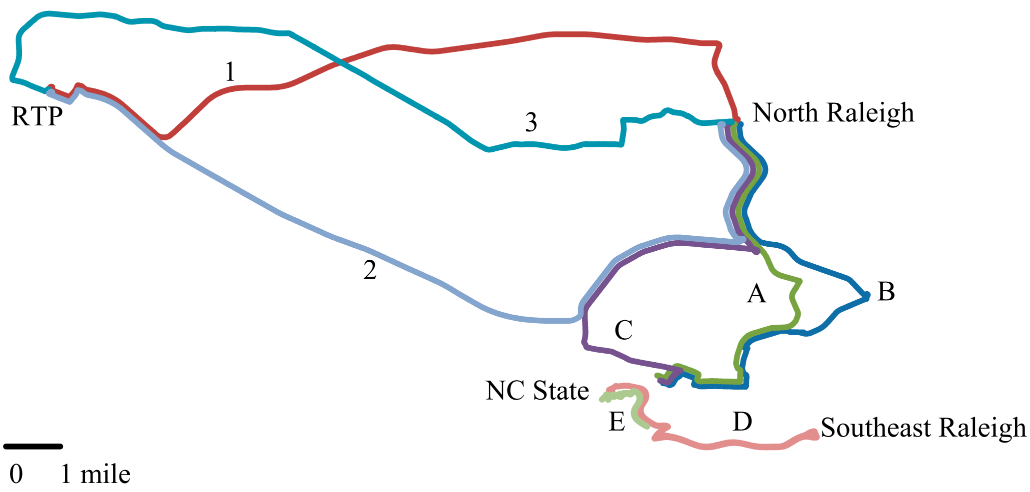

Figure S1 Map of Study Routes for Routes A, B, and C between NC State University and North Raleigh, Route D between NC State and Southeast Raleigh, Route E within NC State, and Routes 1, 2 and 3 between North Raleigh and Research Triangle Park (RTP)

Table S1 The Travel Distance and Percentage of Travel Distance on Freeways for Each Study Route

Routes	A	B	C	D	E	1	2	3
One Way Travel Distance (mile)	10.6	12.1	11.5	12.2	2.8	16.3	20.2	17.6
Percentage of Travel Distance on Freeways (%)	17.9	50.4	44.3	47.5	0	79.8	77.2	0

Table S2 The 2013 Toyota Prius Plug-In Hybrid Test Schedule

Measurement Date	Routes										
18-Jan-2013	C out	C in	D	E	A out	3 out	3 in	1 out	1 in	A in	C out	C in
19-Jan-2013	A out	1 out	1 in	A in	C out	3 out	3 in	C in	B out	B in	-	-
20-Jan-2013	A out	A in	E	D	C out	1 out	1 in	3 out	3 in	C in	-	-
21-Jan-2013	B out	1 out	1 in	B in	A out	A in	C out	3 out	3 in	C in	-	-
22-Jan-2013	B out	B in	A out	1 out	1 in	A in	C out	3 out	3 in	C in	-	-
23-Jan-2013	D	E	A out	1 out	1 in	A in	C out	3 out	3 in	C in	-	-
24-Jan-2013	C out	1 out	1 in	C in	A out	2 out	2 in	3 out	3 in	A in	-	-
25-Jan-2013	C out	1 out	1 in	2 out	2 in	-	-	-	-	-	-	-

Note: Route sequence shown is order in which routes were measured. Routes A, B, C, 1, 2, and 3 have outbound and inbound legs.

Vehicle Specific Power (VSP) Modes

On the basis of statistical analysis of in-use measurement of light duty vehicles, Frey *et al.* defined 14 vehicle specific power (VSP) modes, and developed a VSP-based modal model to estimate energy use and direct tailpipe pollutant mass emission rates for light duty vehicles.[4] Table S3 shows the definitions for 14 VSP modes. VSP values for VSP modes 1 and 2 are negative, representing deceleration or driving downhill; and VSP values for VSP modes 3 to 14 are equal to or greater than 0, representing idling (included in VSP mode 3, VSP = 0 kW/ton), steady speed driving, acceleration, or hill climbing.

Table S3 Vehicle Specific Power (VSP) Mode Definitions[1]

VSP Mode	VSP Inclusive Lower Bound (kW/ton)	VSP Exclusive Upper Bound (kW/ton)
1	-∞	-2
2	-2	0
3	0	1
4	1	4
5	4	7
6	7	10
7	10	13
8	13	16
9	16	19
10	19	23
11	23	28
12	28	33
13	33	39
14	39	∞

[4] Frey, H. C., Unal, A., Chen, J., Li, S., & Xuan, C. (2002). Methodology for developing modal emission rates for EPA's multi-scale motor vehicle & equipment emission system. *EPA420-R-02-027, US Environmental Protection Agency. Ann Arbor, MI.*

Driving Cycle

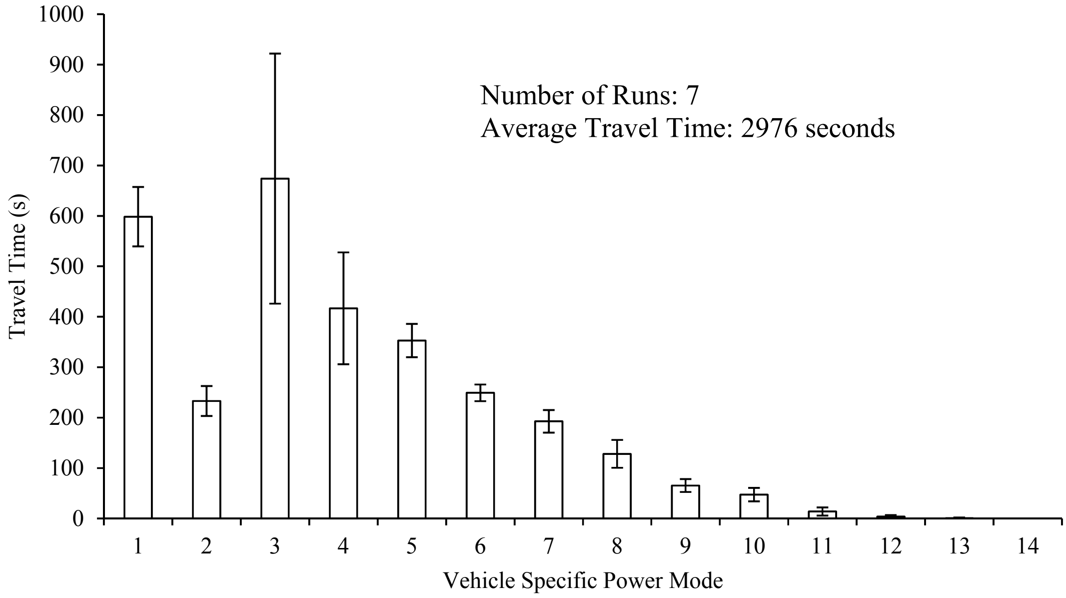

Figure S2 The Travel Time Distribution in Each Vehicle Specific Power Mode for Route A
Note: Error bars indicate 95% confidence intervals on the mean based on run-to-run variability.

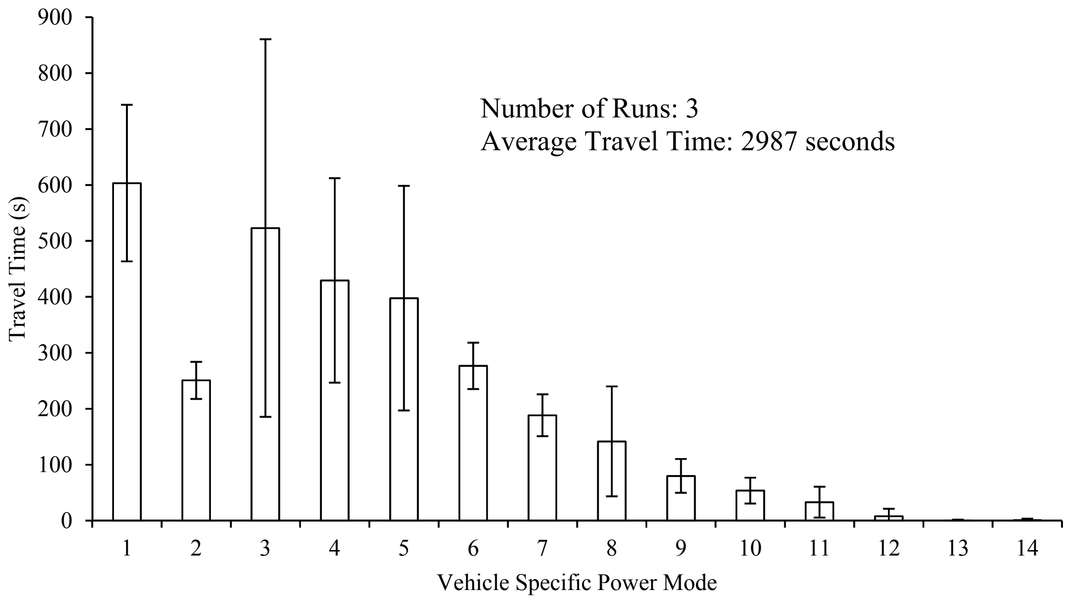

Figure S3 The Travel Time Distribution in Each Vehicle Specific Power Mode for Route B
Note: Error bars indicate 95% confidence intervals on the mean based on run-to-run variability.

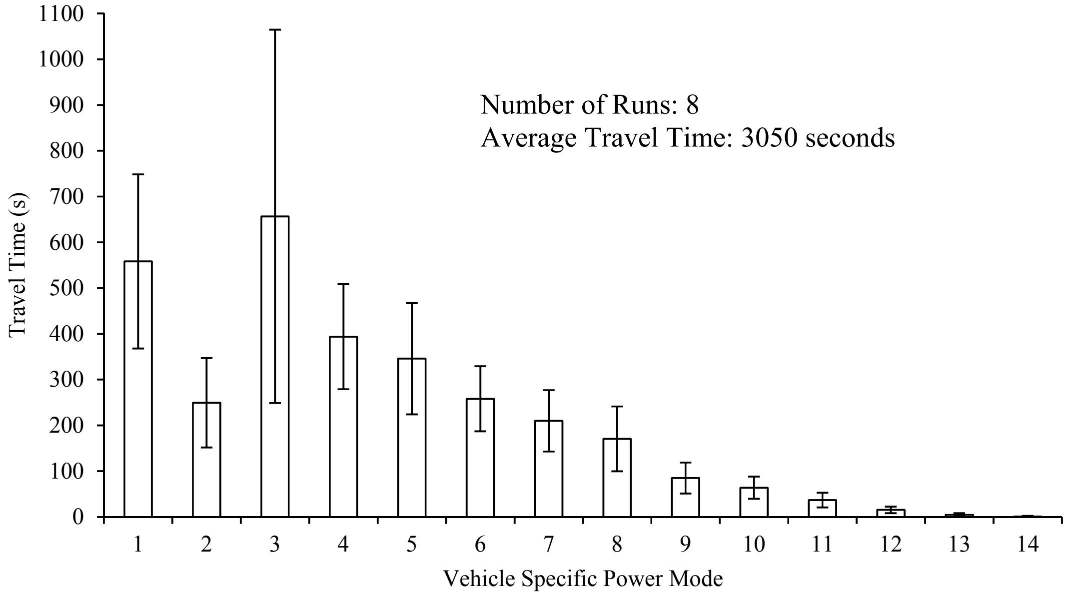

Figure S4 The Travel Time Distribution in Each Vehicle Specific Power Mode for Route C
Note: Error bars indicate 95% confidence intervals on the mean based on run-to-run variability.

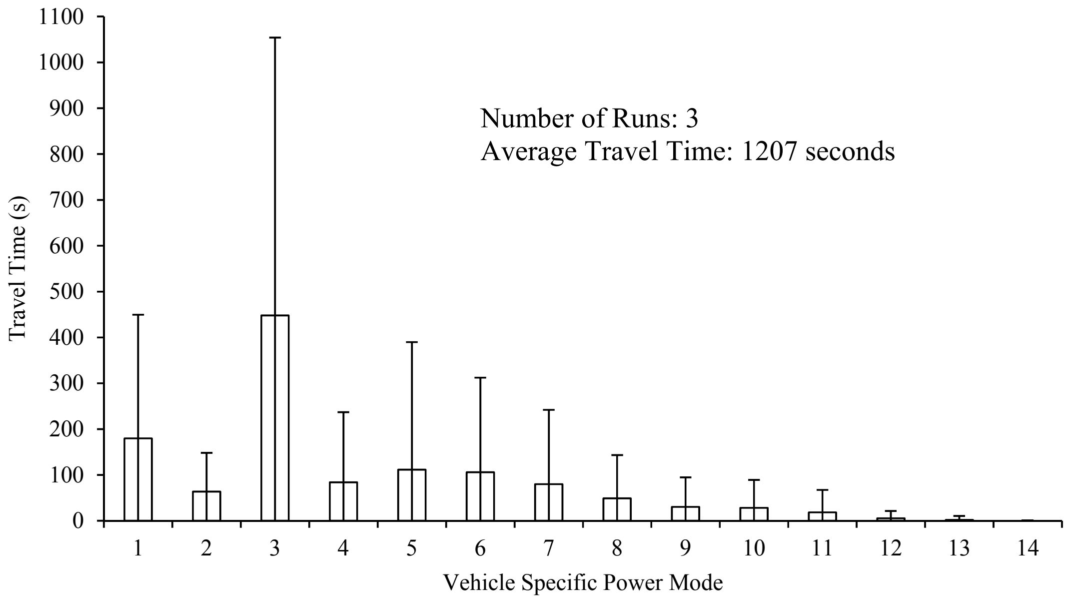

Figure S5 The Travel Time Distribution in Each Vehicle Specific Power Mode for Route D
Note: Error bars indicate 95% confidence intervals on the mean based on run-to-run variability.

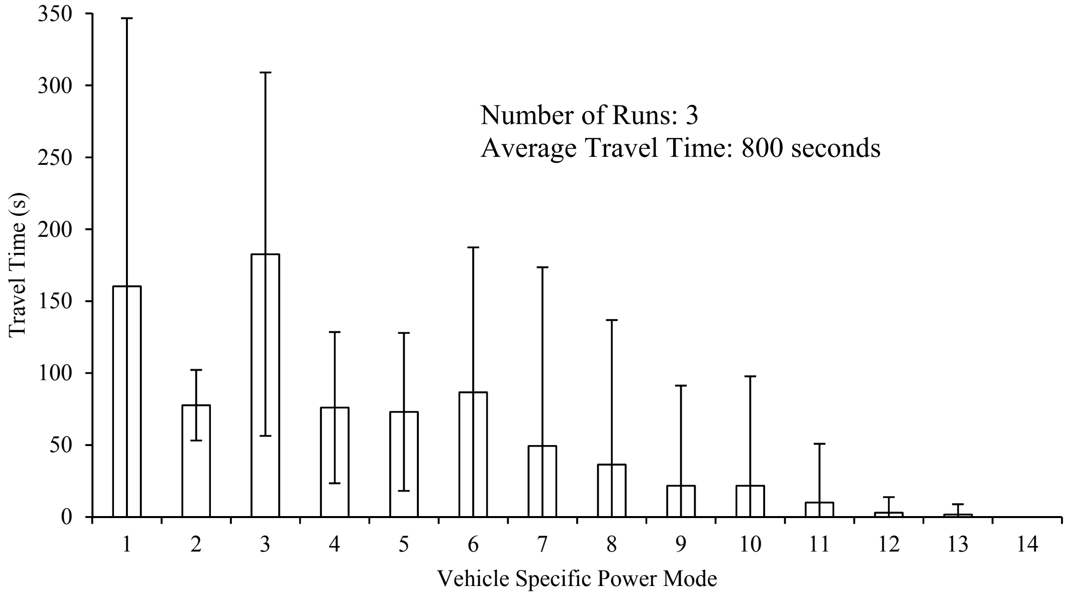

Figure S6 The Travel Time Distribution in Each Vehicle Specific Power Mode for Route E
Note: Error bars indicate 95% confidence intervals on the mean based on run-to-run variability.

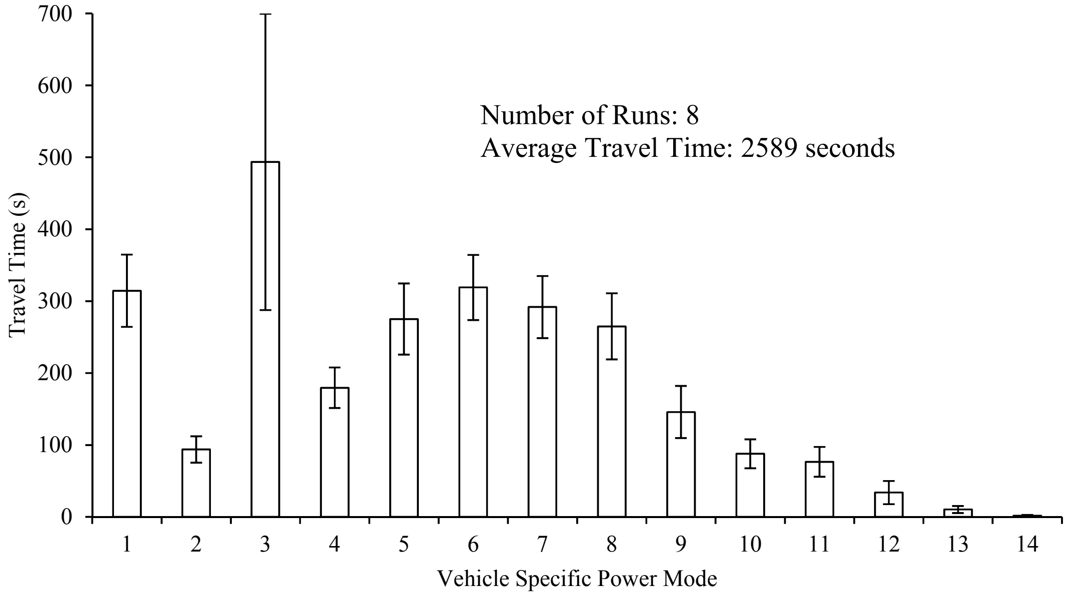

Figure S7 The Travel Time Distribution in Each Vehicle Specific Power Mode for Route 1
Note: Error bars indicate 95% confidence intervals on the mean based on run-to-run variability.

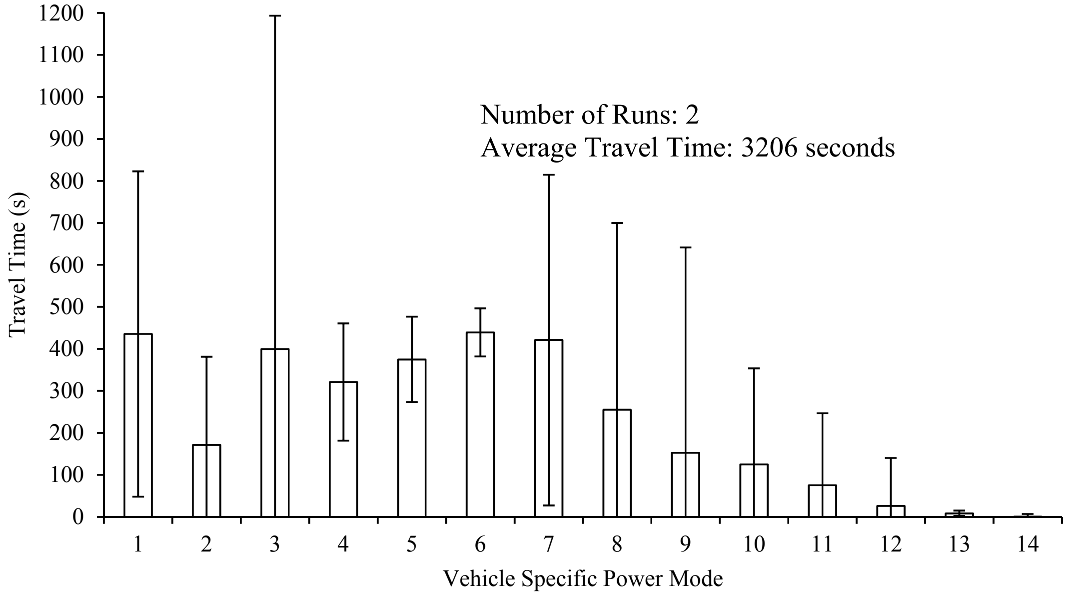

Figure S8 The Travel Time Distribution in Each Vehicle Specific Power Mode for Route 2
Note: Error bars indicate 95% confidence intervals on the mean based on run-to-run variability.

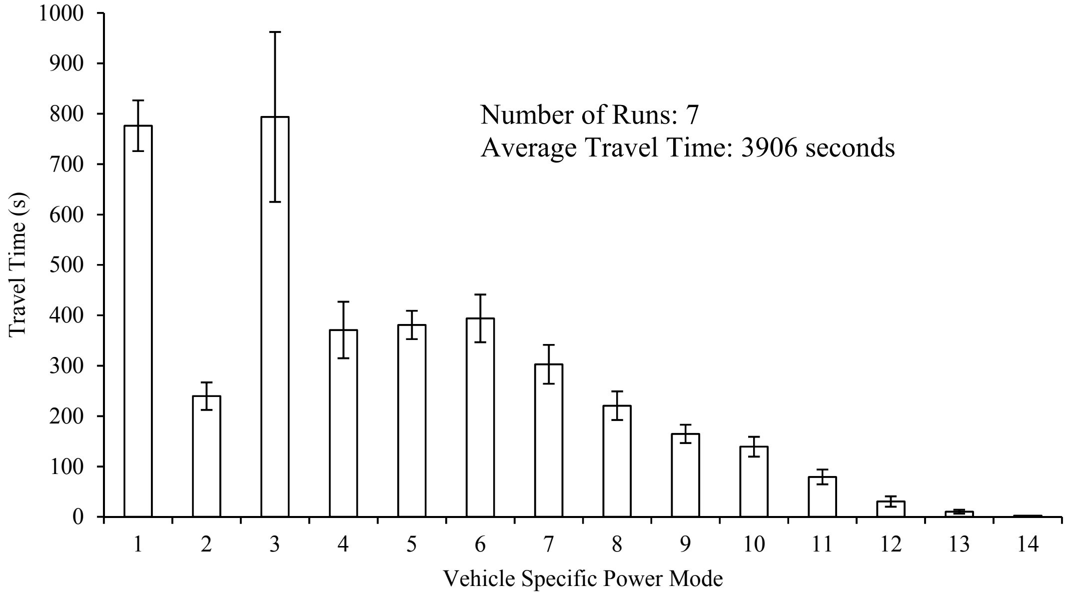

Figure S9 The Travel Time Distribution in Each Vehicle Specific Power Mode for Route 3
Note: Error bars indicate 95% confidence intervals on the mean based on run-to-run variability.

Upstream Energy Use and Emissions for Gasoline Production

Upstream energy use and emissions for gasoline production were considered in this study. Upstream energy use and emissions are from crude oil recovery and transportation, and gasoline refining, transportation and distribution. Emissions related to gasoline refining are from feed inputs, combustion, and non-combustion, such as, crude cracking (both thermal and catalytic), hydrocarbon reforming, catalyst regeneration, sulfur recovery, and blowdown systems. The feed inputs are electricity and gas use, and inputs of other feedstocks other than crude oil. Table S4 shows the fraction of energy use and emission in each gasoline production process.[5]

Based on the upstream energy use and emission factors from the Argonne National Laboratory's Greenhouse Gas, Regulated Emissions, and Energy Use in Transportation (GREET) model, the upstream energy use and emissions related to the amount of gasoline consumed during the measurement were included in the analysis of emission rates for the PHEV. The upstream energy use rate and emission factors for producing 1 gallon of gasoline are shown in Table S5, using the GREET 1 2014 model.[1] Table S5 also shows the fuel use rate and direct tailpipe emission factors from conventional vehicle (CV), hybrid electric vehicle (HEV) and plug-in hybrid electric vehicle (PHEV) from the GREET 1 2014 model.[1]

[5] ANL. (2014). The GREET spreadsheet model: greenhouse gases and regulated emissions and energy use in transportation, Version 1 2014. *Center for Transportation Research, Energy Systems Division, Argonne National Laboratory*. Argonne, IL.

