Emissions and Performance Testing of Plug-in Hybrid Electric Vehicles

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Executive Summary

1. Purpose

- develop a better understanding of battery charging/depletion, fuel economy and emissions characteristics of converted PHEVs through testing.

2. Methodology

- With two converted PHEVs (Priuses) from the City of Houston (CoH)'s vehicle fleet,
- Battery charge/depletion and idling testing under controlled environment;
- In-use real-world energy usage and driving characteristics data collection; and
- In-use real-world emissions and fuel economy testing.

3. Findings

- At higher ambient temperature, PHEV battery recharging time was longer, and its depletion rates were generally lower.
- Operations during the PHEV mode (i.e., no engine operations) can save, on average, about 0.6 gallons of fuel and reduced about 5.4kg, 0.4g, 6.4g and 5.4g of CO_2, NOx, CO and HC, respectively, for one hour of idling over (regular) HEV modes.
- Overall, operations of the vehicles were assisted with or powered by PHEV batteries during the cruising or slow acceleration at a speed range of 0 and 50 mph, or during the idling. At speeds over 50 mph, the vehicles were powered solely by their engines.
- Overall, PHEV energy usage (from the PHEV battery) was 0.17 kWh/mi. It varied during the different driving characteristics, 0.12 – 0.56 kWh/mi.
- Overall, fuel economy was 36.8 & 40.9 mpg for vehicle 1 & 2, respectively, during the PHEV modes while it was 29.3 and 32.3 mpg for vehicle 1 & 2, respectively, during the (regular) HEV modes (i.e., when PHEV batteries were fully depleted).
- Overall, compared during the HEV mode, operations during the PHEV mode reduced CO_2 emissions by 21% for both vehicles and NOx by 13 and 60% for vehicle 1 & 2, respectively. For CO emissions, PHEV mode operations produced approximately 75% less emissions (for hot and stabilized emissions comparisons).

Test Methodologies

- Vehicles: 2 Toyota 2009 Priuses on which A123 Hymotion™ L5 Plug-In Conversion Modules (PCMs), including PHEV battery packs, were installed.

❖ A PCM on a test vehicle

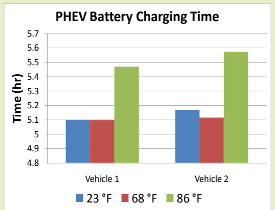
- PHEV battery recharge/depletion testing under controlled environment (23, 68, 86˚F) at TTI's drive-in environmental test chamber (EERF) at the test modes of
  - **A/C mode**: A/C on with the MAX fan speed and re-circulation at 68 & 86°F
  - **Heat mode**: heater on with the MAX fan speed and re-circulation at 23 & 68°F
  - **Key-In mode**: vehicle is on without A/C nor heater on at only at 68°F
- Cold-start and idling (emissions) testing with fully depleted PHEV batteries under the same temperature conditions (23, 68, & 86°F) for the same (A/C, Heat, & Key-In) modes.

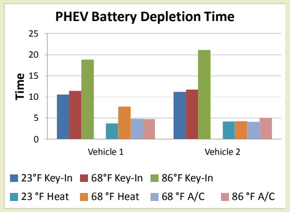
❖ A test vehicle inside TTI's EERF for battery and idling testing

- In-use real-world energy usage and driving characteristics data collection with using GPS (vehicle speeds) and data loggers (battery state-of-charge [SOC]).
- In-use real-world emissions and fuel economy testing with using portable emissions measurement systems (PEMS)

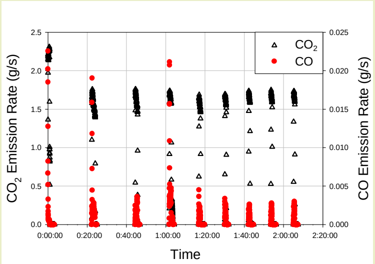
❖ In-use real-world testing with a GPS, a data logger and PEMS