Table S4 The Percentage of Energy Use and Emission in Each Gasoline Production Process

Energy Use and Emission	Crude Oil		Gasoline				
	Recovery (%)	Transportation to U.S. Refineries (%)	Refining: Feed Inputs[a] (%)	Refining: Combustion (%)	Refining: Non-Combustion[b] (%)	Transportation (%)	Distribution (%)
Energy	13.1	9.2	73.7	0.0	0.0	3.1	0.8
CO_2	12.0	10.9	22.7	47.6	2.8	3.2	0.9
CO	23.6	7.9	28.5	29.0	6.3	3.9	0.8
VOC	7.4	4.0	37.2	4.9	43.1	2.6	0.8
NO_x	15.7	27.2	25.1	19.9	3.2	7.9	0.9
SO_x	4.4	23.6	20.8	34.8	12.5	3.8	0.1
$PM_{2.5}$	7.3	29.3	23.6	29.2	5.3	5.1	0.2
PM_{10}	6.9	24.0	25.4	29.4	9.0	5.1	0.2

Source: ANL. (2014). The GREET spreadsheet model: greenhouse gases and regulated emissions and energy use in transportation, Version 1 2014. Center for Transportation Research, Energy Systems Division, Argonne National Laboratory.

Note:

a. *The feed inputs are electricity and gas use, and inputs of other feedstocks other than crude oil.*
b. *Non-combustion process includes crude cracking (both thermal and catalytic), hydrocarbon reforming, catalyst regeneration, sulfur recovery, and blowdown systems.*

Table S5 The Energy Use Rate and Upstream Emission Factors for Gasoline Production, and Fuel Use Rate and Direct Tailpipe Emission Factors for Model Year 2010 Conventional Vehicle, Hybrid Electric Vehicle, and Plug-In Hybrid Electric Vehicle

Stage	Vehicle Type	Energy Use Rates[a] (gallon/gallon)	Emission Factors (g/gallon)						
			CO_2	CO	VOC	NO_x	SO_x	$PM_{2.5}$	PM_{10}
Upstream Gasoline Production[b]	--	0.30	1.61×10^3	2.79	3.40	5.98	4.73	0.42	0.59
Vehicle Operation	Conventional Vehicle[c]	1.00	8.48×10^3	71.09	4.22	2.99	0.13	0.29	0.64
	Hybrid Electric Vehicle[d]	1.00	8.44×10^3	99.53	4.18	3.52	0.13	0.41	0.89
	Plug-In Hybrid Electric Vehicle for Charge Depleting Mode[d]	1.00	8.49×10^3	71.09	2.98	2.51	0.13	0.18	0.19
	Plug-In Hybrid Electric Vehicle for Charge Sustaining Mode[d]	1.00	8.47×10^3	78.99	3.31	2.79	0.13	0.32	0.71

Source: ANL. (2014). The GREET spreadsheet model: greenhouse gases and regulated emissions and energy use in transportation, Version 1 2014. Center for Transportation Research, Energy Systems Division, Argonne National Laboratory.

Note:

a. *For upstream gasoline production, value shown is the energy equivalent amount of gasoline with 10.3% by weight ethanol. For vehicle, value shown is one gallon of consumed fuel.*

b. *Gasoline in GREET model contains 10.3% by weight ethanol, and 82.8% by weight carbon. Its lower heating value is 112,194 Btu/gallon, and its density is 2,836 g/gallon.*[6]

c. *For conventional vehicle, the model year based vehicle tailpipe emission factors in GREET model are based on the EPA mobile-source emission factor model, the Motor Vehicle Emission Simulator (MOVES2010b), using the "default" input database to calculate the U.S. lifetime mileage-weighted average emission factors of a model year vehicle over the calendar years of the vehicle's lifetime.*[7]

d. *For HEV and PHEV, the model year based vehicle tailpipe emission factors in GREET model are calculated with the estimated emission change rates and baseline conventional vehicle tailpipe*

[6] ANL. (2014). The GREET spreadsheet model: greenhouse gases and regulated emissions and energy use in transportation, Version 1 2014. *Center for Transportation Research, Energy Systems Division, Argonne National Laboratory*. Argonne, IL.

[7] Cai, H., Burnham, A., & Wang, M. (2013). Updated emission factors of air pollutants from vehicle operations in GREET using MOVES. *Systems Assessment Section. Energy Systems Division. Argonne National Laboratory*. Argonne, IL.

emission factors. The emission change rates relative to the conventional vehicle are estimated with testing results or engineering analysis.[8]

Table S6 The Direct Fuel Economy and Tailpipe Emission Factors for Eighteen Conventional Vehicles Based on Previous On-Road Real-World Measurement on Routes A, C, 1 and 3

Model	Model Year	Measurement Date	Fuel Economy mpg	CO_2 (g/gallon)	CO (g/gallon)	HC (g/gallon)	NO_x (g/gallon)
Honda	2005	7-Feb-2013	31.4	8.71×10^3	80.57	0.40	4.01
Toyota	2005	20-Jan-2012	25.3	8.84×10^3	3.08	0.19	4.51
Toyota	2005	8-Feb-2013	35.2	8.84×10^3	1.08	0.49	3.88
Toyota	2005	7-Feb-2015	29.8	8.84×10^3	0.87	0.35	0.67
Honda	2006	6-Feb-2011	26.4	8.83×10^3	0.68	2.66	0.40
Honda	2006	11-Sep-2011	23.1	8.83×10^3	6.11	2.40	0.55
Toyota	2006	18-Oct-2010	28.7	8.83×10^3	0.33	3.10	0.84
Honda	2007	16-Sep-2011	25.8	8.82×10^3	13.75	1.63	0.68
Honda	2007	5-Apr-2009	28.1	8.82×10^3	5.50	4.54	0.26
Honda	2007	6-Nov-2009	30.5	8.82×10^3	7.89	1.70	0.92
Honda	2007	11-Feb-2015	29.2	8.83×10^3	5.37	0.47	1.10
Honda	2008	25-Oct-2008	29.8	8.84×10^3	2.18	0.85	0.60
Honda	2008	10-Sep-2011	31.6	8.83×10^3	2.92	3.28	1.03
Honda	2009	25-Sep-2014	28.5	8.82×10^3	15.51	0.80	2.18
Honda	2009	18-Oct-2014	29.8	8.83×10^3	6.08	0.46	2.10
Toyota	2011	20-Dec-2011	27.7	8.84×10^3	3.66	0.09	0.44
Honda	2012	14-Oct-2014	24.3	8.83×10^3	9.55	0.38	1.25
Toyota	2012	1-Oct-2012	29.7	8.83×10^3	4.11	2.62	0.50
Mean			28.6	8.82×10^3	9.40	1.47	1.44
Standard Deviation			2.9	0.03×10^3	18.27	1.33	1.35
95% Confidence Interval Lower Bound on the mean			27.2	8.81×10^3	0.32	0.81	0.77
95% Confidence Interval Upper Bound on the mean			30.1	8.84×10^3	18.49	2.13	2.11

Source: The previous measurement was conducted by H. Christopher Frey, the Department of Civil, Construction, & Environmental Engineering, North Carolina State University.[9, 10, 11, 12, 13]

[8] Wang, M. (2003). Well-to-wheels energy and emission impacts of vehicle/fuel systems. *California Air Resources Board*. Sacramento , CA.

[9] Frey, H. C., Zhang, K., & Rouphail, N. M. (2008). Fuel use and emissions comparisons for alternative routes, time of day, road grade, and vehicles based on in-use measurements. *Environmental Science & Technology*, *42*(7), 2483-2489.

[10] Frey, H. C., Sandhu, G. S., Sun, Y., Lee, T., Swidan, H., Liu, B., & Babaee, S. (2011, June). Incorporating vehicle portable emissions measurement systems into the classroom. *104th Annual Meeting of the Air & Waste Management Association, Orlando, FL.*

[11] Frey, H. C., Yazdani-Boroujeni, B., Hu, J., Liu, B., & Jiao, W. (2013, June). Field Measurements of 1996 to 2013 Model Year Light Duty Gasoline Vehicles. *106th Annual Conference, Air & Waste Management Association, Chicago, IL.*

[12] Sandhu, G. S., & Frey, H. C. (2013). Effects of errors on vehicle emission rates from portable emissions measurement systems. *Transportation Research Record*, *2340*(1), 10-19.

[13] Boroujeni, B. Y., & Frey, H. C. (2014). Road grade quantification based on global positioning system data obtained from real-world vehicle fuel use and emissions measurements. *Atmospheric Environment*, *85*, 179-186.

Note: Gasoline used in the analysis contains 86.4% by weight carbon, and 13.6% by weight hydrogen. Its lower heating value is 113,602 Btu/gallon,[14] and its density is 2,791 g/gallon.

Table S7 The Direct Tailpipe Emission Factors for Three Hybrid Electric Vehicles Based on Previous On-Road Real-World Measurement on Routes A, C, 1 and 3

Model	Model Year	Measurement Date	CO_2 (g/gallon)	CO (g/gallon)	HC (g/gallon)	NO_x (g/gallon)
Honda Civic Hybrid	2006	28-Oct-2010	8.80×10^3	21.65	3.01	0.13
Toyota Prius Hybrid	2006	1-Nov-2010	8.83×10^3	1.72	3.26	2.73
Honda Insight Hybrid	2012	11-Oct-2012	8.83×10^3	1.12	3.06	0.24
Mean			8.82×10^3	8.16	3.11	1.03
Standard Deviation			0.02×10^3	11.68	0.13	1.47
Minimum			8.80×10^3	1.12	3.01	0.13
Maximum			8.83×10^3	21.65	3.26	2.73

Source: The previous measurement was conducted by H. Christopher Frey, the Department of Civil, Construction, & Environmental Engineering, North Carolina State University.[15, 16, 17, 18, 19]
Note: Gasoline used in the analysis contains 86.4% by weight carbon, and 13.6% by weight hydrogen. Its lower heating value is 113,602 Btu/gallon,[20] and its density is 2,791 g/gallon.

[14] DOE. (2015). Hydrogen Analysis Resource Center, Lower and Higher Heating Values of Fuels. U.S. Department of Energy, Energy Efficiency & Renewable Energy. Washington, D.C.. See http://hydrogen.pnl.gov/cocoon/morf/hydrogen/site_specific/fuel_heating_calculator (accessed March 30, 2015).

[15] Frey, H. C., Zhang, K., & Rouphail, N. M. (2008). Fuel use and emissions comparisons for alternative routes, time of day, road grade, and vehicles based on in-use measurements. *Environmental Science & Technology*, *42*(7), 2483-2489.

[16] Frey, H. C., Sandhu, G. S., Sun, Y., Lee, T., Swidan, H., Liu, B., & Babaee, S. (2011, June). Incorporating vehicle portable emissions measurement systems into the classroom. *104th Annual Meeting of the Air & Waste Management Association, Orlando, FL.*

[17] Frey, H. C., Yazdani-Boroujeni, B., Hu, J., Liu, B., & Jiao, W. (2013, June). Field Measurements of 1996 to 2013 Model Year Light Duty Gasoline Vehicles. *106th Annual Conference, Air & Waste Management Association, Chicago, IL.*

[18] Sandhu, G. S., & Frey, H. C. (2013). Effects of errors on vehicle emission rates from portable emissions measurement systems. *Transportation Research Record*, *2340*(1), 10-19.

[19] Boroujeni, B. Y., & Frey, H. C. (2014). Road grade quantification based on global positioning system data obtained from real-world vehicle fuel use and emissions measurements. *Atmospheric Environment*, *85*, 179-186.

[20] DOE. (2015). Hydrogen Analysis Resource Center, Lower and Higher Heating Values of Fuels. U.S. Department of Energy, Energy Efficiency & Renewable Energy. Washington, D.C.. See http://hydrogen.pnl.gov/cocoon/morf/hydrogen/site_specific/fuel_heating_calculator (accessed March 30, 2015).

Table S8 The Direct Tailpipe Emission Factors for the 2013 Toyota Plug-In Hybrid Electric Vehicle Based on On-Road Real-World Eight Days of Measurement Conducted for This Study

Measurement Date	Mode	CO_2 (g/gallon)	CO (g/gallon)	HC (g/gallon)	NO_x (g/gallon)
18-Jan-2013	CD	--	--	--	--
	CS	8.84×10^3	0.22	2.49	1.57
19-Jan-2013	CD	--	--	--	--
	CS	8.84×10^3	0.47	0.48	2.02
20-Jan-2013	CD	8.76×10^3	13.96	0.26	0.20
	CS	8.84×10^3	0.45	0.17	6.71
21-Jan-2013	CD	8.82×10^3	4.45	0.34	0.36
	CS	8.84×10^3	0.52	0.38	1.95
22-Jan-2013	CD	8.83×10^3	1.33	1.60	0.12
	CS	8.84×10^3	0.17	2.08	0.69
23-Jan-2013	CD	8.82×10^3	1.68	1.52	0.31
	CS	8.84×10^3	0.33	1.19	0.89
24-Jan-2013	CD	8.82×10^3	2.51	0.85	0.03
	CS	8.84×10^3	0.15	2.24	1.53
25-Jan-2013	CD	8.83×10^3	1.61	1.33	0.94
	CS	8.84×10^3	0.83	0.27	3.39
Mean	CD	8.81×10^3	4.26	0.98	0.33
Standard Deviation		25.35	4.88	0.59	0.32
95% Confidence Interval Lower Bound on the mean		8.79×10^3	1.70	0.37	0.21
95% Confidence Interval Upper Bound on the mean		8.84×10^3	7.95	1.60	0.46
Mean	CS	8.84×10^3	0.39	1.16	2.34
Standard Deviation		0.91	0.23	0.97	1.95
95% Confidence Interval Lower Bound on the mean		8.84×10^3	0.20	0.35	0.72
95% Confidence Interval Upper Bound on the mean		8.84×10^3	0.58	1.98	3.97

Note: Gasoline used in the analysis contains 86.4% by weight carbon, and 13.6% by weight hydrogen. Its lower heating value is 113,602 Btu/gallon,[21] *and its density is 2,791 g/gallon.*

[21] DOE. (2015). Hydrogen Analysis Resource Center, Lower and Higher Heating Values of Fuels. U.S. Department of Energy, Energy Efficiency & Renewable Energy. Washington, D.C.. See http://hydrogen.pnl.gov/cocoon/morf/hydrogen/site_specific/fuel_heating_calculator (accessed March 30, 2015).

Indirect Energy Use and Emissions for Electricity Generation

Indirect energy use and emissions for electricity generation were considered in this study, including upstream energy use and emissions related to feedstock recovery/production and transportation, and heat input and emissions for generating electricity at power plants. Grid-related emission rates vary depending on electricity generation resource mix. Table S9 shows the percentage of energy resource for electricity generation for year 2011 the state-by-state and U.S. national energy mix. The upstream energy use and emissions related to feedstock recovery/production and transportation for electricity generation for year 2011 the state-by-state and U.S. national energy mix, were shown in Table S10, based on GREET 1 2014 model using Table S9 as input data.[22]

The energy use rates for generating electricity at power plants were estimated from the fuel consumption for electricity generation and net electricity generation data reported by the U.S. Energy Information Administration (EIA)[23]. The Emission factors for generating electricity at power plants were estimated from emission inventory data for electricity generation from each major fuel source (e.g. coal, oil, natural gas, and biomass) reported by EPA[24, 25], and net electricity generation data reported by the U.S. Energy Information Administration (EIA)[26]. Table S11 shows the energy use and emission factors for generating electricity at power plants for year 2011 the state-by-state and U.S. national energy mix. Table S12 shows the total energy use and emission factors for electricity generation for year 2011 the state-by-state and U.S. national energy mix, which include the upstream energy use and emissions related to feedstock recovery/production and transportation (Table S10), and the energy use and emissions for generating electricity at power plants (Table S11).

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[22] ANL. (2014). The GREET spreadsheet model: greenhouse gases and regulated emissions and energy use in transportation, Version 1 2014. *Center for Transportation Research, Energy Systems Division, Argonne National Laboratory*. Argonne, IL.

[23] EIA. (2015). Annual Electric Utility Data – EIA-906/920/923 Data File. *2011: EIA-923*. U.S. Energy Information Administration. See http://www.eia.gov/electricity/data/eia923/ (accessed May 2015).

[24] EPA. (2015). The 2011 National Emissions Inventory. U.S. Environmental Protection of Agency. See http://www.epa.gov/ttnchie1/net/2011inventory.html (accessed Mar 2015).

[25] EPA. (2015). State Energy CO_2 Emissions. *State CO_2 Emissions from Fossil Fuel Combustion, 1990-2012*. U.S. Environmental Protection of Agency. See http://epa.gov/statelocalclimate/resources/state_energyco2inv.html (accessed Mar 2015).

[26] EIA. (2015). Electric Power Detailed State Data. *Net Generation by State by Type of Producer by Energy Source*. U.S. Energy Information Administration. See http://www.eia.gov/electricity/data/state/ (accessed Mar 2015).

Table S9 The Percentage of Energy Resource for Electricity Generation for Year 2011 the State-by-State and U.S. National Energy Mix

State	Energy Resource						
	Coal (%)	Petroleum (%)	Gas (%)	Nuclear (%)	Water (%)	Wind (%)	Biomass (%)
AK	9.6	13.8	56.9	0.0	19.6	0.2	0.0
AL	36.3	0.1	30.7	25.2	5.7	0.0	1.8
AR	48.0	0.1	21.1	23.2	4.8	0.0	2.7
AZ	40.4	0.0	21.5	28.9	8.5	0.2	0.2
CA	1.0	0.5	45.1	18.3	21.2	3.9	3.0
CO	66.0	0.0	19.8	0.0	4.0	10.1	0.1
CT	1.6	0.5	45.0	47.2	1.7	0.0	2.0
DC	0.0	64.6	35.4	0.0	0.0	0.0	0.0
DE	22.1	0.6	75.0	0.0	0.0	0.1	2.2
FL	23.4	1.5	61.5	9.9	0.1	0.0	2.0
GA	48.2	0.4	21.3	25.9	2.2	0.0	2.6
HI	13.3	73.9	0.3	0.0	0.9	3.2	2.9
IA	67.8	0.3	1.8	9.3	1.6	19.0	0.3
ID	0.5	0.0	6.7	0.0	80.9	7.9	3.2
IL	45.1	0.0	3.1	48.0	0.1	3.1	0.3
IN	85.3	1.1	10.0	0.0	0.3	2.7	0.3
KS	69.8	0.1	5.6	16.1	0.0	8.2	0.1
KY	93.2	1.8	1.6	0.0	3.0	0.0	0.4
LA	23.3	4.5	52.7	15.8	1.0	0.0	2.3
MA	10.7	0.5	68.2	13.4	3.0	0.2	3.0
MD	50.4	0.5	5.9	34.4	6.1	0.6	1.3
ME	0.3	1.1	43.1	0.0	24.9	4.4	23.7
MI	54.0	0.3	12.1	30.1	1.2	0.4	2.3
MN	53.2	0.1	6.3	22.5	1.4	12.7	3.2
MO	82.5	0.1	4.8	9.9	1.2	1.2	0.1
MS	18.9	0.1	58.1	20.0	0.0	0.0	2.9
MT	50.0	1.5	1.4	0.0	41.8	4.2	0.0
NC	50.5	0.2	9.4	34.2	3.3	0.0	2.0
ND	77.3	0.1	0.2	0.0	7.4	14.9	0.0
NE	71.9	0.1	1.2	19.2	4.5	2.9	0.2
NH	11.0	0.4	33.2	41.7	8.0	0.3	5.1
NJ	6.4	0.3	39.2	51.9	0.0	0.0	1.4
NM	71.1	0.1	22.4	0.0	0.5	5.5	0.0
NV	16.9	0.0	68.4	0.0	6.9	0.0	0.0
NY	6.9	0.9	37.0	31.1	20.4	2.1	1.5
OH	77.7	1.0	9.3	11.0	0.3	0.1	0.5

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Table S9 Continued

OK	46.2	0.0	44.0	0.0	2.0	7.5	0.4
OR	5.6	0.0	14.2	0.0	70.9	8.0	1.2
PA	44.3	0.2	18.7	33.5	1.4	0.8	1.0
RI	0.0	0.2	98.3	0.0	0.1	0.0	1.5
SC	33.2	0.1	12.6	51.4	1.5	0.0	2.1
SD	21.5	0.1	1.1	0.0	55.1	22.2	0.0
TN	50.3	0.2	4.0	33.2	11.8	0.1	1.2
TX	36.3	0.2	46.8	9.1	0.1	7.0	0.4
UT	81.1	0.1	13.0	0.0	3.0	1.4	0.1
VA	29.8	0.8	27.5	38.3	1.8	0.0	3.3
VT	0.0	0.1	0.0	72.4	21.0	0.5	5.9
WA	4.5	0.0	4.5	4.2	79.7	5.4	1.5
WI	63.1	0.9	9.9	18.3	3.4	1.9	2.5
WV	96.2	0.2	0.4	0.0	1.8	1.4	0.0
WY	86.0	0.1	1.5	0.0	2.6	9.7	0.0
U.S.	42.3	0.7	25.0	19.3	7.8	2.9	1.4

Source: EIA. (2015). Electric Power Detailed State Data. Net Generation by State by Type of Producer by Energy Source. U.S. Energy Information Administration. See http://www.eia.gov/electricity/data/state/ (accessed *May 2015).*

Table S10 The Upstream Energy Use and Emission Factors Related to Feedstock Recovery/Production and Transportation for Electricity Generation for Year 2011 the State-by-State and U.S. National Energy Mix, Based on GREET 1 2014 Model Using Table S9 as Input Data[27]

State	Energy Use (Btu/kWh)	CO_2 (g/kWh)	CO (mg/kWh)	VOC (mg/kWh)	NO_x (mg/kWh)	SO_x (mg/kWh)	$PM_{2.5}$ (mg/kWh)	PM_{10} (mg/kWh)
AK	695	45.0	134.1	56.6	222.2	104.0	7.5	15.8
AL	371	25.2	77.7	51.8	143.9	63.8	8.1	36.9
AR	334	23.5	65.2	54.8	142.1	65.3	10.0	48.0
AZ	306	21.2	60.3	48.6	126.3	59.3	8.1	39.9
CA	386	24.0	91.6	33.4	120.2	43.1	2.6	3.8
CO	313	22.8	63.0	67.0	158.3	70.5	11.8	63.3
CT	422	25.6	95.3	34.6	124.8	44.4	2.9	4.5
DC	1,512	101.5	180.0	70.5	472.3	323.4	21.4	25.2
DE	643	42.4	152.9	70.4	224.0	89.2	7.0	24.6
FL	576	38.0	131.1	63.2	200.3	82.4	7.2	26.0
GA	346	24.4	66.5	55.4	145.3	67.8	10.3	48.5
HI	1,488	101.7	140.7	64.1	482.3	367.9	28.7	44.9
IA	201	15.6	31.7	56.5	121.3	58.0	11.7	64.7
ID	67	4.4	15.5	5.6	22.3	6.7	0.7	1.1
IL	207	14.9	30.2	40.4	94.8	51.3	8.7	44.4
IN	313	24.1	54.3	76.6	173.5	79.6	15.2	81.9
KS	246	19.0	40.3	60.9	135.5	66.3	12.4	67.1
KY	284	22.6	42.9	77.7	170.3	79.4	16.5	89.5
LA	575	37.9	121.2	59.4	196.3	85.3	8.0	26.9
MA	586	37.8	138.7	57.1	192.2	73.5	5.2	14.0
MD	239	17.4	37.9	46.6	111.8	57.3	9.9	49.8
ME	481	31.2	107.8	35.5	151.3	45.1	6.2	7.6
MI	295	21.4	51.6	53.8	133.1	65.1	11.0	53.7
MN	234	17.1	39.6	48.8	115.4	55.0	10.4	52.4
MO	264	20.9	42.8	70.4	153.6	73.2	14.4	79.1
MS	534	34.8	123.3	56.7	181.1	71.8	6.3	21.5
MT	154	11.4	24.5	42.4	92.9	43.9	8.7	47.6
NC	265	19.1	44.9	49.0	120.0	59.7	10.2	50.2
ND	193	15.3	30.6	62.6	129.6	59.0	12.9	73.1
NE	223	17.7	33.2	59.8	129.4	64.9	12.7	69.2

[27] ANL. (2014). The GREET spreadsheet model: greenhouse gases and regulated emissions and energy use in transportation, Version 1 2014. *Center for Transportation Research, Energy Systems Division, Argonne National Laboratory*. Argonne, IL.

NH	370	22.9	80.0	34.5	117.0	44.2	5.1	14.4
NJ	389	23.7	85.6	34.3	117.8	44.0	3.3	8.7
NM	349	25.6	70.0	72.9	173.7	77.6	12.8	68.4

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Table S10 Continued

NV	553	36.1	134.8	60.8	192.4	76.2	5.2	18.6
NY	355	22.0	79.4	32.9	112.3	43.2	3.3	8.9
OH	309	23.7	51.8	70.4	162.5	78.2	14.3	75.3
OK	448	30.7	101.0	67.8	183.9	78.6	9.4	45.6
OR	122	7.9	29.7	14.5	45.0	17.1	1.5	5.9
PA	311	21.8	58.5	50.2	129.7	62.3	9.1	44.1
RI	749	48.1	186.5	68.2	239.2	88.2	3.7	4.1
SC	264	17.6	46.5	37.7	101.0	49.1	7.5	34.1
SD	57	4.0	10.4	18.2	37.7	17.3	3.5	20.1
TN	216	15.8	33.5	45.0	104.9	53.8	9.6	49.3
TX	462	31.2	104.1	62.1	177.0	75.7	8.0	36.6
UT	305	23.2	56.4	74.6	168.2	75.8	14.2	77.6
VA	372	24.6	74.5	45.6	134.2	59.7	7.8	31.8
VT	116	4.0	18.0	3.4	22.3	2.1	2.6	3.4
WA	56	3.5	12.0	7.2	21.4	7.8	1.1	4.6
WI	295	21.9	50.4	59.6	143.5	69.1	12.4	62.2
WV	251	20.4	38.7	78.0	163.6	74.3	16.4	91.4
WY	228	18.2	36.6	70.5	148.0	67.2	14.5	81.6
U.S.	343	23.7	69.0	52.9	141.4	64.5	8.9	42.3

Table S11 The Energy Use and Emission Factors for Generating Electricity at Power Plants for Year 2011 the State-by-State and U.S. National Energy Mix

State	Energy Use (Btu/kWh)	CO_2 (g/kWh)	CO (mg/kWh)	VOC (mg/kWh)	NO_x (mg/kWh)	SO_x (mg/kWh)	$PM_{2.5}$ (mg/kWh)	PM_{10} (mg/kWh)
AK	10,601	459.5	659.5	110.1	3020.0	404.1	104.6	117.7
AL	9,448	464.2	58.2	6.7	358.3	1040.6	28.4	42.7
AR	9,682	553.4	73.3	6.5	480.4	867.5	14.5	32.7
AZ	9,791	479.0	83.7	4.0	297.3	221.3	18.1	19.5
CA	8,979	181.2	56.7	7.1	35.7	8.3	9.1	10.1
CO	10,077	745.7	287.9	13.1	926.8	789.3	16.1	21.7
CT	9,463	194.3	15.1	2.2	34.3	24.8	6.3	7.3
DC	13,304	860.4	0.7	0.1	1107.7	3295.1	1.7	2.4
DE	9,558	576.3	109.0	12.9	501.6	1287.4	108.1	108.2
FL	8,877	491.7	148.6	7.9	282.3	388.7	39.5	47.8
GA	9,616	532.7	98.5	8.7	407.5	1367.2	45.8	65.9
HI	9,664	669.9	668.3	40.2	2104.2	1695.3	164.7	186.1
IA	10,367	651.6	359.7	9.6	653.0	1607.1	81.1	108.7
ID	9,627	26.8	12.6	0.8	8.6	0.6	1.6	1.9
IL	10,441	447.3	96.0	9.5	330.3	993.5	33.8	47.3
IN	10,186	866.1	109.4	13.7	899.7	2636.4	74.0	109.6
KS	10,796	740.8	433.7	14.3	865.2	788.2	35.9	47.0
KY	10,465	928.5	143.4	16.1	855.6	2283.5	87.6	128.0
LA	9,601	438.7	559.7	11.1	415.7	800.3	46.0	62.9
MA	8,917	373.1	51.4	7.6	126.4	545.1	17.8	18.5
MD	10,525	518.1	81.4	6.9	401.1	692.8	53.0	61.8
ME	8,653	130.0	204.6	6.6	103.7	31.4	11.1	11.9
MI	10,341	584.0	130.3	14.4	639.5	1912.7	16.8	30.6
MN	10,485	539.3	185.9	11.4	580.9	705.8	51.7	94.8
MO	10,257	815.1	291.5	15.1	635.2	1961.5	61.4	86.6
MS	9,094	439.9	108.3	8.6	467.9	761.0	28.6	36.7
MT	10,358	545.9	75.0	10.8	543.5	536.7	61.3	74.8
NC	9,951	510.2	251.2	7.1	335.3	642.9	53.0	67.3
ND	10,806	842.5	183.2	19.5	1329.9	2395.6	66.0	89.6
NE	10,365	696.5	222.1	13.4	925.2	1797.1	42.0	55.2
NH	9,735	244.5	112.1	5.6	198.2	1104.9	17.1	22.0
NJ	9,541	239.8	35.6	3.5	79.1	54.4	12.8	13.1
NM	10,010	800.7	408.9	7.2	553.2	142.7	12.0	12.2

NV	8,496	452.4	786.4	20.5	215.3	151.0	21.5	27.8
NY	9,720	244.4	72.1	6.8	158.6	285.2	10.5	15.3

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Table S11 Continued

OH	10,089	796.7	143.6	11.0	701.5	3964.0	226.3	249.1
OK	9,582	652.8	154.5	12.8	986.9	1163.6	43.1	68.6
OR	9,422	105.7	33.5	3.4	79.8	200.1	6.8	12.5
PA	9,907	490.1	87.8	3.0	583.4	1311.5	32.1	51.1
RI	7,756	398.2	120.7	7.9	73.1	22.9	8.6	8.6
SC	10,114	359.5	148.1	5.3	235.7	633.4	75.8	95.6
SD	10,071	233.7	42.2	8.1	810.1	840.4	10.5	11.4
TN	10,231	486.3	61.8	8.6	303.8	1344.2	46.7	58.1
TX	9,270	546.1	355.2	7.8	297.9	890.7	26.1	40.7
UT	9,895	801.3	306.9	6.4	1121.0	454.1	54.3	61.5
VA	10,021	420.9	67.8	10.1	463.2	952.9	15.5	78.6
VT	10,562	0.9	147.5	2.3	39.9	0.5	0.3	0.4
WA	9,691	63.4	14.2	0.4	59.5	9.5	2.3	2.6
WI	10,154	652.8	173.3	11.2	459.0	1313.7	52.5	64.7
WV	10,008	897.1	116.0	11.6	623.4	1068.9	104.5	127.1
WY	10,518	853.4	249.5	13.7	752.3	677.7	58.2	109.3
U.S.	9,772	514.6	171.1	8.9	441.5	1013.0	43.1	58.5

Note: The energy use rates for generating electricity at power plants were estimated from the fuel consumption for electricity generation and net electricity generation data reported by the U.S. Energy Information Administration (EIA)[28]. The emission factors for generating electricity at power plants were estimated from emission inventory data for electricity generation from each major fuel source (e.g. coal, oil, natural gas, and biomass) reported by EPA[29, 30], and net electricity generation data reported by the U.S. Energy Information Administration (EIA)[31].

[28] EIA. (2015). Annual Electric Utility Data – EIA-906/920/923 Data File. *2011: EIA-923*. U.S. Energy Information Administration. See http://www.eia.gov/electricity/data/eia923/ (accessed May 2015).

[29] EPA. (2015). The 2011 National Emissions Inventory. U.S. Environmental Protection of Agency. See http://www.epa.gov/ttnchie1/net/2011inventory.html (accessed Mar 2015).

[30] EPA. (2015). State Energy CO_2 Emissions. *State CO_2 Emissions from Fossil Fuel Combustion, 1990-2012*. U.S. Environmental Protection of Agency. See http://epa.gov/statelocalclimate/resources/state_energyco2inv.html (accessed Mar 2015).

[31] EIA. (2015). Electric Power Detailed State Data. *Net Generation by State by Type of Producer by Energy Source*. U.S. Energy Information Administration. See http://www.eia.gov/electricity/data/state/ (accessed Mar 2015).

Table S12 The Total Energy Use and Emission Factors for Electricity Generation for Year 2011 the State-by-State and U.S. National Energy Mix, Including Feedstock Recovery, Fuel Production, Fuel Transport, Power Plant Electricity Generation, and Electricity Transmission

State	Energy Use (Btu/kWh)	CO_2 (g/kWh)	CO (mg/kWh)	VOC (mg/kWh)	NO_x (mg/kWh)	SO_x (mg/kWh)	$PM_{2.5}$ (mg/kWh)	PM_{10} (mg/kWh)
AK	11,296	504.5	793.6	166.7	3242.2	508.1	112.1	133.5
AL	9,820	489.4	135.9	58.5	502.2	1104.4	36.5	79.6
AR	10,016	576.9	138.5	61.3	622.5	932.8	24.5	80.7
AZ	10,097	500.2	144.0	52.6	423.6	280.6	26.2	59.4
CA	9,365	205.2	148.3	40.5	155.9	51.4	11.7	13.9
CO	10,390	768.5	350.9	80.1	1085.1	859.8	27.9	85.0
CT	9,885	219.9	110.4	36.8	159.1	69.2	9.2	11.8
DC	14,817	961.9	180.7	70.6	1580.0	3618.5	23.1	27.6
DE	10,201	618.7	261.9	83.3	725.6	1376.6	115.1	132.8
FL	9,453	529.7	279.7	71.1	482.6	471.1	46.7	73.8
GA	9,962	557.1	165.0	64.1	552.8	1435.0	56.1	114.4
HI	11,152	771.6	809.0	104.3	2586.5	2063.2	193.4	231.0
IA	10,567	667.2	391.4	66.1	774.3	1665.1	92.8	173.4
ID	9,694	31.2	28.1	6.4	30.9	7.3	2.3	3.0
IL	10,649	462.2	126.2	49.9	425.1	1044.8	42.5	91.7
IN	10,499	890.2	163.7	90.3	1073.2	2716.0	89.2	191.5
KS	11,042	759.8	474.0	75.2	1000.7	854.5	48.3	114.1
KY	10,749	951.1	186.3	93.8	1025.9	2362.9	104.1	217.5
LA	10,176	476.6	680.9	70.5	612.0	885.6	54.0	89.8
MA	9,503	410.9	190.1	64.7	318.6	618.6	23.0	32.5
MD	10,764	535.5	119.3	53.5	512.9	750.1	62.9	111.6
ME	9,134	161.2	312.4	42.1	255.0	76.5	17.3	19.5
MI	10,636	605.4	181.9	68.2	772.6	1977.8	27.8	84.3
MN	10,719	556.4	225.5	60.2	696.3	760.8	62.1	147.2
MO	10,521	836.0	334.3	85.5	788.8	2034.7	75.8	165.7
MS	9,628	474.7	231.6	65.3	649.0	832.8	34.9	58.2
MT	10,513	557.3	99.5	53.2	636.4	580.6	70.0	122.4
NC	10,217	529.3	296.1	56.1	455.3	702.6	63.2	117.5
ND	10,999	857.8	213.8	82.1	1459.5	2454.6	78.9	162.7
NE	10,588	714.2	255.3	73.2	1054.6	1862.0	54.7	124.4
NH	10,105	267.4	192.1	40.1	315.2	1149.1	22.2	36.4

NJ	9,931	263.5	121.2	37.8	196.9	98.4	16.1	21.8
NM	10,359	826.3	478.9	80.1	726.9	220.3	24.8	80.6
NV	9,048	488.5	921.2	81.3	407.7	227.2	26.7	46.4

Continued on Next Page

Table S12 Continued

NY	10,075	266.4	151.5	39.7	270.9	328.4	13.8	24.2
OH	10,398	820.4	195.4	81.4	864.0	4042.2	240.6	324.4
OK	10,030	683.5	255.5	80.6	1170.8	1242.2	52.5	114.2
OR	9,544	113.6	63.2	17.9	124.8	217.2	8.3	18.4
PA	10,218	511.9	146.3	53.2	713.1	1373.8	41.2	95.2
RI	8,505	446.3	307.2	76.1	312.3	111.1	12.3	12.7
SC	10,378	377.1	194.6	43.0	336.7	682.5	83.3	129.7
SD	10,128	237.7	52.6	26.3	847.8	857.7	14.0	31.5
TN	10,447	502.1	95.3	53.6	408.7	1398.0	56.3	107.4
TX	9,732	577.3	459.3	69.9	474.9	966.4	34.1	77.3
UT	10,200	824.5	363.3	81.0	1289.2	529.9	68.5	139.1
VA	10,393	445.5	142.3	55.7	597.4	1012.6	23.3	110.4
VT	10,678	4.9	165.5	5.7	62.2	2.6	2.9	3.8
WA	9,747	66.9	26.2	7.6	80.9	17.3	3.4	7.2
WI	10,449	674.7	223.7	70.8	602.5	1382.8	64.9	126.9
WV	10,259	917.5	154.7	89.6	787.0	1143.2	120.9	218.5
WY	10,746	871.6	286.1	84.2	900.3	744.9	72.7	190.9
U.S.	10,115	538.3	240.1	61.8	582.9	1077.5	52.0	100.8

Note: The total energy use and emission factors for electricity generation for year 2011 the state-by-state and U.S. national energy mix, include the upstream energy use and emissions related to feedstock recovery/production and transportation (Table S10), and the energy use and emissions for generating electricity at power plants (Table S11).

Charge Depleting (CD) and Charge Sustaining (CS) Modes

PHEVs operate in either charge depleting (CD) or charge sustaining (CS) mode.[32, 33, 34] Fully charged PHEV starts operating in CD mode. After the traction battery (TB) state of charge (SOC) reaches the minimum, PHEV starts operating in the CS mode. The lower SOC operation limit is mostly set by the battery manufacturer to prolong the battery life, and PHEV operates in the CD mode over a usable SOC window set by the battery manufacturer.[35]

Since in CD mode the TB SOC is generally decreasing, CD mode is defined as the operation that ends when the TB SOC stabilizes, and the engine turns on. The rest of the operation is defined as CS mode. According to 8 days of measurement, when the PHEV operation modes changed from CD to CS mode, the TB SOC was 23.1%~23.9%, with an average of 23.4% and a standard deviation of 0.3%. Based on one of eight days' data, Figure S10 shows the TB SOC decreased in the CD mode and maintained within the narrow range in the CS mode, and Figure S11 shows the engine speed increased rapidly when CD mode ended, indicating that the engine was turning on.

[32] Karbowski, D., Rousseau, A., Pagerit, S., & Sharer, P. (2006). Plug-in vehicle control strategy: from global optimization to real time application. In *22nd Electric Vehicle Symposium, EVS22, Yokohama, Japan*.

[33] Wirasingha, S. G., & Emadi, A. (2011). Classification and review of control strategies for plug-in hybrid electric vehicles. *Vehicular Technology, IEEE Transactions on*, *60*(1), 111-122.

[34] Sun, L., Liang, R., & Wang, Q. (2008). The control strategy and system preferences of plug-in HEV. In *Vehicle Power and Propulsion Conference, 2008. VPPC'08. IEEE* (pp. 1-5). IEEE.

[35] Shidore, N., Bohn, T., Duoba, M., Lohse-Busch, H., & Sharer, P. (2007). PHEV 'All electric range'and fuel economy in charge sustaining mode for low SOC operation of the JCS VL41M Li-ion battery using Battery HIL. In *Proceeding of the Electric Vehicle Symposium* (Vol. 23, pp. 2-5).

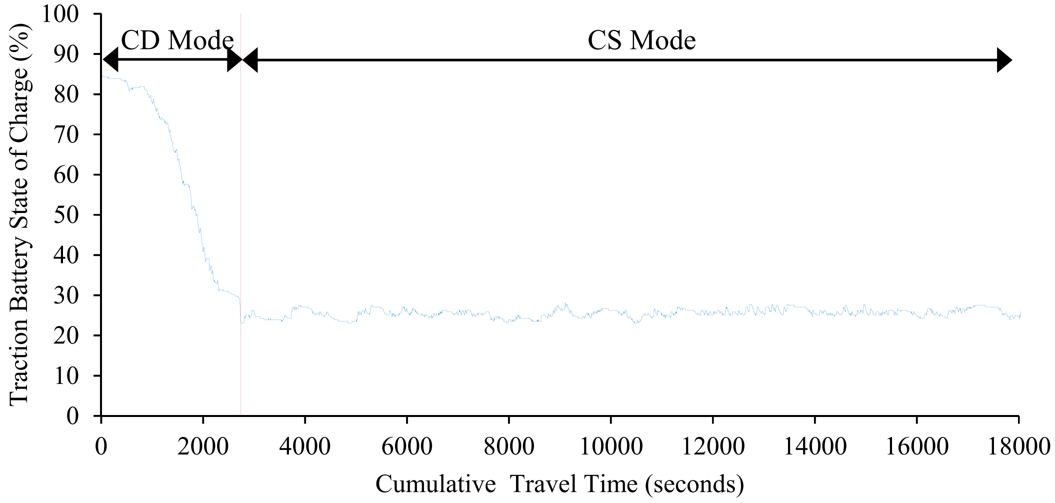

Figure S10 Second-by-Second the Traction Battery State of Charge Data for Charge Depleting (CD) and Charge Sustaining (CS) Modes for a 2013 Toyota Prius Plug-In Hybrid Measured on January 21, 2013 in Raleigh/Research Triangle Park, NC Area

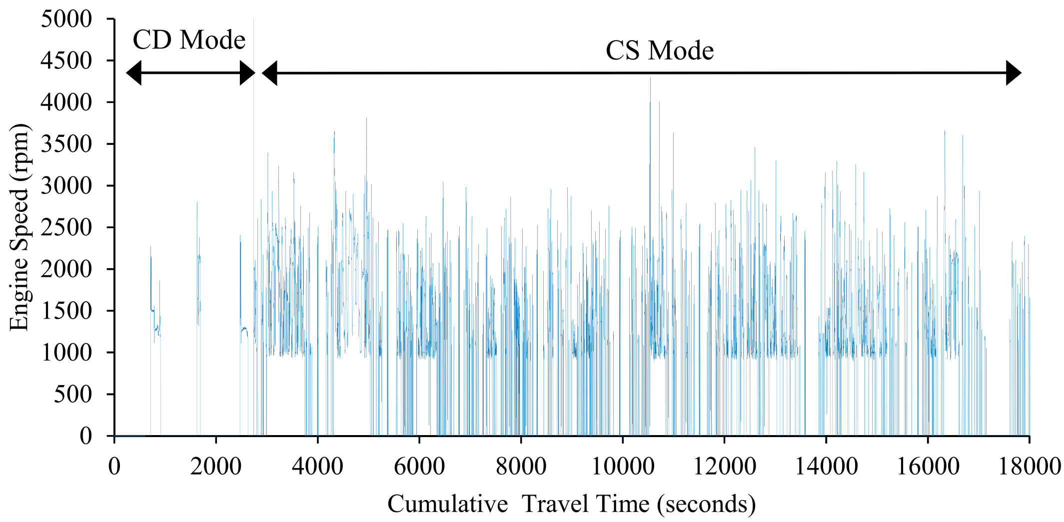

Figure S11 Second-by-Second the Engine Speed Data for Charge Depleting (CD) and Charge Sustaining (CS) Modes for a 2013 Toyota Prius Plug-In Hybrid Measured on January 21, 2013 in Raleigh/Research Triangle Park, NC Area

Table S13 The Vehicle Activity on Each Study Route for Charge Depleting (CD) Mode for a 2013 Toyota Prius Plug-In Hybrid Measured from January 18, 2013 to January 25, 2013 in Raleigh/Research Triangle Park, NC Area

Route	A	A	B	B	C	C	D	1
Direction	Out	In	Out	In	Out	In	--	Out
Number of Runs on CD Mode	2	1	2	1	3	1	1	1
Duration (s)	2854	218	3169	294	4009	235	1249	129
Distance (miles)	20.7	0.7	23.9	0.8	32.6	0.7	10.1	0.3
Number of Engine Starts	1	1	3	0	4	1	1	1
Engine On Duration (s)	191	158	432	0	857	14	335	18
Engine On Distance (miles)	0.3	0.2	2.9	0.0	8.5	0.0	1.4	0.0
Average Speed (mph)	26.2	12.0	27.1	10.3	29.3	10.3	29.3	8.8
Number of Engine Starts per Mile	0.0	1.4	0.1	0.0	0.1	1.5	0.1	3.2
Engine On Duration Percentage (%)	6.7	72.5	13.6	0.0	21.4	6.0	26.8	14.0
Engine On Distance Percentage (%)	1.4	26.8	12.0	0.0	26.2	0.1	13.5	0.1
Average Duration Between Engine Starts (s)	2854	218	1056	--	1002	235	1249	129
Average Distance Between Engine Starts (miles)	20.7	0.7	8.0	--	8.1	0.7	10.1	0.3
Average Engine On Duration per Engine Start (s)	191	158	144	--	214	14	335	18
Average Engine On Distance per Engine Start (miles)	0.3	0.2	1.0	--	2.1	0.0	1.4	0.0

Table S14 The Vehicle Activity on Each Study Route for Charge Sustaining (CS) Mode for a 2013 Toyota Prius Plug-In Hybrid Measured from January 18, 2013 to January 25, 2013 in Raleigh/Research Triangle Park, NC Area

Route	A	A	B	B	C	C	D	E	1	1	2	2	3	3
Direction	Out	In	Out	In	Out	In	--	--	Out	In	Out	In	Out	In
Number of Runs on CS Mode	5	7	1	3	8	8	3	3	8	8	2	2	7	7
Duration (s)	8219	9542	1417	4080	9163	10992	2581	2192	9642	10944	3012	3400	13548	13791
Distance (miles)	54.3	69.6	11.9	33.3	71.2	89.4	25.1	8.1	116.0	130.7	36.6	41.2	123.8	123.9
Number of Engine Starts	252	262	43	103	225	220	47	40	86	88	39	52	244	246
Engine On Duration (s)	2816	3581	620	1947	4050	4382	1492	354	6822	7513	2127	2364	7922	7724
Engine On Distance (miles)	26.6	36.5	6.8	21.6	48.0	56.4	20.0	2.7	107.3	120.5	32.5	35.9	97.2	94.4
Average Speed (mph)	23.8	26.3	30.3	29.4	28.0	29.3	35.1	13.3	43.3	43.0	43.8	43.7	32.9	32.3
Number of Engine Starts per Mile	4.6	3.8	3.6	3.1	3.2	2.5	1.9	4.9	0.7	0.7	1.1	1.3	2.0	2.0
Engine On Duration Percentage (%)	34.3	37.5	43.8	47.7	44.2	39.9	57.8	16.1	70.8	68.6	70.6	69.5	58.5	56.0
Engine On Distance Percentage (%)	48.9	52.5	56.8	64.9	67.4	63.1	79.7	33.7	92.5	92.2	88.9	87.2	78.5	76.1
Average Duration Between Engine Starts (s)	33	36	33	40	41	50	55	55	112	124	77	65	56	56
Average Distance Between Engine Starts (miles)	0.2	0.3	0.3	0.3	0.3	0.4	0.5	0.2	1.3	1.5	0.9	0.8	0.5	0.5
Average Engine On Duration per Engine Start (s)	11	14	14	19	18	20	32	9	79	85	55	45	32	31
Average Engine On Distance per Engine Start (miles)	0.1	0.1	0.2	0.2	0.2	0.3	0.4	0.1	1.2	1.4	0.8	0.7	0.4	0.4

Table S15 The Vehicle Energy Demand per Mile (kilowatt-second per ton per mile) for Each Study Route for Charge Depleting (CD) Mode

Route	A	B	C	D
Number of Runs	2	2	3	1
Mean	379.9	379.8	427.6	401.8
Standard Deviation	13.6	0.7	10.2	--
Minimum	370.2	379.3	421.4	401.8
Maximum	389.5	380.4	439.5	401.8

Table S16 The Vehicle Energy Demand per Mile (kilowatt-second per ton per mile) for Each Study Route for Charge Sustaining (CS) Mode

Route	A	B	C	D	E	1	2	3
Number of Runs	12	4	16	3	3	16	4	14
Mean	323.9	356.9	379.9	387.2	238.6	543.9	505.3	397.1
Standard Deviation	24.8	15.0	46.1	83.2	49.1	30.2	32.1	21.5
95% Confidence Interval Lower Bound on the mean	308.2	333.0	355.3	180.5	116.7	527.8	454.2	384.7
95% Confidence Interval Upper Bound on the mean	339.7	380.8	404.5	593.8	360.5	560.0	556.4	409.5

Table S17 The Vehicle Energy Demand per Mile (kilowatt-second per ton per mile) for Charge Depleting (CD) and Charge Sustaining (CS) Modes for a 2013 Toyota Prius Plug-In Hybrid Measured from January 18, 2013 to January 25, 2013 in Raleigh/Research Triangle Park, NC Area