Test Results – PHEV Battery





Test Results – Idling Emissions

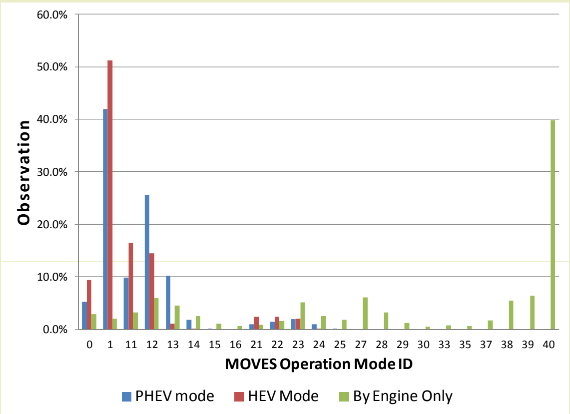


- Depleted PHEVs (i.e., regular HEVs) – three different types of idling emissions
  - The first (cold-start) emissions peak
  - Transient emissions peaks
  - Stabilized emissions peaks
- No continuous idling (i.e., automatic engine on-off cycles)
- For an hour of idling over regular HEVs (i.e., depleted PHEVs), charged PHEVs, which do no idle, can save 0.6 gallons of fuel and reduce about 5.4kg of CO_2, 6.4g of CO, 0.4g of NOx, and 5.4g of HC emissions, on average.

Test Results – Driving Characteristics

Vehicle/Mode*	Total vehicle miles driven	PHEV battery SOC usage (%/mi)
Vehicle 1/PHEV mode	50.2	3.31
Vehicle 1/HEV mode	18.3	Not Applicable
Vehicle 2/PHEV mode	37.1	3.45
Vehicle 2/HEV mode	79.7	Not Applicable

* PHEV mode: vehicles driven by or with assistance of both PHEV and HEV batteries, HEV mode: by HEV battery only.



Test Results – In-Use Real-World Emissions

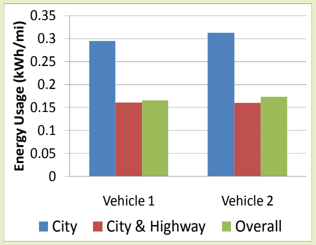
Emission Rate (g/mi) for the overall driving*

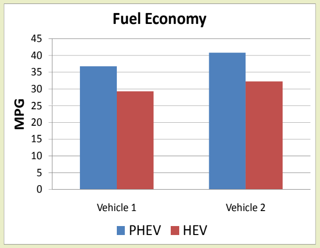
	Vehicle 1			Vehicle 2		
	CO_2	NOx	CO*	CO_2	NOx	CO*
PHEV mode	248	0.048	0.0007	223	0.053	0.0015
HEV mode	312	0.056	0.0025	282	0.132	0.0070
Emission Reduction	21%	13%	72%	21%	60%	78%

* Measured PM emissions were under the detection limits or negligible, and HC emission data were unavailable due to malfunctioning of HC analyzers.

* All of the cold start idling emissions (high CO emissions) were belong to the PHEV mode. For fair comparisons, authors compared hot and stabilized emissions results from only MOVES operating mode bin 12 and 13, in which most of the PHEV and HEV operation data were observed compared with any other bins except idling.

Test Results – Energy & Fuel Economy





Conclusions

- Converted PHEVs, the major type of PHEVs on roads, were tested in the aspects of
  - Battery charge/depletion and idling emissions under different temperature conditions along with different test modes at TTI's EERF
  - In-use PHEV battery energy usage and driving characteristics during the real-world operations
  - In-use emissions and fuel economy during the real-world operations
- Battery charge and depletion times were longer at high temperature and with running A/C or Heat, and, while idling, charged PHEV could save fuel and reduce emissions over regular HEVs.
- Real-world energy usage and emissions data were collected along with vehicle driving characteristics data. Battery powered or assisted driving were observed at lower speeds (< 50 mph). Fuel economy was improved and emissions were reduced during the PHEV mode compared to (regular) HEV mode.
- Although the findings of this project is valuable, but the findings were based on the limited resources and time, more studies with following aspects will facilitate and expand this research:
  - More vehicles and more vehicle types such as commercial PHEVs and BEVs
  - Life cycle emissions (including emissions from power generation for recharging)
  - More refined test protocol (especially, to cover driving at higher power)

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