Measurement Date	Mode	
	CD	CS
18-Jan-2013	443.8	394.6
19-Jan-2013	379.8	422.0
20-Jan-2013	358.2	433.6
21-Jan-2013	395.3	415.9
22-Jan-2013	398.3	398.5
23-Jan-2013	375.8	407.3
24-Jan-2013	589.0	451.9
25-Jan-2013	415.5	455.2
Mean	419.5	422.4
Standard Deviation	73.3	23.0
95% Confidence Interval Lower Bound on the mean	358.2	403.2
95% Confidence Interval Upper Bound on the mean	480.7	441.6

Table S18 The Energy Use and Tailpipe Pollutant Emissions During Measurement for Charge Depleting (CD) and Charge Sustaining (CS) Modes for a 2013 Toyota Prius Plug-In Hybrid Measured from January 18, 2013 to January 25, 2013 in Raleigh/Research Triangle Park, NC Area

Measurement Date	Mode	Distance (mile)	Electricity (kWh)	Gasoline (g)	CO_2 (g)	CO (mg)	HC (mg)	NO_x (mg)
18-Jan-13	CD	13.2	3.37	--	--	--	--	--
	CS	136.8	--	6,646	21,047	1,622	1,450	814
19-Jan-13	CD	11.2	3.37	--	--	--	--	--
	CS	125.8	--	6,120	19,382	3,259	559	406
20-Jan-13	CD	12.1	3.35	187	587	2,936	276	20
	CS	118.1	--	6,101	19,322	3,120	195	470
21-Jan-13	CD	13.0	3.29	222	701	1,119	136	17
	CS	126.7	--	6,804	21,547	3,992	544	381
22-Jan-13	CD	13.7	3.33	226	716	342	196	9
	CS	122.3	--	6,000	19,005	1,182	880	217
23-Jan-13	CD	12.3	3.31	221	699	421	229	25
	CS	117.3	--	6,237	19,752	2,363	1,007	321
24-Jan-13	CD	12.2	3.35	180	570	513	157	2
	CS	141.9	--	7,718	24,444	1,307	1,050	575
25-Jan-13	CD	11.0	3.33	183	578	335	160	54
	CS	74.9	--	5,023	15,903	4,740	455	552

Table S19 The Energy Economy for Charge Depleting (CD) and Charge Sustaining (CS) Modes for a 2013 Toyota Prius Plug-In Hybrid Measured from January 18, 2013 to January 25, 2013 in Raleigh/Research Triangle Park, NC Area, Based on North Carolina Electric Grid

Measurement Date	Mode	Energy Economy (mpg)		
		Electricity	Gasoline	Total
18-Jan-2013	CD	43.4	--	43.4
	CS	--	44.4	44.4
19-Jan-2013	CD	36.8	--	36.8
	CS	--	44.3	44.3
20-Jan-2013	CD	40.1	139.4	31.2
	CS	--	41.7	41.7
21-Jan-2013	CD	44.0	126.4	32.7
	CS	--	40.1	40.1
22-Jan-2013	CD	45.9	130.8	34.0
	CS	--	43.9	43.9
23-Jan-2013	CD	41.4	120.2	30.8
	CS	--	40.5	40.5
24-Jan-2013	CD	40.6	146.4	31.8
	CS	--	39.6	39.6
25-Jan-2013	CD	36.9	130.0	28.7
	CS	--	32.1	32.1

Note: The energy economy takes account of upstream energy use for gasoline production (including crude oil recovery, crude oil transport, gasoline refining, and gasoline transport) and electricity generation (including feedstock recovery, fuel production, fuel transport, power plant electricity generation, and electricity transmission), and electricity use and gasoline consumption during measurement. Based on Table S5, the upstream energy use for producing 1 gallon of gasoline is equal to a gasoline equivalent fuel use of 0.3 gallons. North Carolina annual average total energy use for generating 1 kWh of grid electricity is 1.02×10^4 *Btu of thermal energy (Table S12). The lower heating value for reformulated or low-sulfur gasoline (RFG) is 113,602 Btu/gallon.*[36] *Thus, each kWh of grid electricity corresponds to a gasoline equivalent fuel use of 0.09 gallons.*

[36] DOE. (2015). Hydrogen Analysis Resource Center, Lower and Higher Heating Values of Fuels. U.S. Department of Energy, Energy Efficiency & Renewable Energy. Washington, D.C.. See http://hydrogen.pnl.gov/cocoon/morf/hydrogen/site_specific/fuel_heating_calculator (accessed March 30, 2015).

Table S20 The Pollutant Mass Emission Rates for Charge Depleting (CD) and Charge Sustaining (CS) Modes for a 2013 Toyota Prius Plug-In Hybrid Measured from January 18, 2013 to January 25, 2013 in Raleigh/Research Triangle Park, NC Area

Measurement Date	Mode	Distance (mile)	CO_2 (g/mile)			CO (mg/mile)			HC (mg/mile)			NO_x (mg/mile)		
			Electricity Production	Gasoline Production	Tailpipe Emission	Electricity Production	Gasoline Production	Tailpipe Emission	Electricity Production	Gasoline Production	Tailpipe Emission	Electricity Production	Gasoline Production	Tailpipe Emission
18-Jan-2013	CD	13.2	135.5	--	--	75.8	--	--	14.4	--	--	116.6	--	--
	CS	136.8	--	28.0	153.9	--	48.6	11.9	--	59.2	10.6	--	104.0	5.9
19-Jan-2013	CD	11.2	159.7	--	--	89.4	--	--	16.9	--	--	137.4	--	--
	CS	125.8	--	28.1	154.1	--	48.7	25.9	--	59.3	4.4	--	104.2	3.2
20-Jan-2013	CD	12.1	146.7	8.9	48.5	82.1	15.5	242.7	15.5	18.8	22.8	126.2	33.1	1.6
	CS	118.1	--	29.8	163.7	--	51.7	26.4	--	63.0	1.7	--	110.6	4.0
21-Jan-2013	CD	13.0	133.6	9.8	53.9	74.8	17.1	85.9	14.2	20.8	10.4	114.9	36.5	1.3
	CS	126.7	--	31.0	170.1	--	53.7	31.5	--	65.5	4.3	--	115.0	3.0
22-Jan-2013	CD	13.7	128.3	9.5	52.1	71.8	16.5	24.9	13.6	20.1	14.2	110.4	35.3	0.6
	CS	122.3	--	28.3	155.4	--	49.1	9.7	--	59.8	7.2	--	105.1	1.8
23-Jan-2013	CD	12.3	142.1	10.4	56.7	79.5	17.9	34.2	15.1	21.9	18.6	122.2	38.4	2.0
	CS	117.3	--	30.7	168.3	--	53.2	20.1	--	64.8	8.6	--	113.8	2.7
24-Jan-2013	CD	12.2	145.0	8.5	46.5	81.1	14.7	41.9	15.4	17.9	12.8	124.7	31.5	0.1
	CS	141.9	--	31.4	172.3	--	54.4	9.2	--	66.3	7.4	--	116.5	4.1
25-Jan-2013	CD	11.0	159.7	9.6	52.4	89.3	16.6	30.3	16.9	20.2	14.5	137.4	35.5	4.9
	CS	74.9	--	38.7	212.3	--	67.1	63.3	--	81.7	6.1	--	143.6	7.4

Measurement Date	Mode	Distance (mile)	SO_x (mg/mile)			$PM_{2.5}$ (mg/mile)			PM_{10} (mg/mile)		
			Electricity Production	Gasoline Production	Tailpipe Emission	Electricity Production	Gasoline Production	Tailpipe Emission	Electricity Production	Gasoline Production	Tailpipe Emission
18-Jan-2013	CD	13.2	179.9	--	--	16.2	--	--	30.1	--	--
	CS	136.8	--	82.3	1.5	--	7.3	--	--	10.3	--
19-Jan-2013	CD	11.2	212.0	--	--	19.1	--	--	35.5	--	--
	CS	125.8	--	82.4	1.5	--	7.3	--	--	10.3	--
20-Jan-2013	CD	12.1	194.7	26.2	0.5	17.5	2.3	--	32.6	3.3	--
	CS	118.1	--	87.5	1.6	--	7.7	--	--	10.9	--
21-Jan-2013	CD	13.0	177.4	28.9	0.5	16.0	2.5	--	29.7	3.6	--
	CS	126.7	--	90.9	1.6	--	8.0	--	--	11.3	--
22-Jan-2013	CD	13.7	170.4	27.9	0.5	15.3	2.5	--	28.5	3.5	--
	CS	122.3	--	83.1	1.5	--	7.3	--	--	10.4	--
23-Jan-2013	CD	12.3	188.6	30.4	0.5	17.0	2.7	--	31.5	3.8	--
	CS	117.3	--	90.0	1.6	--	7.9	--	--	11.2	--
24-Jan-2013	CD	12.2	192.4	24.9	0.4	17.3	2.2	--	32.2	3.1	--
	CS	141.9	--	92.1	1.6	--	8.1	--	--	11.5	--
25-Jan-2013	CD	11.0	212.0	28.1	0.5	19.1	2.5	--	35.5	3.5	--
	CS	74.9	--	113.6	2.0	--	10.0	--	--	14.1	--

Note: Emission rates for gasoline production are based on emission factors in Table S5. Emission rates for electricity generation are based on emission factors of North Carolina (NC) electric mix in Table S12. Gasoline production includes crude oil recovery, crude oil transport, gasoline refining, and gasoline transport. Electricity production includes feedstock recovery, fuel production, fuel transport, power plant electricity generation, and electricity transmission.

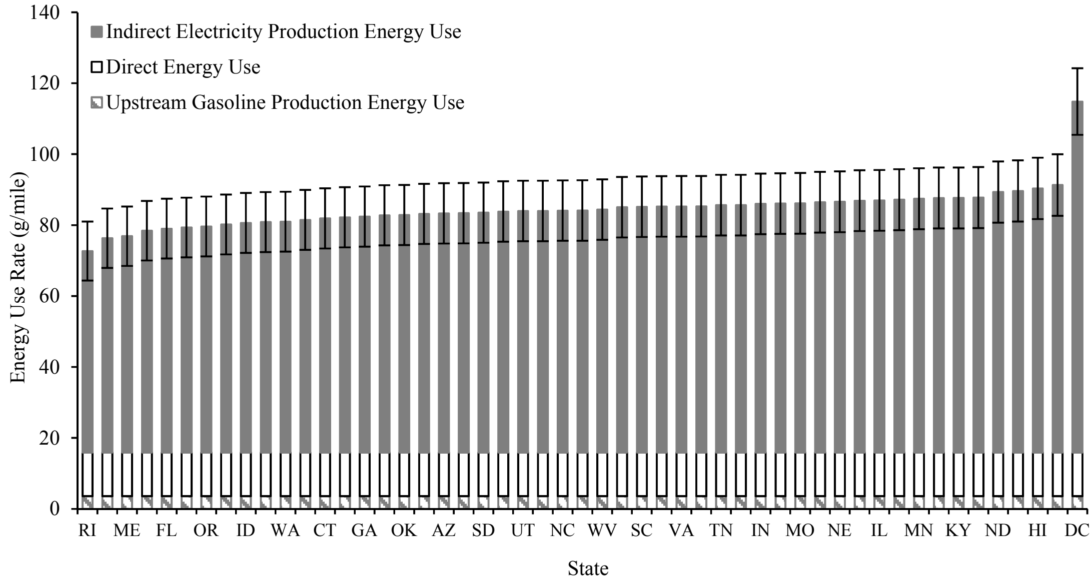

Figure S12 The Daily Average Energy Use Rate Versus State for Charge Depleting (CD) Mode
Note: Error bars indicate 95% confidence intervals on the mean based on day-to-day variability (Sample Size = 8); The energy use rate includes indirect energy use for electricity production (including feedstock recovery, fuel production, fuel transport, power plant electricity generation, and electricity transmission), upstream energy use for gasoline production (including crude oil recovery, crude oil transport, gasoline refining, and gasoline transport.), and direct energy use of gasoline consumption.

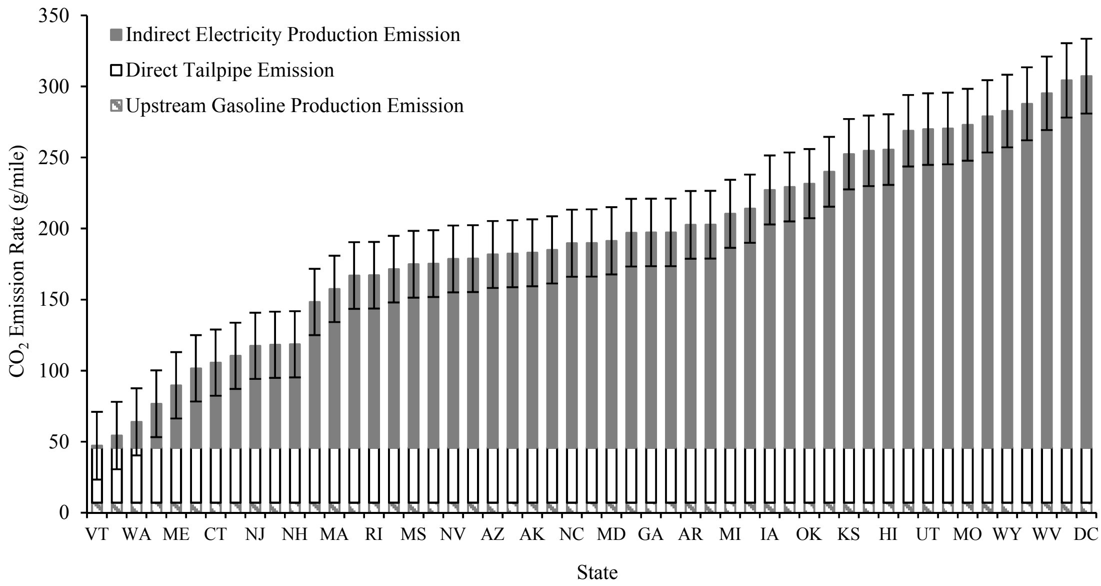

Figure S13 The Daily Average Carbon Dioxide (CO_2) Emission Rate Versus State for Charge Depleting (CD) Mode
Note: Error bars indicate 95% confidence intervals on the mean based on day-to-day variability (Sample Size = 8); The CO_2 emission rate includes indirect emissions from electricity production (including feedstock recovery, fuel production, fuel transport, power plant electricity generation, and electricity

transmission), upstream emissions from gasoline production (including crude oil recovery, crude oil transport, gasoline refining, and gasoline transport.), and direct tailpipe emissions.

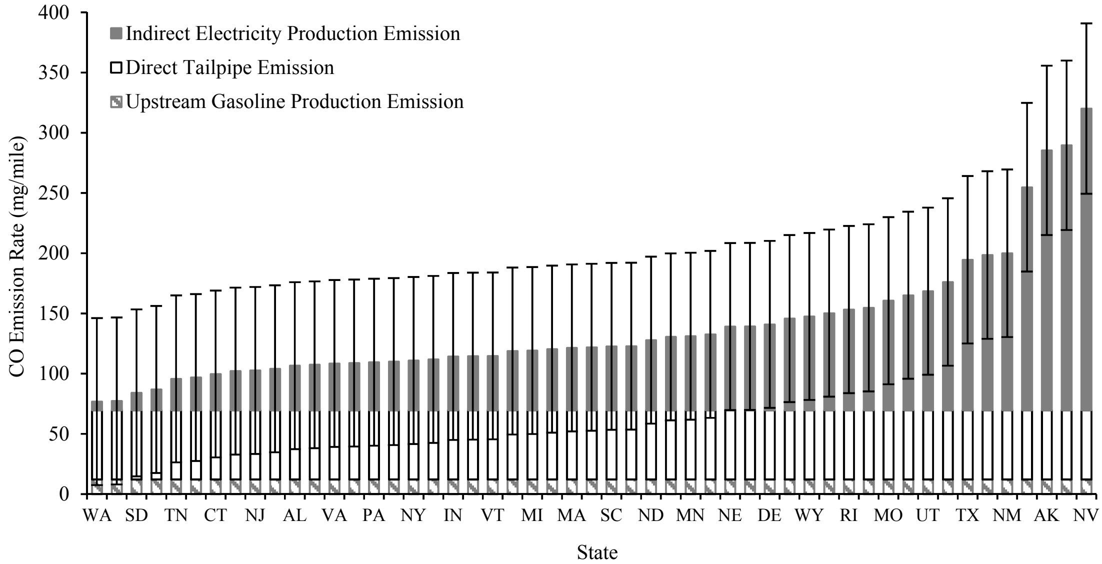

Figure S14 The Daily Average Carbon Monoxide (CO) Emission Rate Versus State for Charge Depleting (CD) Mode

Note: Error bars indicate 95% confidence intervals on the mean based on day-to-day variability (Sample Size = 8); The CO emission rate includes indirect emissions from electricity production (including feedstock recovery, fuel production, fuel transport, power plant electricity generation, and electricity transmission), upstream emissions from gasoline production (including crude oil recovery, crude oil transport, gasoline refining, and gasoline transport.), and direct tailpipe emissions.

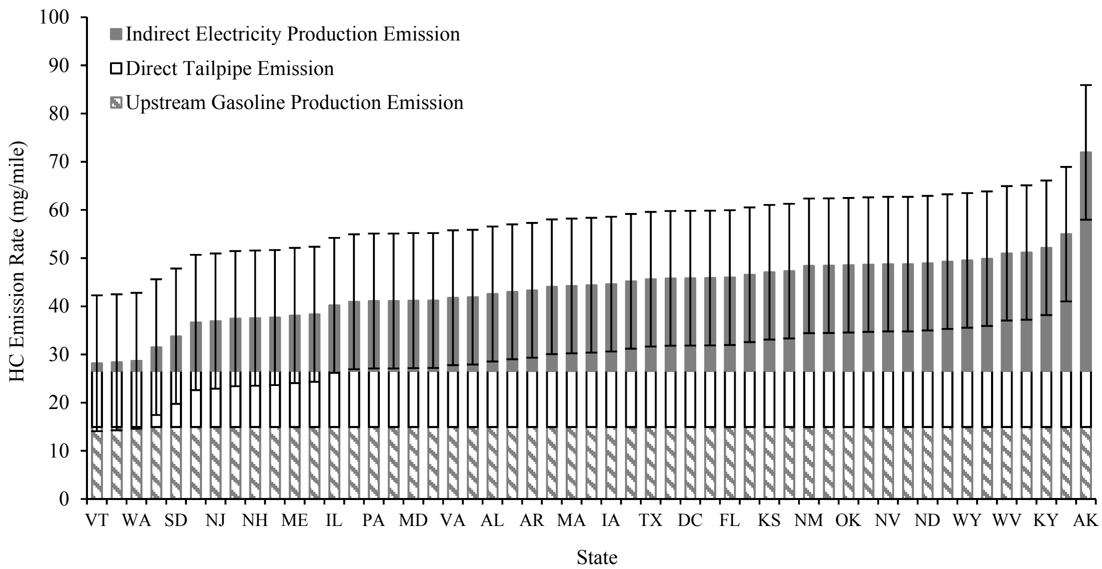

Figure S15 The Daily Average Hydrocarbon (HC) Emission Rate Versus State for Charge Depleting (CD) Mode

Note: Error bars indicate 95% confidence intervals on the mean based on day-to-day variability (Sample Size = 8); The HC emission rate includes indirect emissions from electricity production (including feedstock recovery, fuel production, fuel transport, power plant electricity generation, and electricity

transmission), upstream emissions from gasoline production (including crude oil recovery, crude oil transport, gasoline refining, and gasoline transport.), and direct tailpipe emissions.

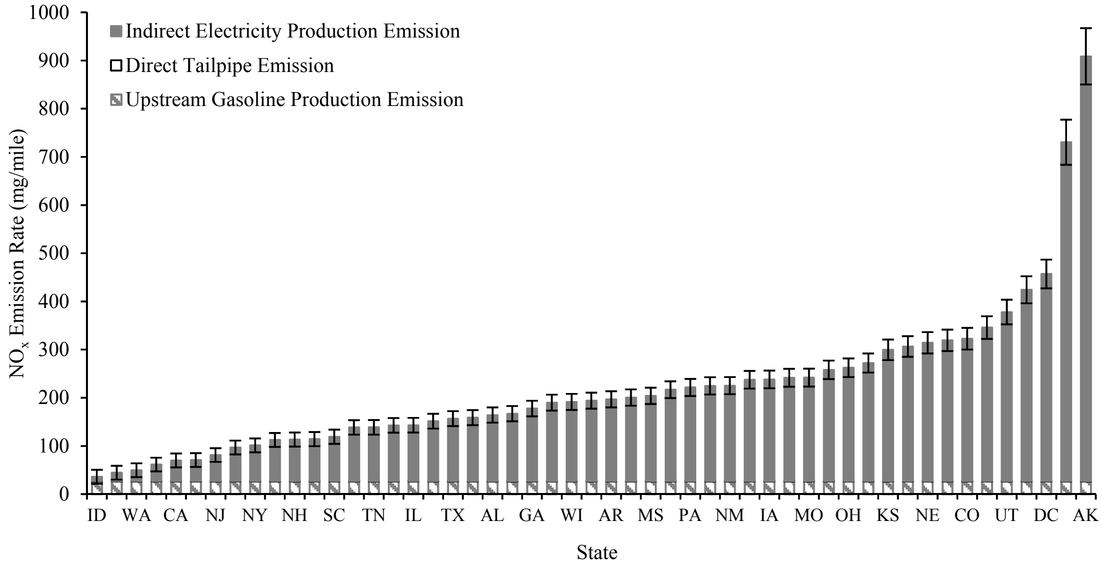

Figure S16 The Daily Average Oxide of Nitrogen (NO_x) Emission Rate Versus State for Charge Depleting (CD) Mode

Note: Error bars indicate 95% confidence intervals on the mean based on day-to-day variability (Sample Size = 8); The NO_x emission rate includes indirect emissions from electricity production (including feedstock recovery, fuel production, fuel transport, power plant electricity generation, and electricity transmission), upstream emissions from gasoline production (including crude oil recovery, crude oil transport, gasoline refining, and gasoline transport.), and direct tailpipe emissions.

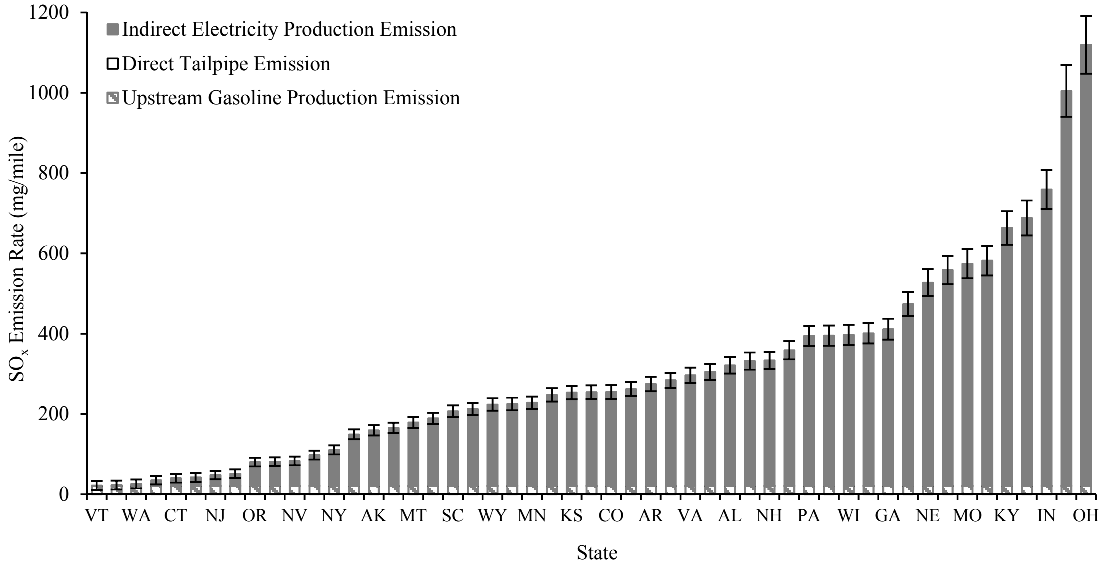

Figure S17 The Daily Average Oxide of Sulfur (SO_x) Emission Rate Versus State for Charge Depleting (CD) Mode

Note: Error bars indicate 95% confidence intervals on the mean based on day-to-day variability (Sample Size = 8); The SO_x emission rate includes indirect emissions from electricity production (including feedstock recovery, fuel production, fuel transport, power plant electricity generation, and electricity

transmission), upstream emissions from gasoline production (including crude oil recovery, crude oil transport, gasoline refining, and gasoline transport.), and direct tailpipe emissions.

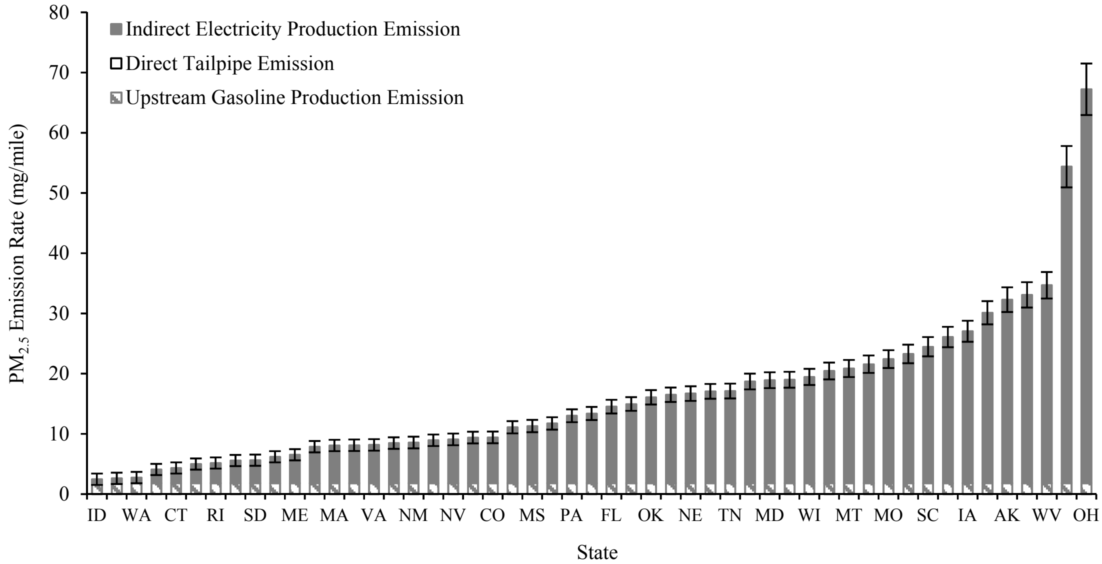

Figure S18 The Daily Average Particulate Matter with Diameters of 2.5 Micrometers or Less ($PM_{2.5}$) Emission Rate Versus State for Charge Depleting (CD) Mode

Note: Error bars indicate 95% confidence intervals on the mean based on day-to-day variability (Sample Size = 8); The $PM_{2.5}$ emission rate includes indirect emissions from electricity production (including feedstock recovery, fuel production, fuel transport, power plant electricity generation, and electricity transmission), upstream emissions from gasoline production (including crude oil recovery, crude oil transport, gasoline refining, and gasoline transport.), and direct tailpipe emissions.

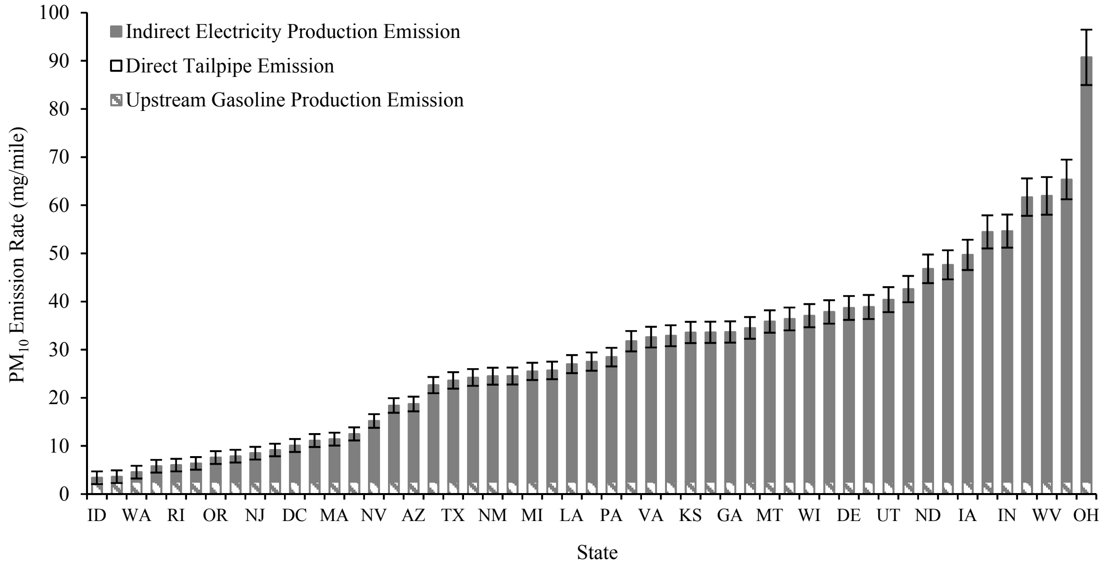

Figure S19 The Daily Average Particulate Matter with Diameters of 10 Micrometers or Less (PM_{10}) Emission Rate Versus State for Charge Depleting (CD) Mode

Note: Error bars indicate 95% confidence intervals on the mean based on day-to-day variability (Sample Size = 8); The PM_{10} emission rate includes indirect emissions from electricity production (including feedstock recovery, fuel production, fuel transport, power plant electricity generation, and electricity

transmission), upstream emissions from gasoline production (including crude oil recovery, crude oil transport, gasoline refining, and gasoline transport.), and direct tailpipe emissions.

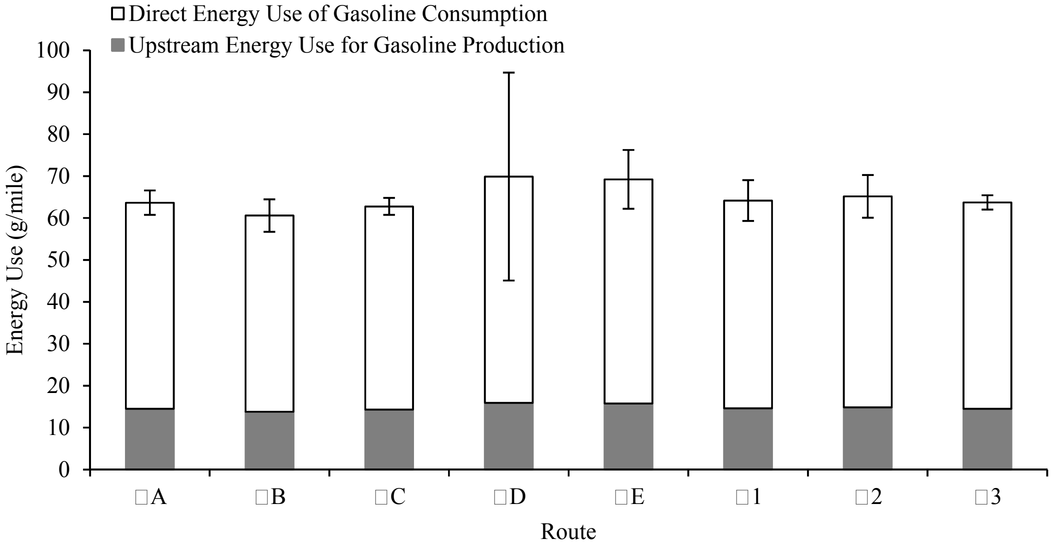

Figure S20 The Daily Average Energy Use Rate Versus Route for Charge Sustaining (CS) Mode

Note: Error bars indicate 95% confidence intervals on the mean based on run-to-run variability (Number of Runs on Each Route are 12, 4, 15, 3, 2, 16, 4, and 14 for Routes A, B, C, D, E, 1, 2, and 3.); The energy use rate includes upstream energy use for gasoline production (including crude oil recovery, crude oil transport, gasoline refining, and gasoline transport.), and direct energy use of gasoline consumption.

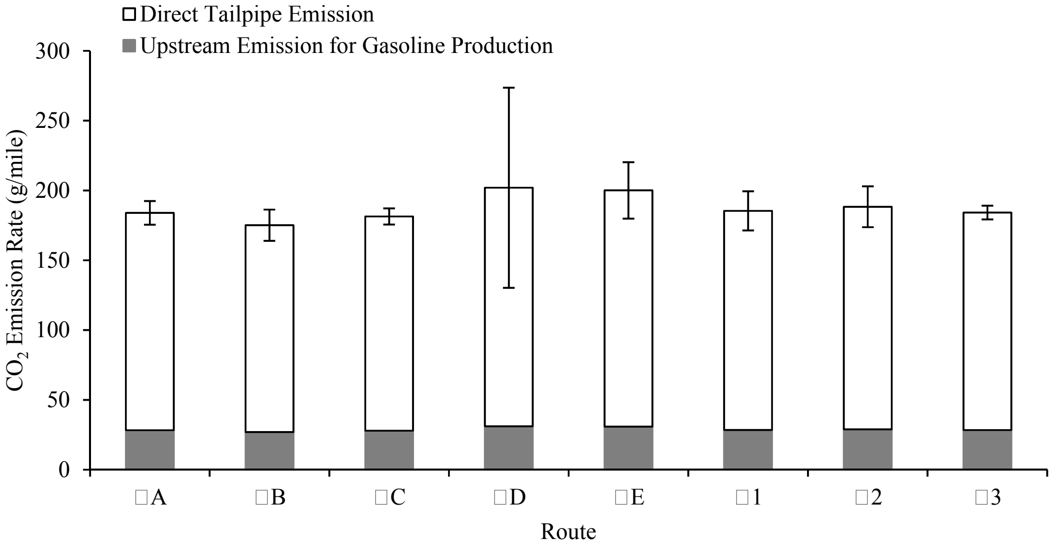

Figure S21 The Daily Average Carbon Dioxide (CO_2) Emission Rate Versus Route for Charge Sustaining (CS) Mode

Note: Error bars indicate 95% confidence intervals on the mean based on run-to-run variability (Number of Runs on Each Route are 12, 4, 15, 3, 2, 16, 4, and 14 for Routes A, B, C, D, E, 1, 2, and 3.); The CO_2 emission rate includes indirect emissions from upstream emissions from gasoline production (including crude oil recovery, crude oil transport, gasoline refining, and gasoline transport.), and direct tailpipe emissions.

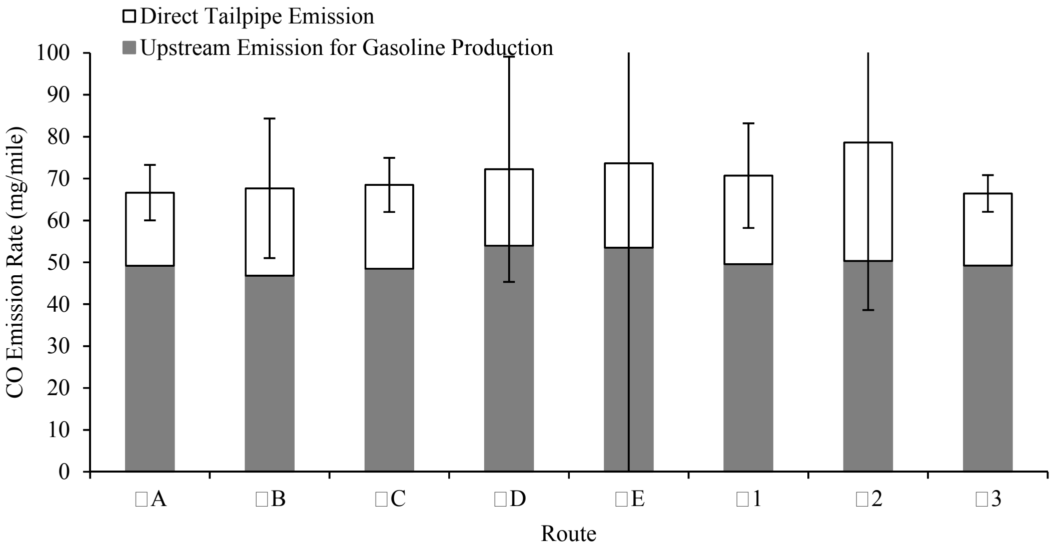

Figure S22 The Daily Average Carbon Monoxide (CO) Emission Rate Versus Route for Charge Sustaining (CS) Mode

Note: Error bars indicate 95% confidence intervals on the mean based on run-to-run variability (Number of Runs on Each Route are 12, 4, 15, 3, 2, 16, 4, and 14 for Routes A, B, C, D, E, 1, 2, and 3.); The CO emission rate includes indirect emissions from upstream emissions from gasoline production (including crude oil recovery, crude oil transport, gasoline refining, and gasoline transport.), and direct tailpipe emissions.

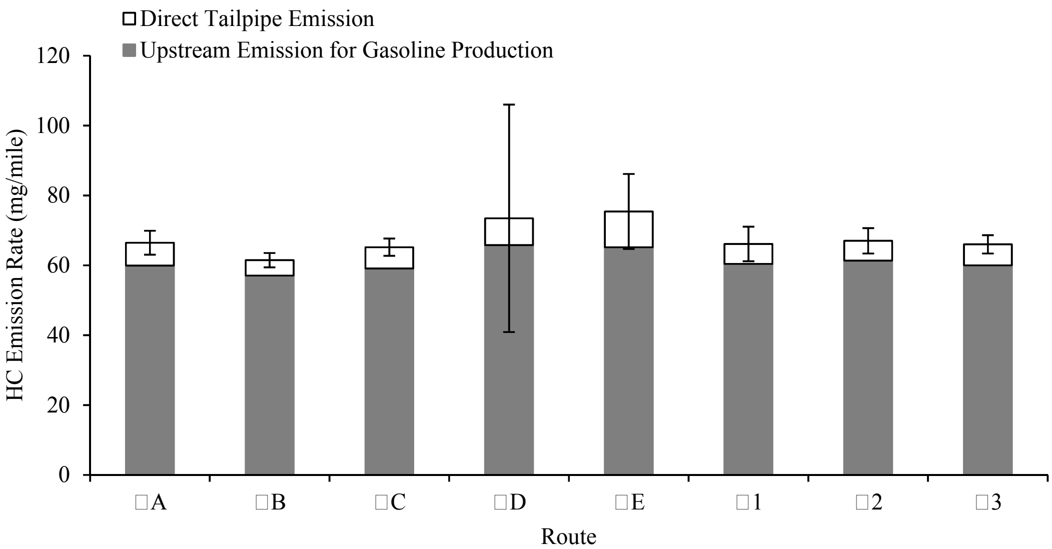

Figure S23 The Daily Average Hydrocarbon (HC) Emission Rate Versus Route for Charge Sustaining (CS) Mode

Note: Error bars indicate 95% confidence intervals on the mean based on run-to-run variability (Number of Runs on Each Route are 12, 4, 15, 3, 2, 16, 4, and 14 for Routes A, B, C, D, E, 1, 2, and 3.); The HC emission rate includes indirect emissions from upstream emissions from gasoline production (including crude oil recovery, crude oil transport, gasoline refining, and gasoline transport.), and direct tailpipe emissions.

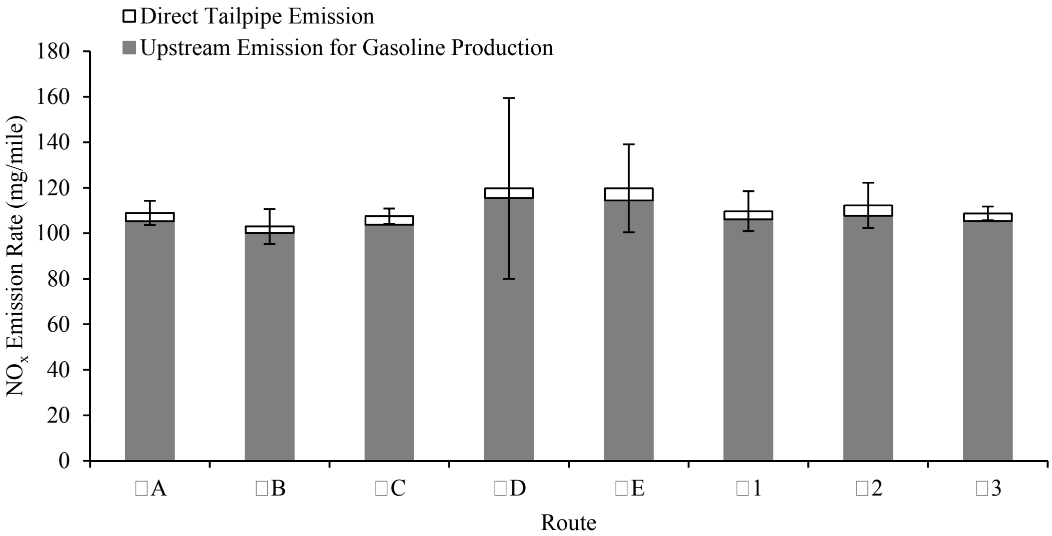

Figure S24 The Daily Average Oxide of Nitrogen (NO_x) Emission Rate Versus Route for Charge Sustaining (CS) Mode

Note: Error bars indicate 95% confidence intervals on the mean based on run-to-run variability (Number of Runs on Each Route are 12, 4, 15, 3, 2, 16, 4, and 14 for Routes A, B, C, D, E, 1, 2, and 3.); The NO_x emission rate includes indirect emissions from upstream emissions from gasoline production (including crude oil recovery, crude oil transport, gasoline refining, and gasoline transport.), and direct tailpipe emissions.

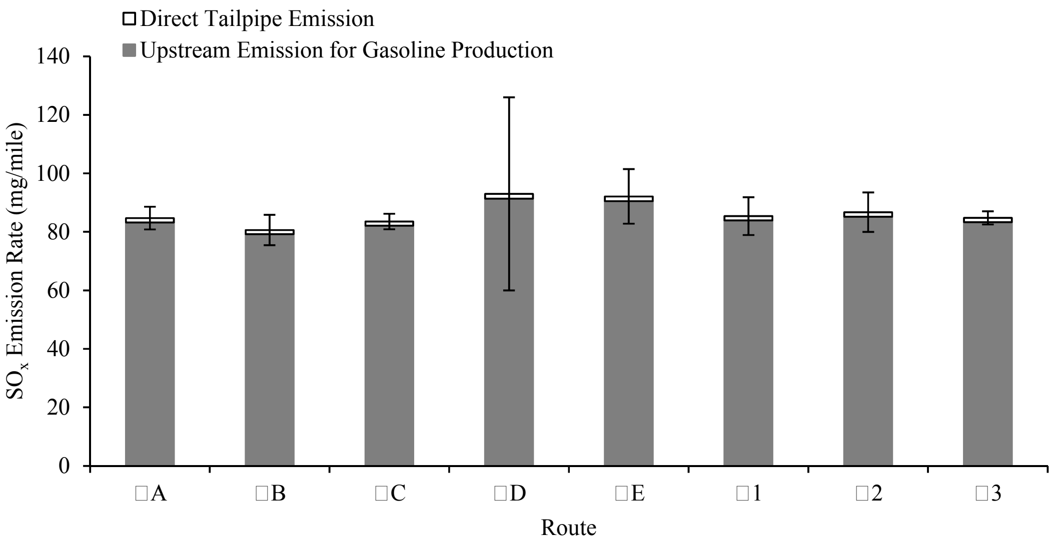

Figure S25 The Daily Average Oxide of Sulfur (SO_x) Emission Rate Versus Route for Charge Sustaining (CS) Mode

Note: Error bars indicate 95% confidence intervals on the mean based on run-to-run variability (Number of Runs on Each Route are 12, 4, 15, 3, 2, 16, 4, and 14 for Routes A, B, C, D, E, 1, 2, and 3.); The SO_x emission rate includes indirect emissions from upstream emissions from gasoline production (including crude oil recovery, crude oil transport, gasoline refining, and gasoline transport.), and direct tailpipe emissions, which are calculated by gasoline use rate and the maximum sulfur concentration of gasoline.

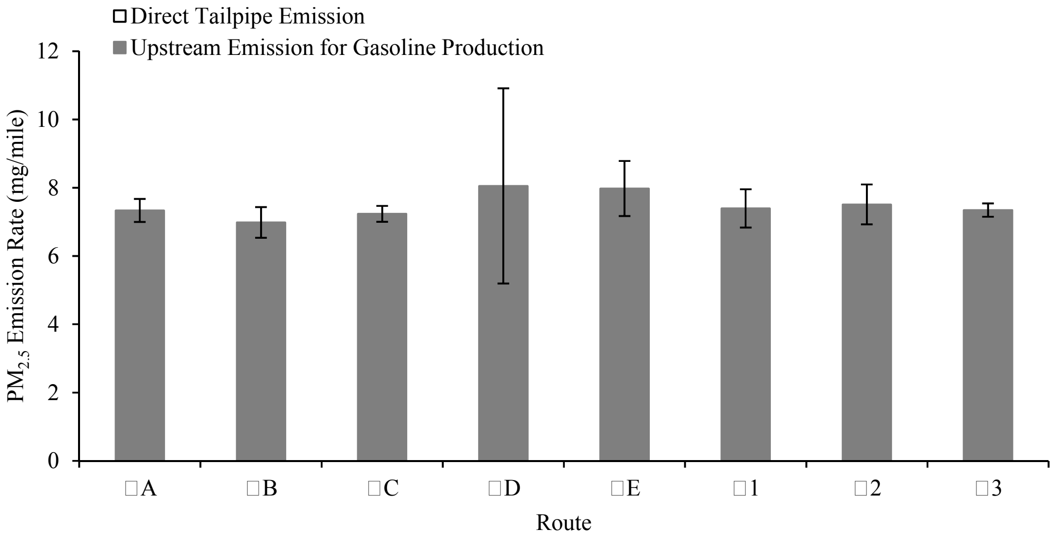

Figure S26 The Daily Average Particulate Matter with Diameters of 2.5 Micrometers or Less ($PM_{2.5}$) Emission Rate Versus Route for Charge Sustaining (CS) Mode

Note: Error bars indicate 95% confidence intervals on the mean based on run-to-run variability (Number of Runs on Each Route are 12, 4, 15, 3, 2, 16, 4, and 14 for Routes A, B, C, D, E, 1, 2, and 3.); The $PM_{2.5}$ *emission rate includes indirect emissions from upstream emissions from gasoline production (including crude oil recovery, crude oil transport, gasoline refining, and gasoline transport.), and direct tailpipe emissions, which are not measured during the measurement and are assumed as 0.*

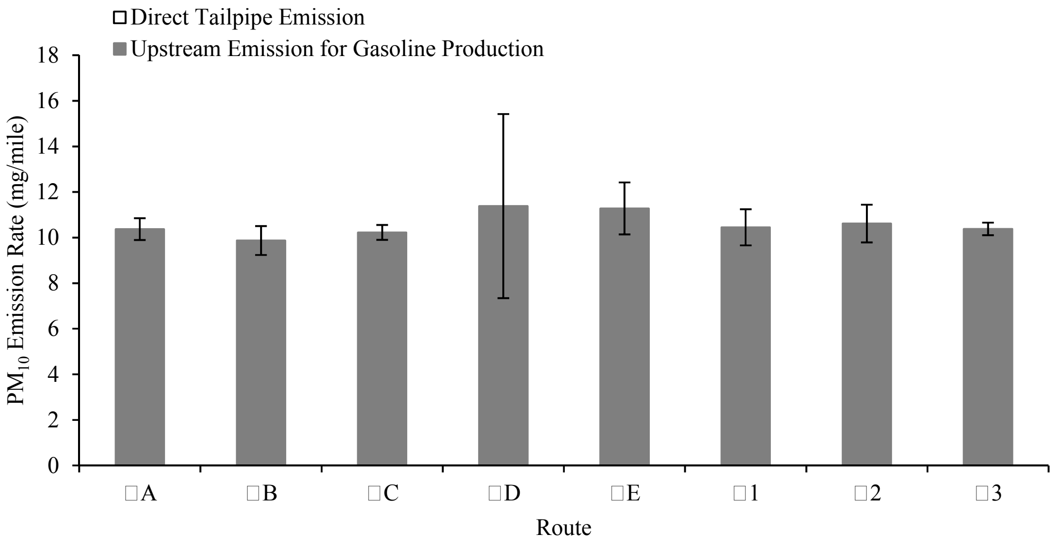

Figure S27 The Daily Average Particulate Matter with Diameters of 10 Micrometers or Less (PM_{10}) Emission Rate Versus Route for Charge Sustaining (CS) Mode

Note: Error bars indicate 95% confidence intervals on the mean based on run-to-run variability (Number of Runs on Each Route are 12, 4, 15, 3, 2, 16, 4, and 14 for Routes A, B, C, D, E, 1, 2, and 3.); The PM_{10} *emission rate includes indirect emissions from upstream emissions from gasoline production (including crude oil recovery, crude oil transport, gasoline refining, and gasoline transport.), and direct tailpipe emissions, which are not measured during the measurement and are assumed as 0.*

Engine On and Engine Off

The PHEV internal combustion engine (ICE) has the ability to turn on and off during operation, depending on power demand, the TB SOC, and the ability of electric motor to provide requested power.[37, 38, 39] During CD mode, engine is mainly off. The ICE usually turns on to assist propulsion when electric motor could not meet the high power demand.[1] During CS mode, the engine is mainly on. The ICE is off typically under situations of low power demand that can be met solely with the electric motor, or no power demand when driving downhill, decelerating, or braking.[3]

As seen in Figure S11, the engine turned on and off during the measurement. When engine speed is greater than or equal to 1000 rpm, the engine is usually running. More than 98% of data that had engine speed greater than or equal to 1000 rpm had fuel use greater than or equal to 0.70 l/hr. More than 88% of data that had engine speed greater than or equal to 500 rpm and less than 1000 rpm had fuel use greater than or equal to 0.70 l/hr. Thus, engine was defined as "on" when engine speed was greater than or equal to 500 rpm and fuel use was greater than or equal to 0.70 l/hr.

More than 95% of data that had engine speed less than 500 rpm was less than or equal to 0.15 l/hr, which is inferred to be a condition of engine off.

The remaining data were checked within their individual sequences of engine activity using forward differencing of engine speed ($\Delta RPM_i = RPM_{i+1} - RPM_i$). When engine transition was from "off" to "on", ΔRPM_i was greater than 0. When engine transition was from "on" to "off", ΔRPM_i was less than or equal to 0. Thus, the remaining seconds of data were defined as either "startup" or "shutdown," depending on ΔRPM_i.

Figures S28 and S29 show the cumulative distributions of engine speed and fuel use, respectively, for engine "on", "startup", "shutdown", and "off". Even though the engine speed cutoff for "on" is as low as 500 rpm, less than 11% of engine "on" data had engine speed less than 100 rpm, and less than 1% of engine "on" data had engine speed less than 900 rpm.

For engine "off", 100% of engine speed was 0, and 91% of fuel use was less than 0.1 l/hr. It appears that the on-board diagnostic (OBD) scan tool reports a fuel flow rate of as high as 0.15 l/hr even when the engine speed is 0. Thus, such values are inferred to be a *de*

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[37] Wirasingha, S. G., & Emadi, A. (2011). Classification and review of control strategies for plug-in hybrid electric vehicles. *Vehicular Technology, IEEE Transactions on*, *60*(1), 111-122.

[38] Bradley, T. H., & Frank, A. A. (2009). Design, demonstrations and sustainability impact assessments for plug-in hybrid electric vehicles. *Renewable and Sustainable Energy Reviews*, *13*(1), 115-128.

[39] Shidore, N., Bohn, T., Duoba, M., Lohse-Busch, H., & Sharer, P. (2007). PHEV 'All electric range'and fuel economy in charge sustaining mode for low SOC operation of the JCS VL41M Li-ion battery using Battery HIL. In *Proceeding of the Electric Vehicle Symposium* (Vol. 23, pp. 2-5).

minimis level that is not significantly different than 0. In contrast, even though only 23% of "startup" had engine speed greater than 100 rpm, fuel flow rate values between 0.15 l/hr and 0.7 l/hr were with 72% frequency range. This range of fuel flow is substantially higher than the *de minimis* rate of engine "off", but not as high as for engine "on". Thus, the "startup" fuel flow rate represents a transition from "off" to "on". For engine "on", engine speed exceeded 500 rpm 100% of the time and exceeded 1000 rpm 90% of the time, while fuel flow rate exceeded 1.0 l/hr 93% of the time. Hence, engine "on" fuel flow rate was consistently higher than for the transition during startup. "Shutdown" tended to have higher engine speed than "startup", since prior to "shutdown" the engine had been running typically at over 1000 rpm. "Shutdown" appeared to involve fuel cut-off during which engine speed coasted down to 0. However, there can be cases for which the engine restarted before it had fully shut off. Typically, "startup" took less time than "shutdown". The amount of "shutdown" time was a factor of five greater than for "startup". The average "startup" duration per engine start was 0.36 seconds, and the average "shutdown" duration per engine shutdown was 2.06 seconds.

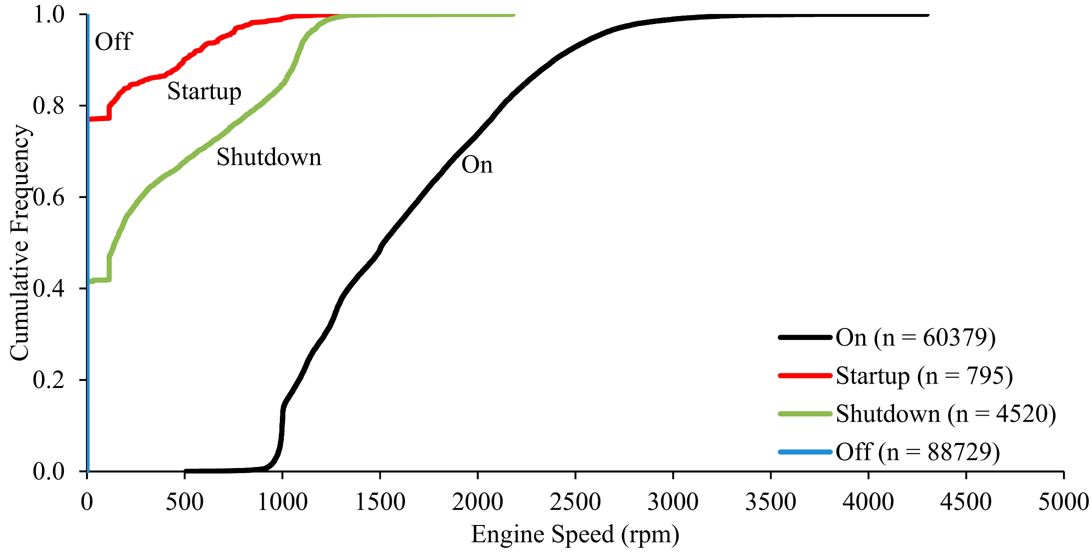

Figure S28 The Cumulative Distribution of Engine Speed for Engine “on”, “startup”, “shutdown”, and “off”, for All Vehicle Operation, Including Charge Depleting and Charge Sustaining Modes

Note: Engine speed was 0 during engine “off”.

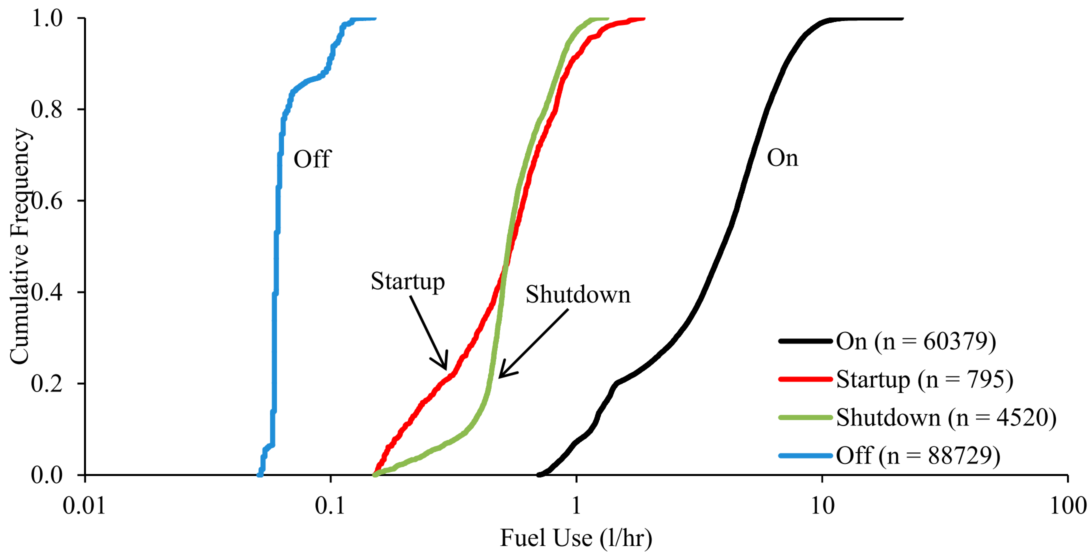

Figure S29 The Cumulative Distribution of Engine Fuel Use for Engine “on”, “startup”, “shutdown”, and “off”, for All Vehicle Operation, Including Charge Depleting and Charge Sustaining Modes

Note: The scale for horizontal axis (Fuel Use (l/hr)) is logarithmic.

Table S21 The Travel Time Spent in Each Vehicle Specific Power (VSP) Mode for Charge Depleting (CD) Mode During Engine On and Off for a 2013 Toyota Prius Plug-In Hybrid Measured from January 18, 2013 to January 25, 2013 in Raleigh/Research Triangle Park, North Carolina Area

VSP Mode	Engine On (s)	Engine Off (s)
1	99	2270
2	59	1191
3	1165	5098
4	167	1973
5	139	1695
6	115	1009
7	101	719
8	31	480
9	31	228
10	42	126
11	19	54
12	1	11
13	0	0
14	0	0

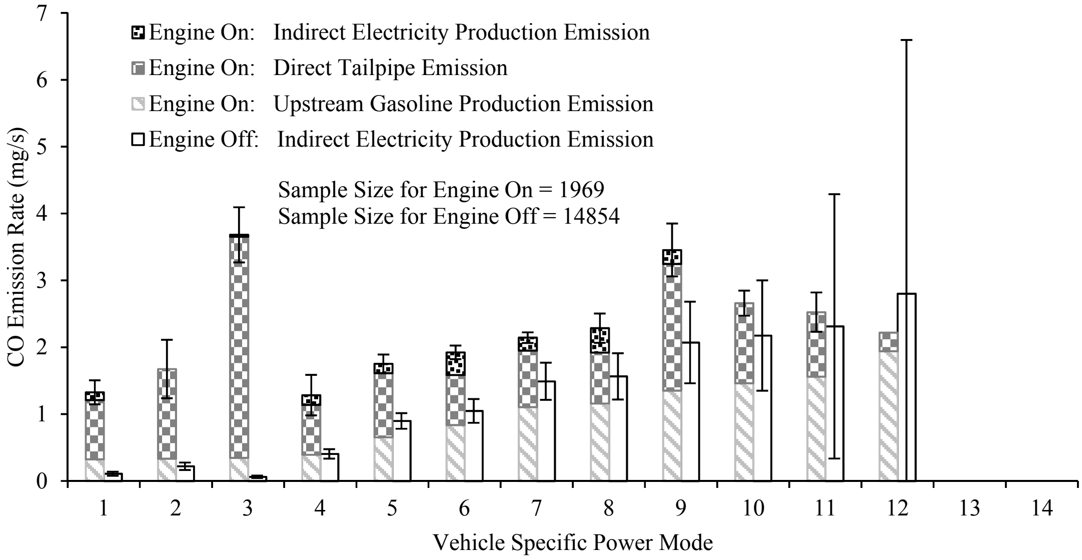

Figure S30 The Carbon Monoxide (CO) Emission Rate Versus Vehicle Specific Power (VSP) Mode for Engine On and Off for Charge Depleting (CD) Mode for a 2013 Toyota Prius Plug-In Hybrid Measured from January 18, 2013 to January 25, 2013 in Raleigh/Research Triangle Park, North Carolina Area

Note: Error bars indicate 95% confidence intervals on the mean based on second-by-second variability in total emission; Sample size in each VSP mode is shown in Table S21; There is no data point for VSP modes 13 and 14.

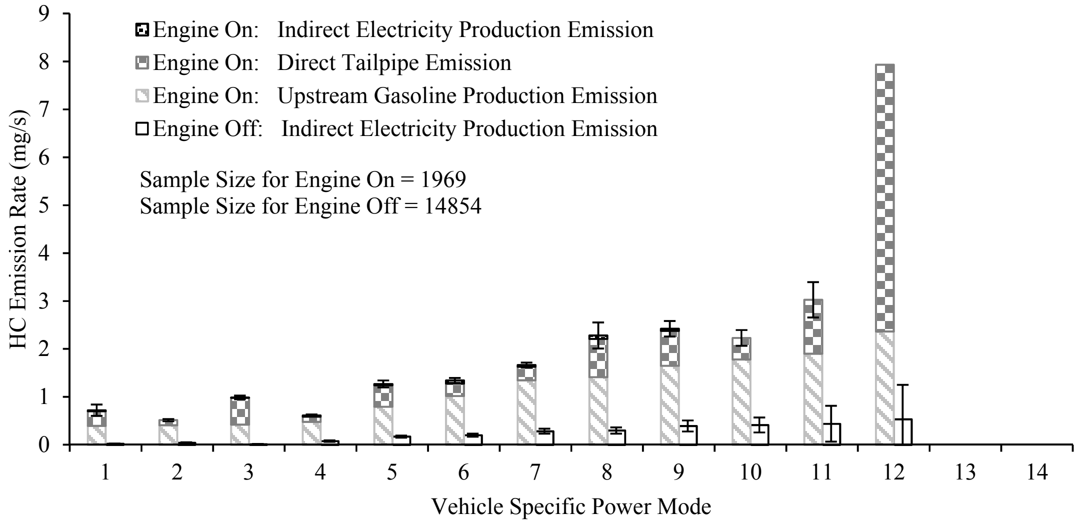

Figure S31 The Hydrocarbon (HC) Emission Rate Versus Vehicle Specific Power (VSP) Mode for Engine On and Off for Charge Depleting (CD) Mode for a 2013 Toyota Prius Plug-In Hybrid Measured from January 18, 2013 to January 25, 2013 in Raleigh/Research Triangle Park, North Carolina Area

Note: Error bars indicate 95% confidence intervals on the mean based on second-by-second variability in total emission; Sample size in each VSP mode is shown in Table S21; There is no data point for VSP modes 13 and 14.

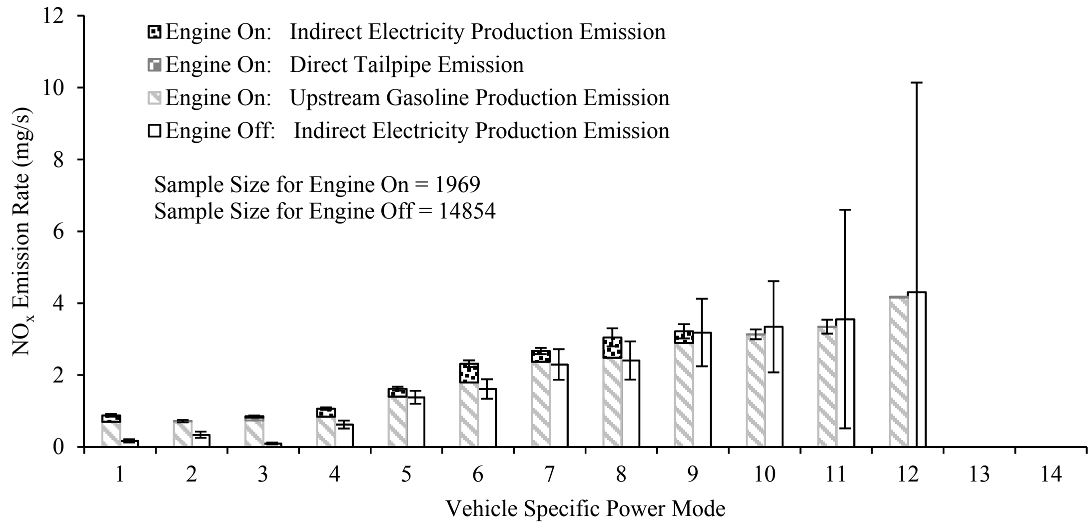

Figure S32 The Oxide of Nitrogen (NO_x) Emission Rate Versus Vehicle Specific Power (VSP) Mode for Engine On and Off for Charge Depleting (CD) Mode for a 2013 Toyota Prius Plug-In Hybrid Measured from January 18, 2013 to January 25, 2013 in Raleigh/Research Triangle Park, North Carolina Area

Note: Error bars indicate 95% confidence intervals on the mean based on second-by-second variability in total emission; Sample size in each VSP mode is shown in Table S21; There is no data point for VSP modes 13 and 14.

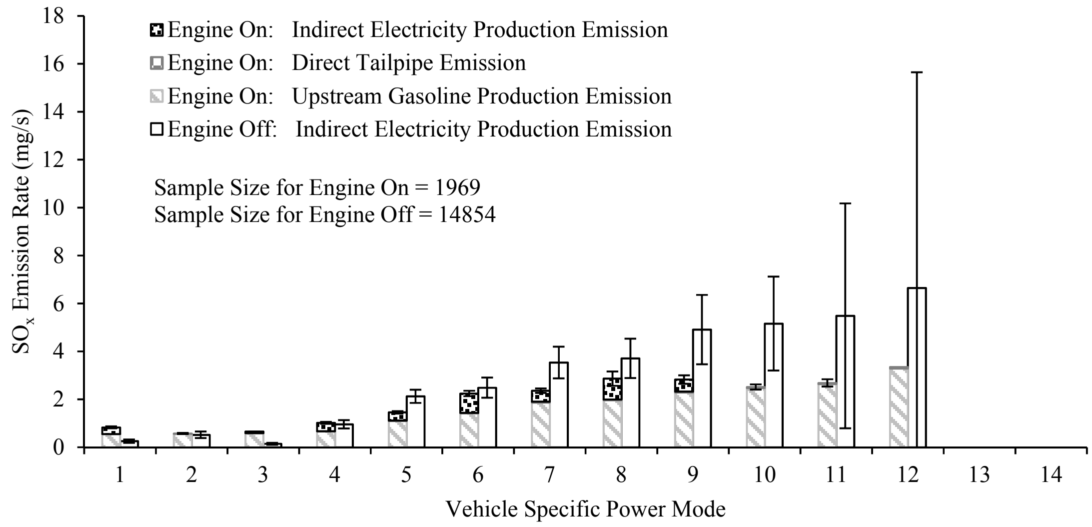

Figure S33 The Oxide of Sulfur (SO_x) Emission Rate Versus Vehicle Specific Power (VSP) Mode for Engine On and Off for Charge Depleting (CD) Mode for a 2013 Toyota Prius Plug-In Hybrid Measured from January 18, 2013 to January 25, 2013 in Raleigh/Research Triangle Park, North Carolina Area

Note: Error bars indicate 95% confidence intervals on the mean based on second-by-second variability in total emission; Sample size in each VSP mode is shown in Table S21; There is no data point for VSP modes 13 and 14.

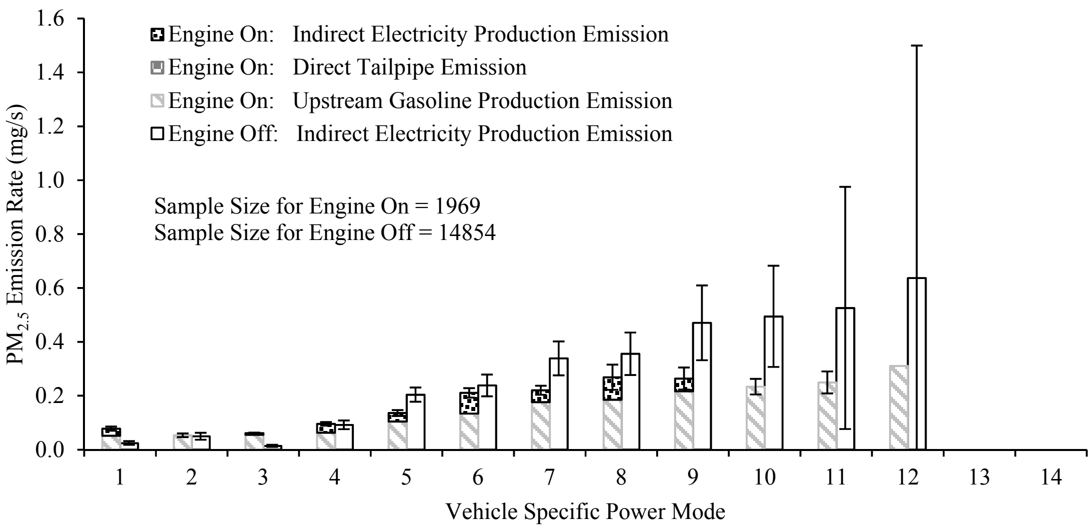

Figure S34 The Particulate Matter with Diameters of 2.5 Micrometers or Less ($PM_{2.5}$) Emission Rate Versus Vehicle Specific Power (VSP) Mode for Engine On and Off for Charge Depleting (CD) Mode for a 2013 Toyota Prius Plug-In Hybrid Measured from January 18, 2013 to January 25, 2013 in Raleigh/Research Triangle Park, North Carolina Area

Note: Error bars indicate 95% confidence intervals on the mean based on second-by-second variability in total emission; Sample size in each VSP mode is shown in Table S21; There is no data point for VSP modes 13 and 14.

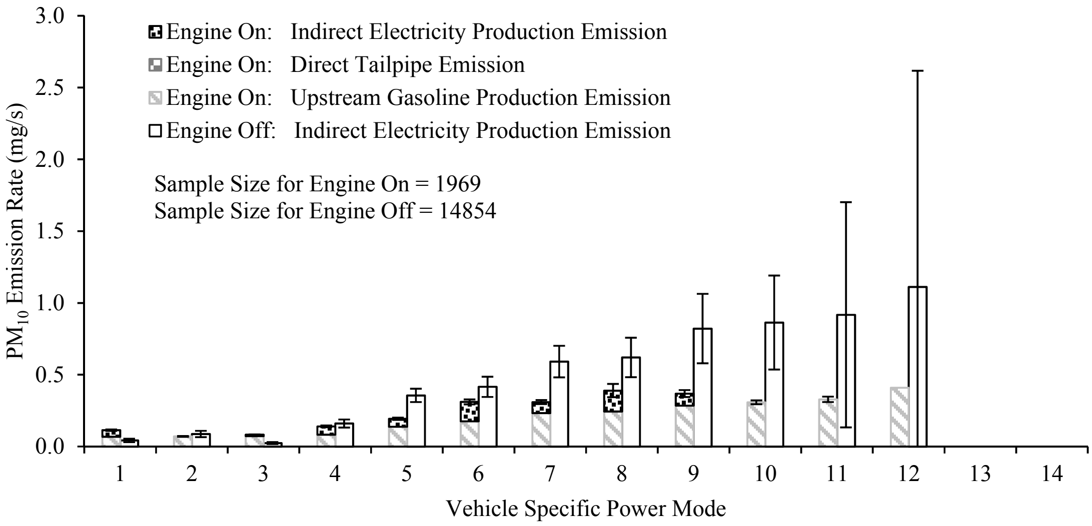

Figure S35 The Particulate Matter with Diameters of 10 Micrometers or Less (PM_{10}) Emission Rate Versus Vehicle Specific Power (VSP) Mode for Engine On and Off for Charge Depleting (CD) Mode for a 2013 Toyota Prius Plug-In Hybrid Measured from January 18, 2013 to January 25, 2013 in Raleigh/Research Triangle Park, North Carolina Area
Note: Error bars indicate 95% confidence intervals on the mean based on second-by-second variability in total emission; Sample size in each VSP mode is shown in Table S21; There is no data point for VSP modes 13 and 14.

Table S22 The Travel Time Spent in Each Vehicle Specific Power (VSP) Mode for Charge Sustaining (CS) Mode During Engine On and Off for a 2013 Toyota Prius Plug-In Hybrid Measured from January 18, 2013 to January 25, 2013 in Raleigh/Research Triangle Park, North Carolina Area

VSP Mode	Engine On (s)	Engine Off (s)
1	3482	12300
2	1289	5083
3	1819	36360
4	4338	5262
5	7463	2434
6	8739	1094
7	7928	402
8	6341	130
9	3875	34
10	2917	5
11	1834	0
12	724	1
13	225	0
14	45	0

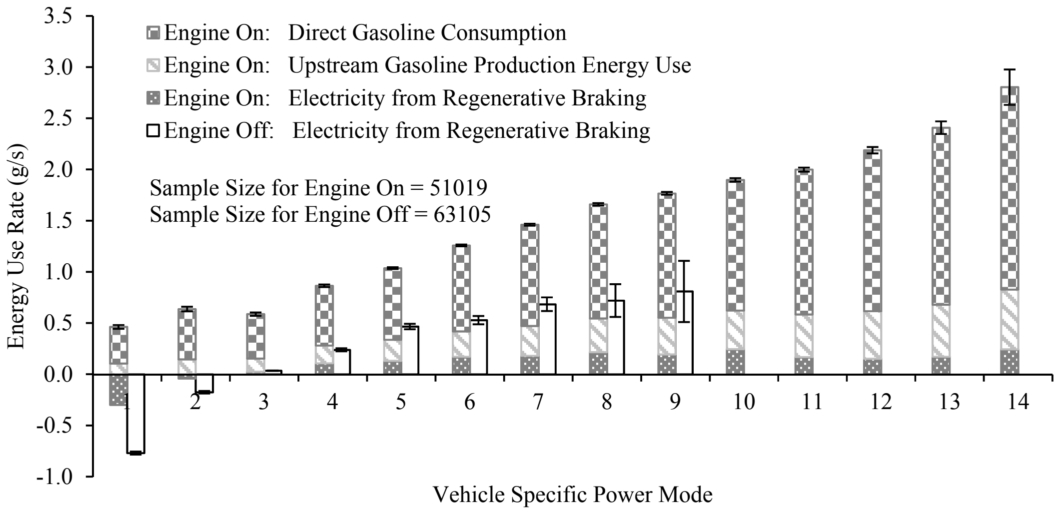

Figure S36 The Energy Use Rate Versus Vehicle Specific Power (VSP) Mode for Engine On and Off for Charge Sustaining (CS) Mode for a 2013 Toyota Prius Plug-In Hybrid Measured from January 18, 2013 to January 25, 2013 in Raleigh/Research Triangle Park, North Carolina Area
Note: Error bars indicate 95% confidence intervals on the mean based on second-by-second variability in total energy use; Sample size in each VSP mode is shown in Table S22; There is no data point for engine off in VSP modes 11, 13 and 14; For VSP mode 12, there were only 1 second of engine off data, which are not shown.

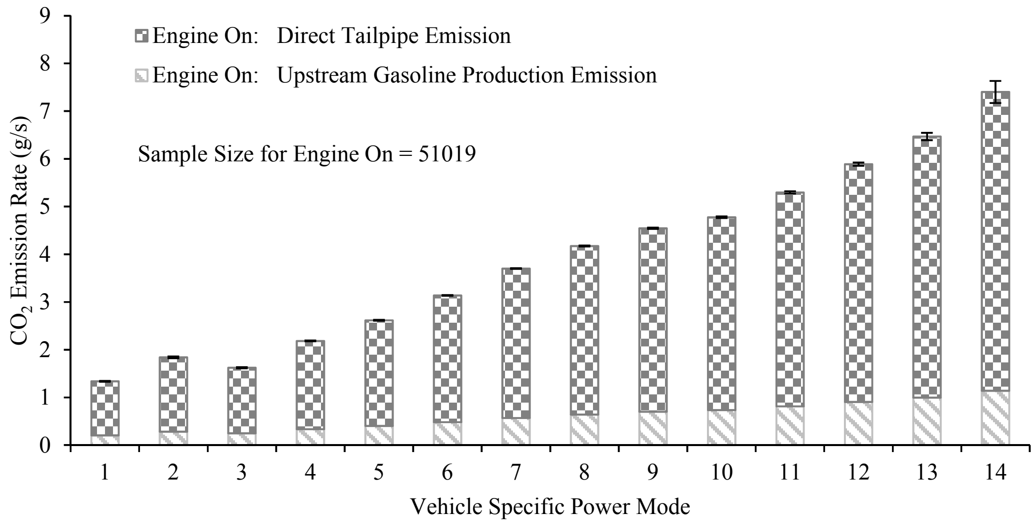

Figure S37 The Carbon Dioxide (CO_2) Emission Rate Versus Vehicle Specific Power (VSP) Mode for Engine On for Charge Sustaining (CS) Mode for a 2013 Toyota Prius Plug-In Hybrid Measured from January 18, 2013 to January 25, 2013 in Raleigh/Research Triangle Park, North Carolina Area
Note: Error bars indicate 95% confidence intervals on the mean based on second-by-second variability in total emission; Sample size in each VSP mode is shown in Table S22.

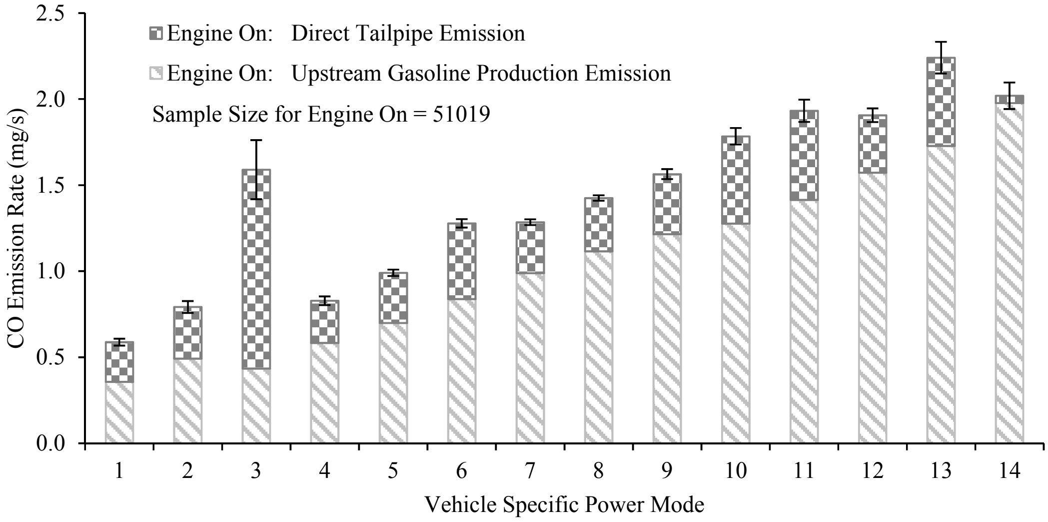

Figure S38 The Carbon Monoxide (CO) Emission Rate Versus Vehicle Specific Power (VSP) Mode for Engine On for Charge Sustaining (CS) Mode for a 2013 Toyota Prius Plug-In Hybrid Measured from January 18, 2013 to January 25, 2013 in Raleigh/Research Triangle Park, North Carolina Area
Note: Error bars indicate 95% confidence intervals on the mean based on second-by-second variability in total emission; Sample size in each VSP mode is shown in Table S22.

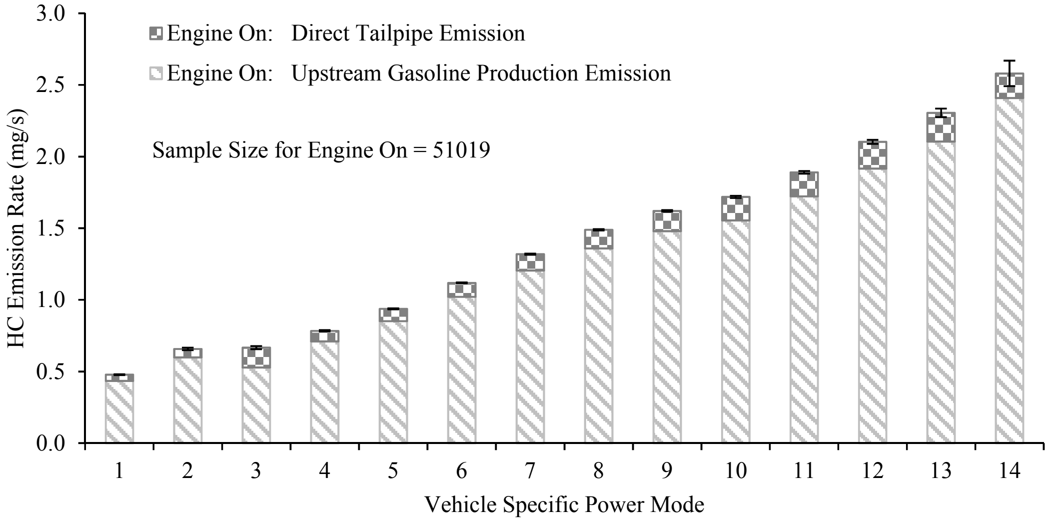

Figure S39 The Hydrocarbon (HC) Emission Rate Versus Vehicle Specific Power (VSP) Mode for Engine On for Charge Sustaining (CS) Mode for a 2013 Toyota Prius Plug-In Hybrid Measured from January 18, 2013 to January 25, 2013 in Raleigh/Research Triangle Park, North Carolina Area
Note: Error bars indicate 95% confidence intervals on the mean based on second-by-second variability in total emission; Sample size in each VSP mode is shown in Table S22.

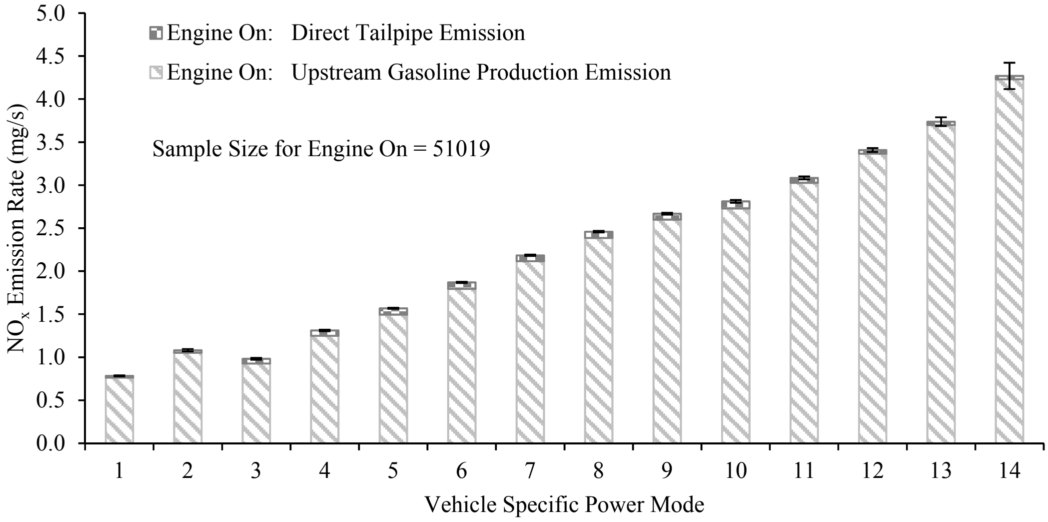

Figure S40 The Oxide of Nitrogen (NO_x) Emission Rate Versus Vehicle Specific Power (VSP) Mode for Engine for Charge Sustaining (CS) Mode for a 2013 Toyota Prius Plug-In Hybrid Measured from January 18, 2013 to January 25, 2013 in Raleigh/Research Triangle Park, North Carolina Area

Note: Error bars indicate 95% confidence intervals on the mean based on second-by-second variability in total emission; Sample size in each VSP mode is shown in Table S22.

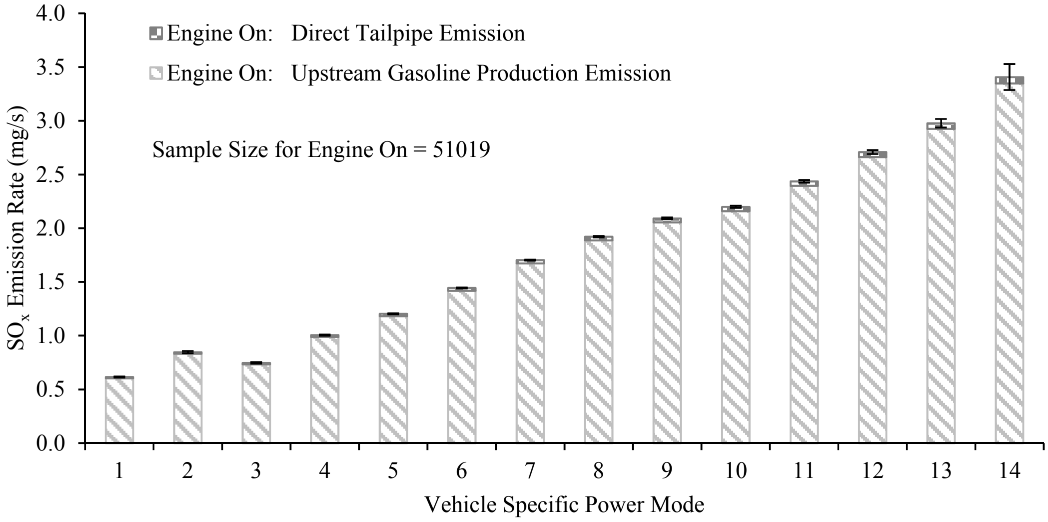

Figure S41 The Oxide of Sulfur (SO_x) Emission Rate Versus Vehicle Specific Power (VSP) Mode for Engine On for Charge Sustaining (CS) Mode for a 2013 Toyota Prius Plug-In Hybrid Measured from January 18, 2013 to January 25, 2013 in Raleigh/Research Triangle Park, North Carolina Area

Note: Error bars indicate 95% confidence intervals on the mean based on second-by-second variability in total emission; Sample size in each VSP mode is shown in Table S22.

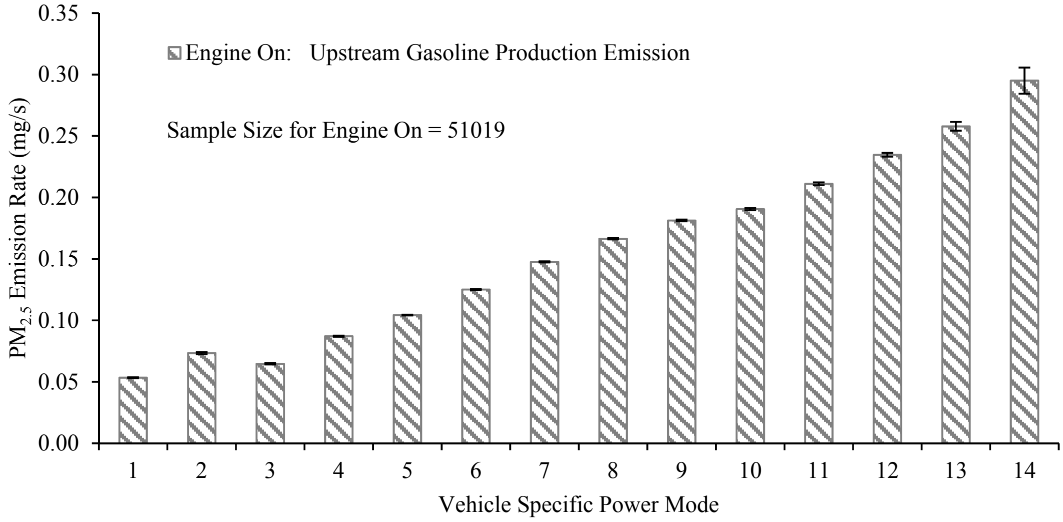

Figure S42 The Particulate Matter with Diameters of 2.5 Micrometers or Less ($PM_{2.5}$) Emission Rate Versus Vehicle Specific Power (VSP) Mode for Engine On for Charge Sustaining (CS) Mode for a 2013 Toyota Prius Plug-In Hybrid Measured from January 18, 2013 to January 25, 2013 in Raleigh/Research Triangle Park, North Carolina Area
Note: Error bars indicate 95% confidence intervals on the mean based on second-by-second variability in total emission; Sample size in each VSP mode is shown in Table S22.

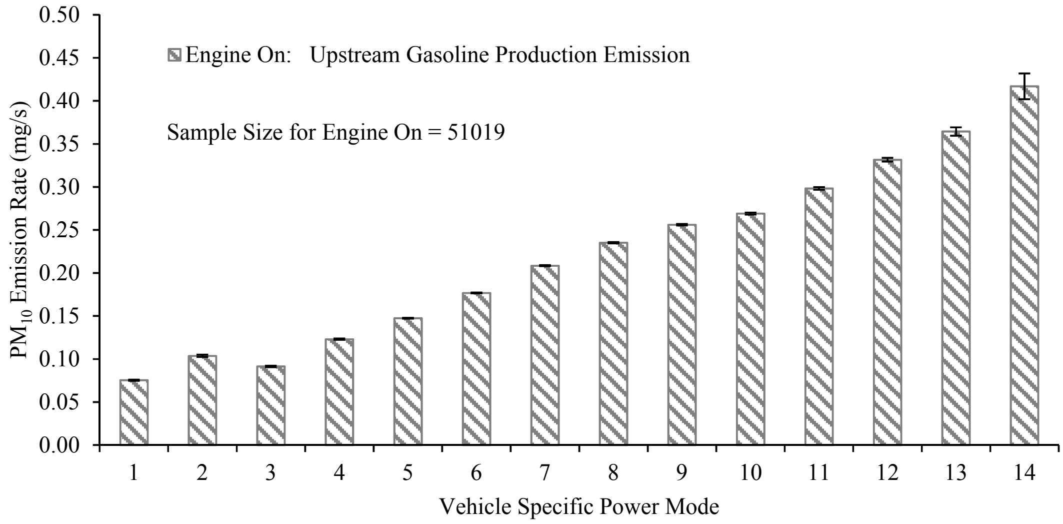

Figure S43 The Particulate Matter with Diameters of 10 Micrometers or Less (PM_{10}) Emission Rate Versus Vehicle Specific Power (VSP) Mode for Engine On for Charge Sustaining (CS) Mode for a 2013 Toyota Prius Plug-In Hybrid Measured from January 18, 2013 to January 25, 2013 in Raleigh/Research Triangle Park, North Carolina Area
Note: Error bars indicate 95% confidence intervals on the mean based on second-by-second variability in total emission; Sample size in each VSP mode is shown in Table S22.

Cold Start and Hot Stabilized Running

Starting a vehicle when its engine is colder than its typical operating temperature, due to the ambient air temperature, would cause cold start. It is more difficult to start an engine because of lower temperature during cold start period.[40] Lower temperature makes fuel more viscous and air denser, and lack of thermal energy makes ignition more difficult. Therefore, to ensure the presence of sufficient fuel vapor of combustion, engine is usually running fuel rich, which can increase products of incomplete combustion including carbon monoxide (CO), and hydrocarbons (HC).[41] Until the catalytic converter warms to its "light-off temperature", it will be ineffective at controlling emissions of CO, HC and oxides of nitrogen (NO_x).[42, 43] Thus, emissions produced during cold start are typically caused by a combination of fuel rich operation and ineffective catalyst performance.

For CVs, cold starts occur at the point of origin of a trip. Until the TB SOC reaches the lower limit, PHEVs can operate mainly on battery power using electricity stored from the electric grid for distances of 10 or more miles.[44] Therefore, for a PHEV in CD mode, the first engine start could occur some distance form the trip origin, thus altering the real-world location of cold starts. Furthermore, PHEVs may have extended periods of engine off activity, during which engine coolant temperature (T_{EC}) and catalyst temperature (T_{cat}) may decrease.[2, 45] As a result, a subsequent engine start may have a cold start effect. These characteristics could lead to multiple cold start events per trip for a PHEV, which potentially could effect tailpipe emissions during CD mode and the first few minutes of CS mode.

To identify cold start, the changes in T_{EC}, T_{cat}, CO and HC concentrations as travel time went by were studies. Figures S44 to S47 show the second-by-second T_{EC}, T_{cat}, CO and HC concentrations data for the PHEV measured on January 21, 2013. When the vehicle operated in the hot stabilized condition, T_{EC} was around 90 $°C$, T_{cat} was around 600 $°C$, and CO and HC emissions were low. In this study, cold start was defined as when engine turned on in condition of T_{EC} less than 90 $°C$, T_{cat} less than 600 $°C$, and CO and HC

[40] Nogi, T., & Hunt, F. W. (1999). *U.S. Patent No. 5,894,832*. Washington, DC: U.S. Patent and Trademark Office.

[41] Markey, J. (1993). *Federal Test Procedure Review Project: Technical Report*. EPA 420-R-93-007, Certification Division, Office of Mobile Sources, U.S. Environmental Protection Agency.

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emissions significantly greater than hot stabilized emissions. During the measurement, there were periods during which both T_{EC} and T_{cat} dropped as a result of extended engine shutoff, which might cause partial cold start. However, the engine shutoff during hot stabilized operation had smaller or no effect on the CO and HC emission, relative to cold start. Therefore, only the first few engine turning on events were classified as cold start for analysis purpose in this study. For example, only the first four engine starts were counted as cold start for the measurement on January 21, 2013, including the three engine starts in CD mode and the first engine starts in CS mode. Figure S48 shows the second-by-second NO_x concentration data for the PHEV measured on January 21, 2013. It shows that cold start has little or no effect on the NO_x emission.

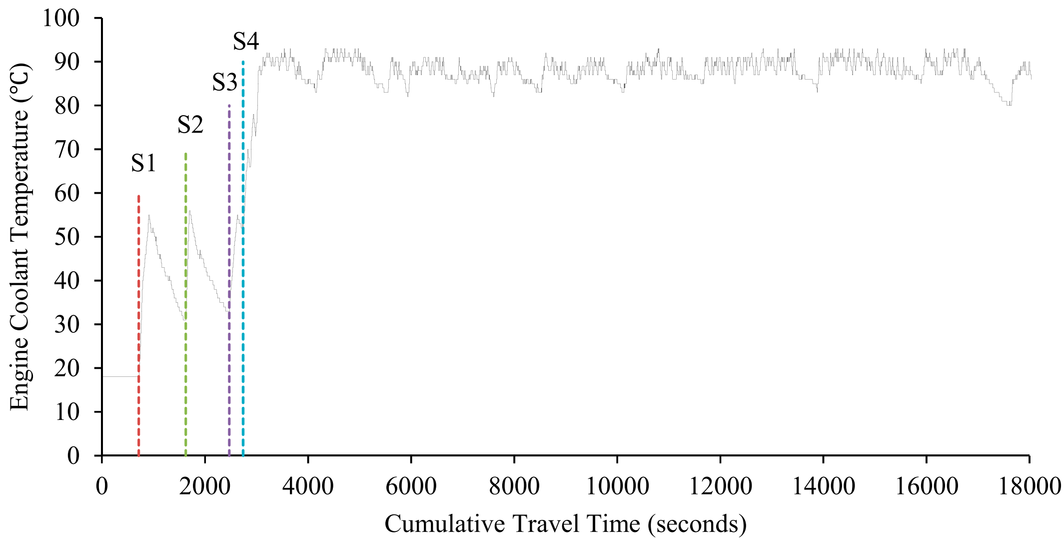

Figure S44 Second-by-Second the Engine Coolant Temperature Data for a 2013 Toyota Prius Plug-In Hybrid Measured on January 21, 2013 in Raleigh/Research Triangle Park, NC Area
Note: S# indicates number # engine start time.

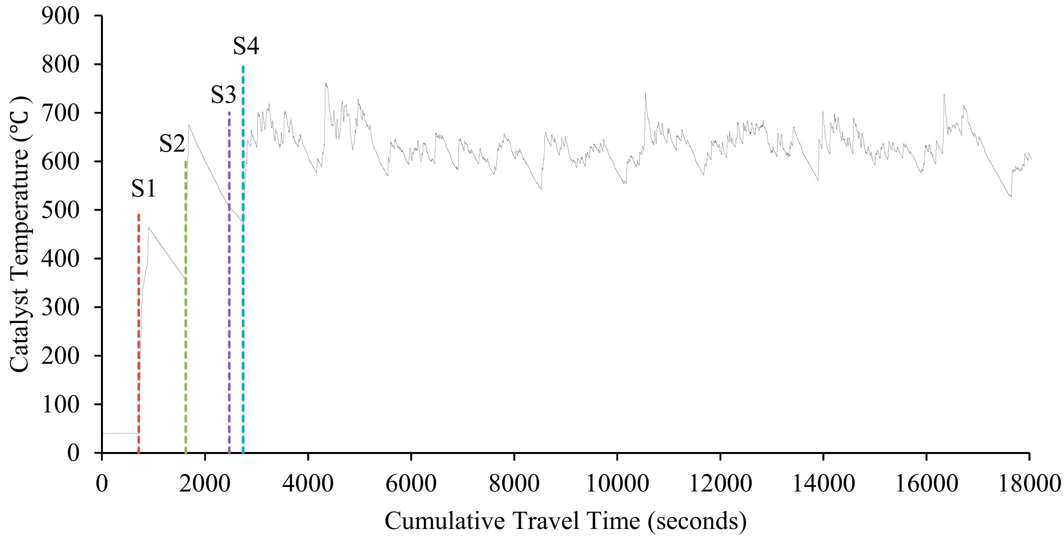

Figure S45 Second-by-Second the Catalyst Temperature Data for a 2013 Toyota Prius Plug-In Hybrid Measured on January 21, 2013 in Raleigh/Research Triangle Park, NC Area
Note: S# indicates number # engine start time.

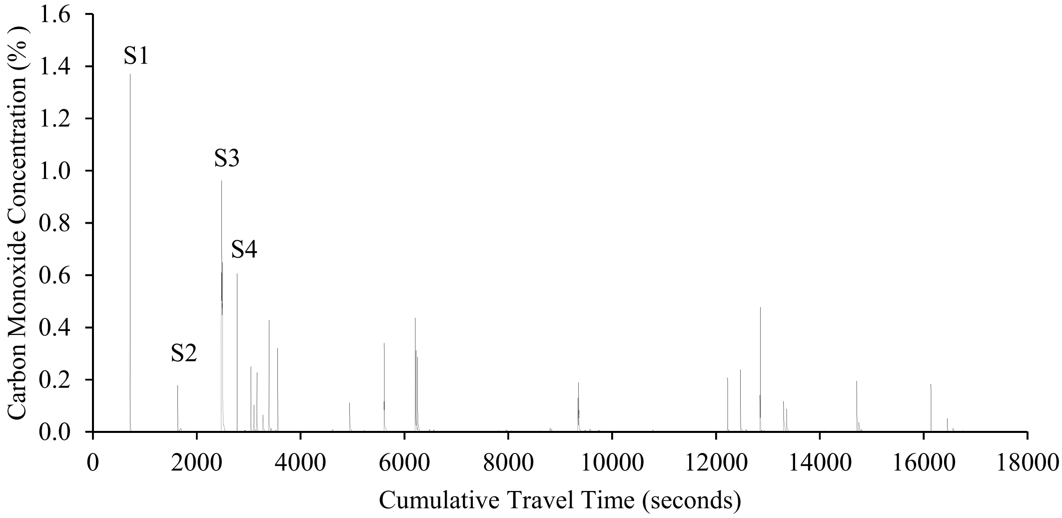

Figure S46 Second-by-Second the Carbon Monoxide (CO) Concentration Data for a 2013 Toyota Prius Plug-In Hybrid Measured on January 21, 2013 in Raleigh/Research Triangle Park, NC Area
Note: S# indicates number # engine start time.

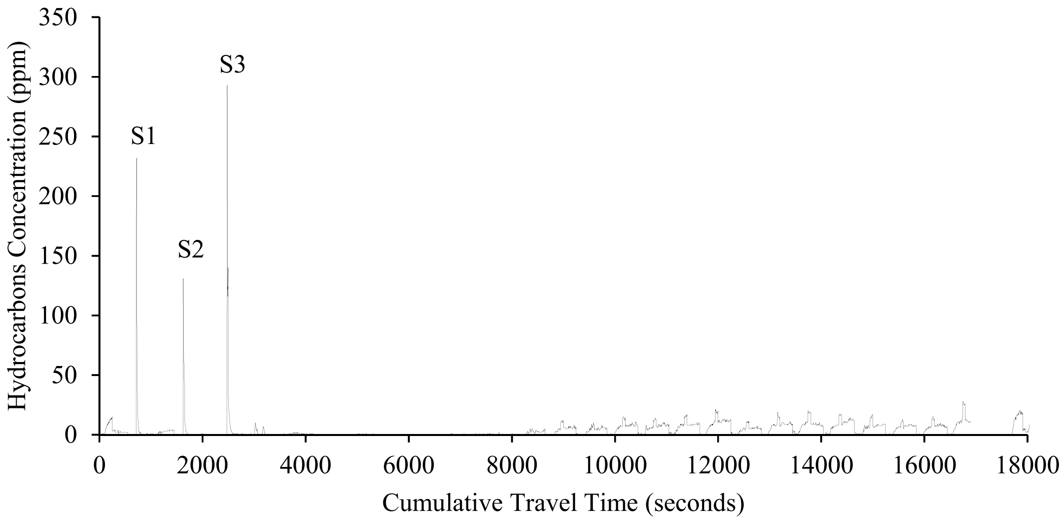

Figure S47 Second-by-Second the Hydrocarbons (HC) Concentration Data for a 2013 Toyota Prius Plug-In Hybrid Measured on January 21, 2013 in Raleigh/Research Triangle Park, NC Area
Note: S# indicates number # engine start time.

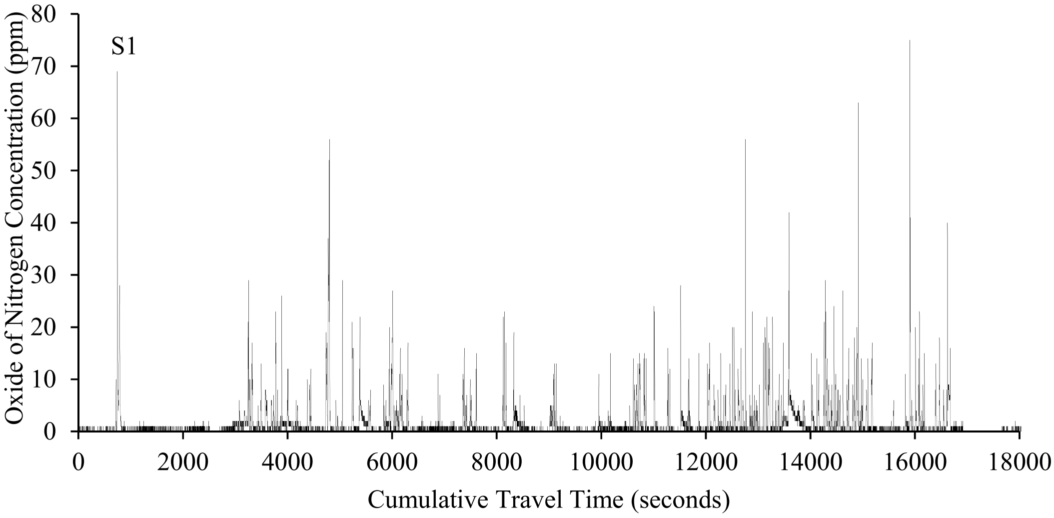

Figure S48 Second-by-Second the Oxide of Nitrogen (NO_x) Concentration Data for a 2013 Toyota Prius Plug-In Hybrid Measured on January 21, 2013 in Raleigh/Research Triangle Park, NC Area

Table S23 The Total Travel Time Spent in Each Vehicle Specific Power (VSP) Mode for Cold Start and Hot Stabilized Running During Engine On for a 2013 Toyota Prius Plug-In Hybrid Measured from January 18, 2013 to January 25, 2013 in Raleigh/Research Triangle Park, North Carolina Area

VSP Mode	Hot Stabilized Running (s)	Cold Start (s)
1	3451	130
2	1249	99
3	1556	1428
4	4278	227
5	7454	148
6	8676	178
7	7932	97
8	6333	39
9	3863	43
10	2924	35
11	1839	14
12	723	2
13	225	0
14	45	0

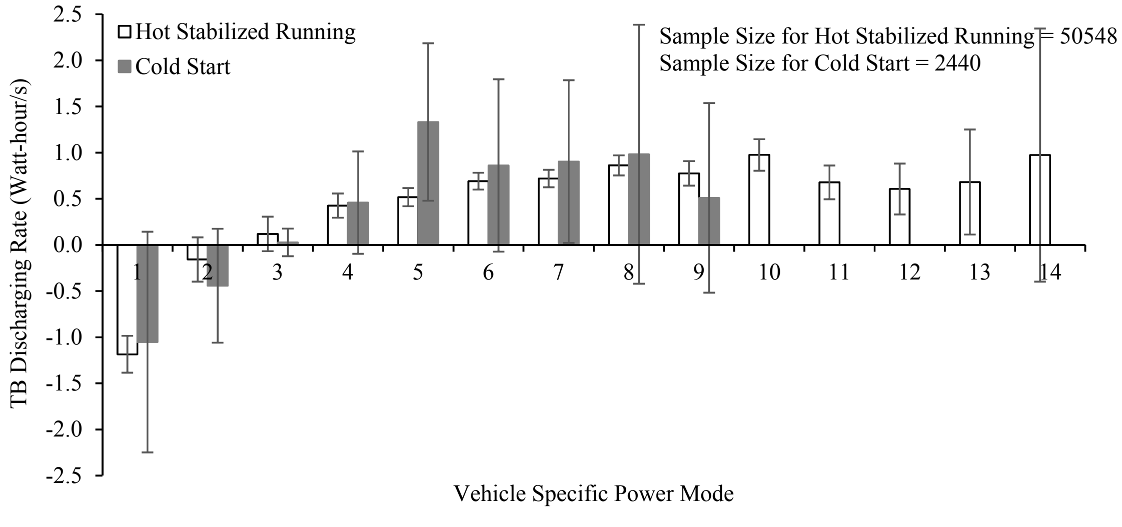

Figure S49 The Average Traction Battery (TB) Discharging Rate Versus Vehicle Specific Power (VSP) Mode for Cold Start and Hot Stabilized Running During Engine On for a 2013 Toyota Prius Plug-In Hybrid Measured from January 18, 2013 to January 25, 2013 in Raleigh/Research Triangle Park, North Carolina Area

Note: There is no data point for cold start in VSP modes 13 and 14, and the value for VSP modes10 to 12 is 0. Error bars indicate 95% confidence intervals on the mean based on second-by-second variability. Sample size in each VSP mode is shown in Table S23. For VSP modes 5, and 10 to 12, the differences of TB discharging rates between cold start and hot stabilized running, are statistically significant, and for other VSP modes, the differences are not statistically significant.

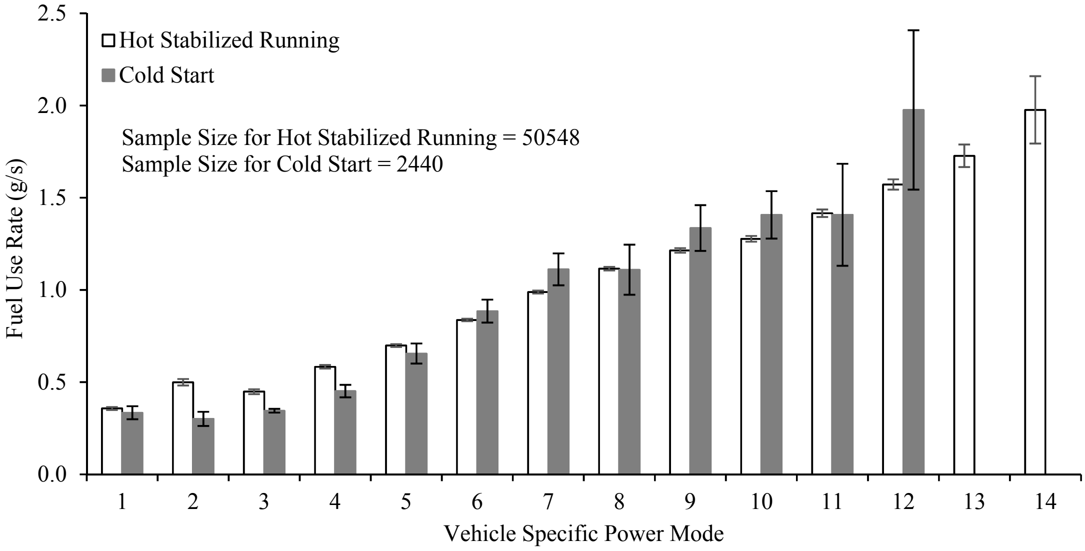

Figure S50 The Average Fuel Use Rate Versus Vehicle Specific Power (VSP) Mode for Cold Start and Hot Stabilized Running During Engine On for a 2013 Toyota Prius Plug-In Hybrid Measured from January 18, 2013 to January 25, 2013 in Raleigh/Research Triangle Park, North Carolina Area

Note: There is no data point for cold start in VSP modes 13 and 14. Error bars indicate 95% confidence intervals on the mean based on second-by-second variability. Sample size in each VSP mode is shown in Table S23. For VSP modes 2 to 4, 7, 9, 10, and 12, the differences of fuel use rates between cold start and hot stabilized running, are statistically significant, and for other VSP modes, the differences are not statistically significant.

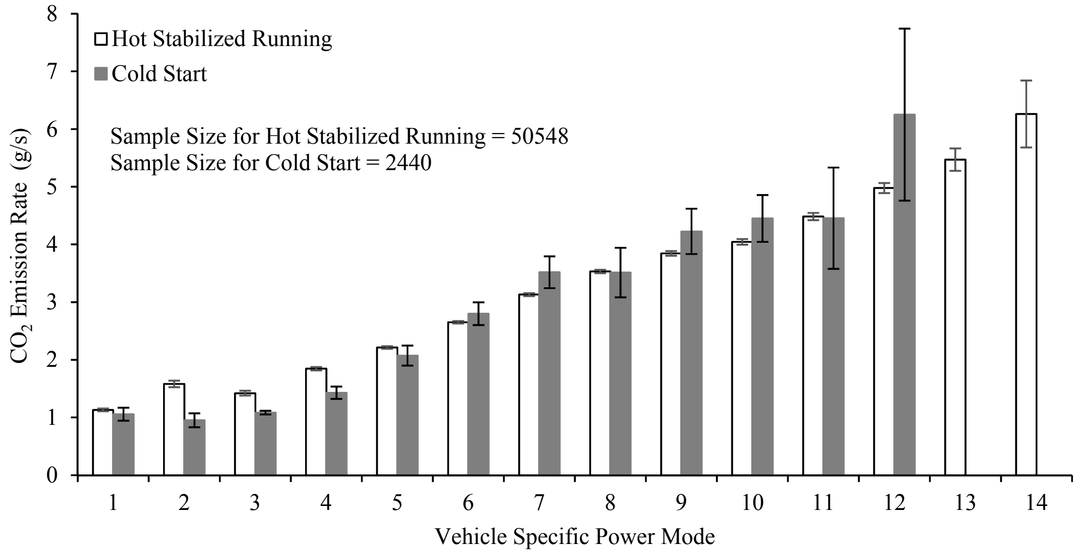

Figure S51 The Average Tailpipe Carbon Dioxide (CO_2) Emission Rate Versus Vehicle Specific Power (VSP) Mode for Cold Start and Hot Stabilized Running During Engine On for a 2013 Toyota Prius Plug-In Hybrid Measured from January 18, 2013 to January 25, 2013 in Raleigh/Research Triangle Park, North Carolina Area

Note: There is no data point for cold start in VSP modes 13 and 14. Error bars indicate 95% confidence intervals on the mean based on second-by-second variability. Sample size in each VSP mode is shown in Table S23. For VSP modes 2 to 4, 7, 9, 10, and 12, the differences of CO_2 emission rates between cold start and hot stabilized running, are statistically significant, and for other VSP modes, the differences are not statistically significant.

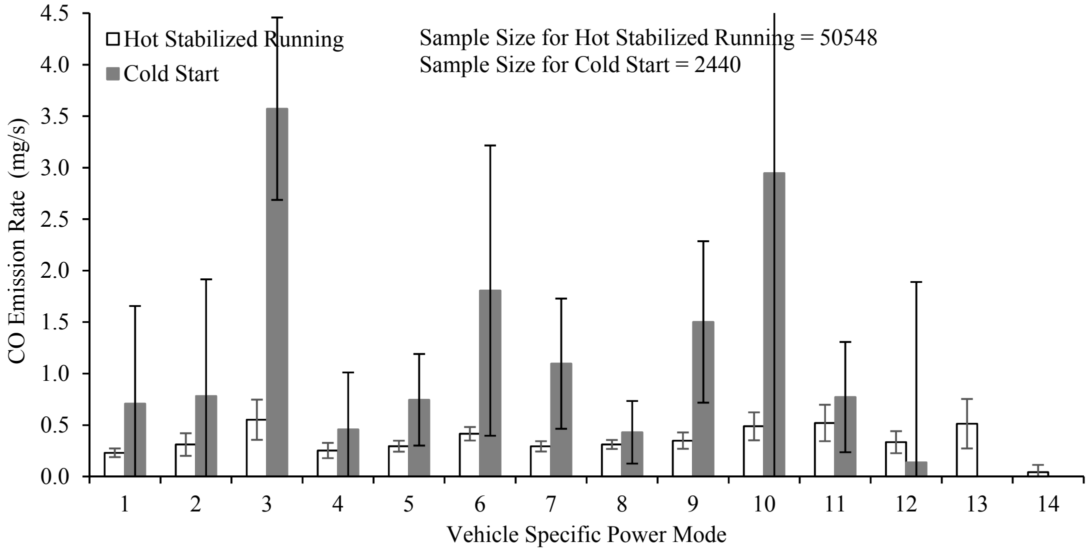

Figure S52 The Average Tailpipe Carbon Monoxide (CO) Emission Rate Versus Vehicle Specific Power (VSP) Mode for Cold Start and Hot Stabilized Running During Engine On for a 2013 Toyota Prius Plug-In Hybrid Measured from January 18, 2013 to January 25, 2013 in Raleigh/Research Triangle Park, North Carolina Area

Note: There is no data point for cold start in VSP modes 13 and 14. Error bars indicate 95% confidence intervals on the mean based on second-by-second variability. Sample size in each VSP mode is shown in Table S23. For VSP modes 3, 5 to 7, and 9, the differences of CO emission rates between cold start and hot stabilized running, are statistically significant, and for other VSP modes, the differences are not statistically significant.

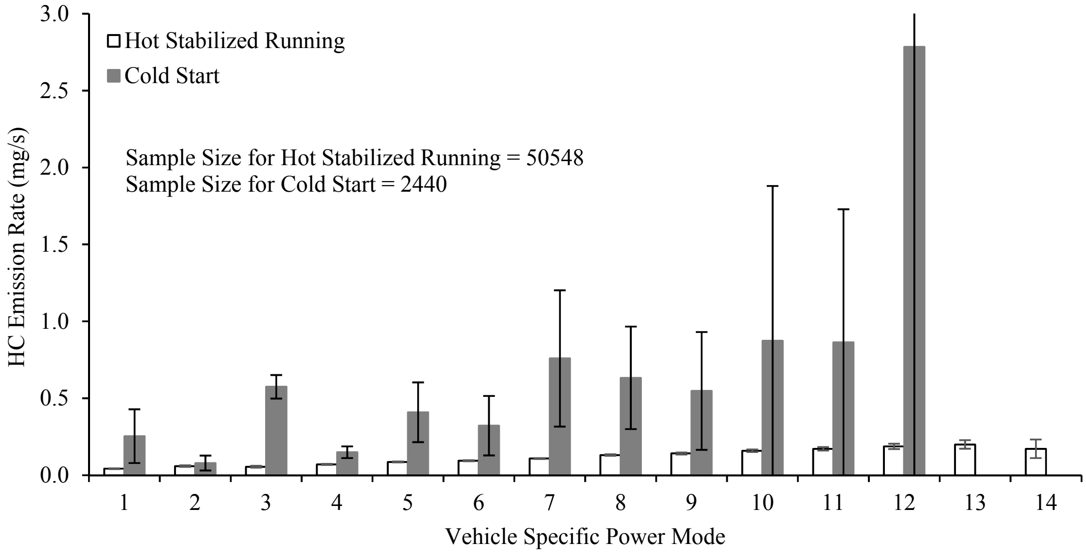

Figure S53 The Average Tailpipe Hydrocarbon (HC) Emission Rate Versus Vehicle Specific Power (VSP) Mode for Cold Start and Hot Stabilized Running During Engine On for a 2013 Toyota Prius Plug-In Hybrid Measured from January 18, 2013 to January 25, 2013 in Raleigh/Research Triangle Park, North Carolina Area

Note: There is no data point for cold start in VSP modes 13 and 14. Error bars indicate 95% confidence intervals on the mean based on second-by-second variability. Sample size in each VSP mode is shown in Table S23. For VSP modes 1, 3 to 9, and 11, the differences of HC emission rates between cold start and hot stabilized running, are statistically significant, and for other VSP modes, the differences are not statistically significant.

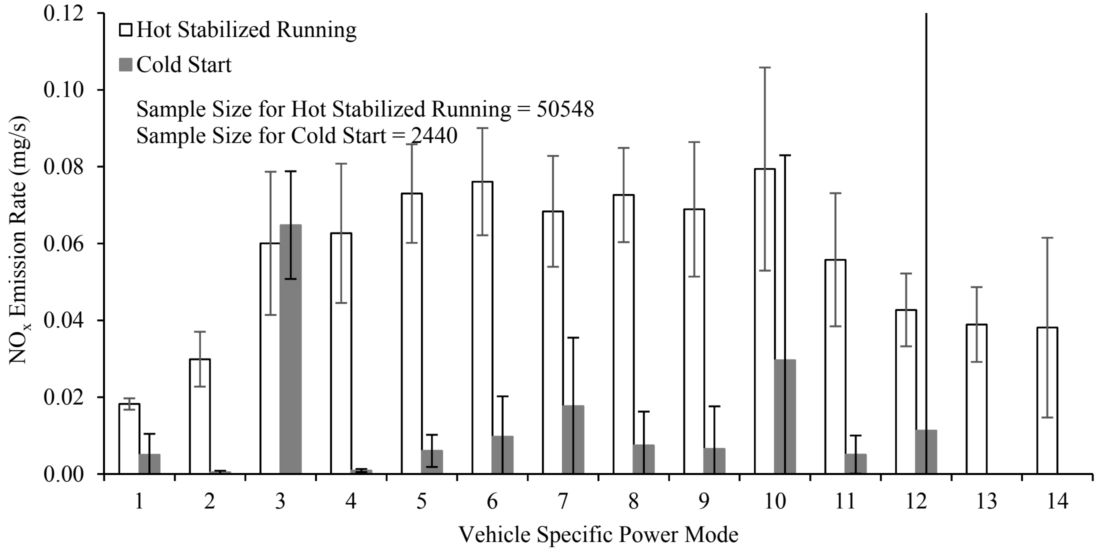

Figure S54 The Average Tailpipe Oxides of Nitrogen (NO_x) Emission Rate Versus Vehicle Specific Power (VSP) Mode for Cold Start and Hot Stabilized Running During Engine On for a 2013 Toyota Prius Plug-In Hybrid Measured from January 18, 2013 to January 25, 2013 in Raleigh/Research Triangle Park, North Carolina Area

Note: There is no data point for cold start in VSP modes 13 and 14. Error bars indicate 95% confidence intervals on the mean based on second-by-second variability. Sample size in each VSP mode is shown in Table S23. For VSP modes 1, 2, and 4 to 12, the differences of NO_x *emission rates between cold start and hot stabilized running, are statistically significant, and for other VSP modes, the differences are not statistically significant.*

Table S24 The Air to Fuel Ratio Versus Vehicle Specific Power (VSP) Mode for Cold Start and Hot Stabilized Running

VSP Mode	Cold Start	Hot Stabilized Running
1	15.1	15.6
2	15.0	15.9
3	15.1	17.3
4	15.0	16.5
5	15.1	16.4
6	15.0	16.1
7	15.2	16.0
8	15.2	15.7
9	15.1	15.6
10	15.2	15.5
11	15.6	15.4
12	16.0	15.3
13	--	15.2
14	--	15.2

Note: There is no data point for cold start in VSP modes 13 and 14. For VSP modes 1 to 10, the differences of air to fuel ratios between cold start and hot stabilized running, are statistically significant, and for other VSP modes, the differences are not statistically significant.

Table S25 The Average Cold Start Cycle Time Distribution Versus Vehicle Specific Power (VSP) Mode

VSP Mode	Number of Seconds in Average Cold Start Cycle
1	9
2	7
3	102
4	16
5	11
6	13
7	7
8	3
9	3
10	3
11	1
12	0
13	0
14	0

Note: Average cold start cycle is average number of seconds for 1 cold start in each VSP mode. For VSP modes 13 and 14, there is no data point, and for VSP 12, there are 0.14 seconds of data, shown as 0.

Table S26 The Differences of Cycle Average Energy Use and Tailpipe Emission Rates between Cold Start and Hot Stabilized Running Based on Average Cold Start Cycle

Cycle Average Energy Use and Tailpipe Emission Rates	Hot Stabilized Running	Cold Start	Difference
Traction Battery Discharging (Watt-hour/s)	0.20	0.19	-4%
Fuel Use (g/s)	0.57	0.49	-13%
CO_2 (g/s)	1.79	1.56	-13%
CO (mg/s)	0.45	2.50	453%
HC (mg/s)	0.07	0.48	616%
NO_x (mg/s)	0.06	0.04	-32%

*Note: Difference = (Cold Start-Hot Stabilized Running)/Hot Stabilized Running × 100%*n