Memorandum

To: Sam Pournazeri, ARB
Jeff Long, ARB

From: John Koupal, ERG
Cindy Palacios, ERG

Date: January 23, 2020

Re: Analysis of PHEV Engine Start Activity in UC Davis Study

This memo documents ERG's final task for ARB project 17AQP005, "Cold Start Emission Impacts of Blended Plug-In Hybrids", an analysis of PHEV engine start activity from instrumented vehicle data. ARB staff is developing PHEV running and start emission factors (EFs) for EMFAC from PEMS data collected on 10 vehicles tested over various routes in Southern California and plans to derive engine-on activity for running EFs from telematics data. To complement this effort, ARB requested that ERG analyze PHEV activity data collected by UC Davis to develop engine start activity inputs for EMFAC.

Data & Processing

Data used for this analysis were provided by UC Davis to ERG in May 2019, gathered during Phases 1 and 2 of the broader ARB research project 12-319, "Advanced Plug-In Electric Vehicle Usage and Charging Behavior".[1] UC Davis provided data on 164 PHEVs, distributed as shown in Figure 1 below. UC Davis produced custom output of real-time data for ERG which consisted of a single flat file per vehicle, populated with the following data fields:

- Date/Time Stamp in UTC (data rate depends on manufacturer, generally < 1 Hz)
- Accelerator Pedal Position (percent)
- Engine RPM
- Vehicle Speed (km/hour)
- Catalyst Temperature (°C)
- State of Charge (percent)

[1] UC Davis PHEV study information available via CARB Research Contract website https://ww3.arb.ca.gov/research/single-project.php?row_id=65206

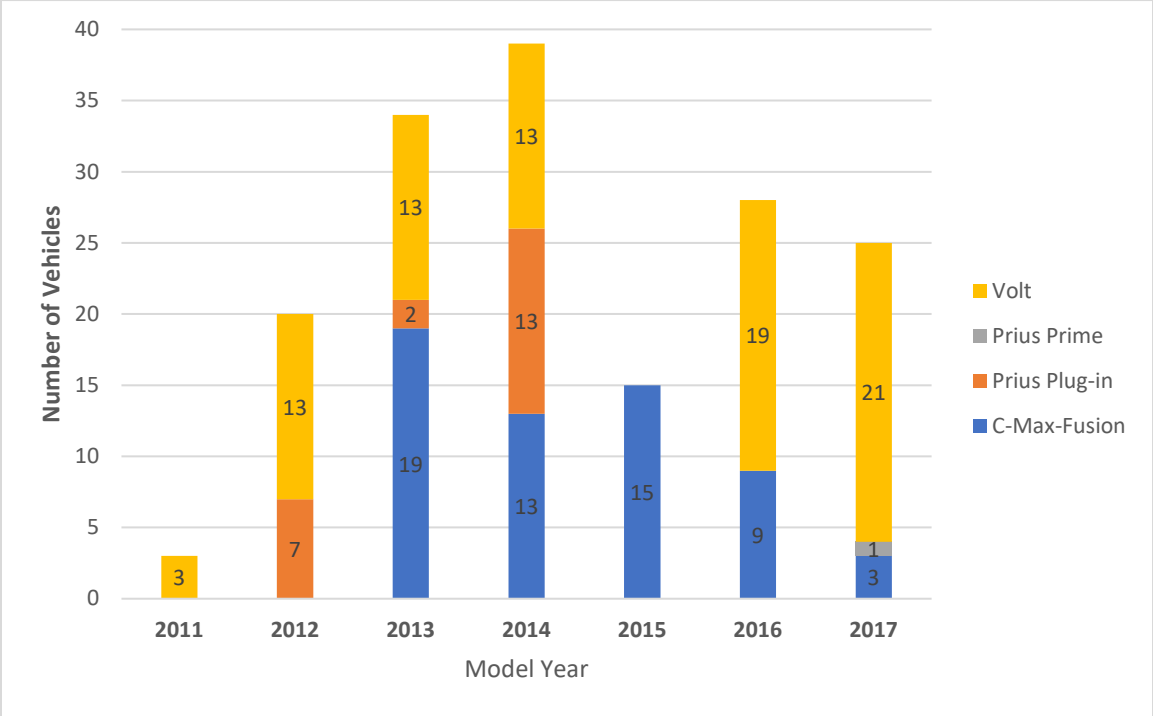

Figure 1. Breakdown of PHEVs Included in Start Analysis

Data from each vehicle were compiled into a single SAS dataset, and UTC time stamps converted to Pacific time accounting for daylight vs. standard time. From this, a summary of engine-on events was generated from raw data, with a record generated for every engine-on event which included test vehicle, time at start of the event, soak time, event duration, and state-of-charge (event summary file "uc davis_phev events_summary.csv" provided to ARB). Only weekday trips were included. Vehicle were categorized as either blended PHEVs or non-blended PHEVs per ARB definitions, to allow separate analysis of each group. For this sample, all Chevrolet Volts were considered non-blended, while the Toyota Prius, Ford CMAX, and Ford Fusion were deemed blended. For activity calculations, "starts" are separated by first engine-on event in a vehicle trip (first start) versus all subsequent engine-on events (non-first start). All initial engine-on events in each trip are included in the first-start activity distributions. Non-first starts are included only if following an engine-off period (soak time) of 5 minutes or longer.

Start activity was characterized separately for 4 categories:

1. Blended PHEV, first start
2. Blended PHEV, non-first start
3. Non-Blended PHEV, first start
4. Non-Blended PHEV, non-first start

Vehicles in the dataset were weighted according to their prevalence in the California fleet as determined by 2019 California DMV registration counts provided by ARB (Table 1). The sample of blended hybrids was weighted by vehicle model and model year, while the non-blended Chevrolet Volts were weighted by model year only. These weighting factors were used in calculation of starts per day, start hour distribution, and soak time distribution discussed it the next section.

Table 1. Vehicle Weighting Factors

Category	Model	Model Year	DMV Count	Weight
Non-Blended	Chevy Volt	2011	1,239	2.1%
		2012	4,142	7.1%
		2013	10,644	18.2%
		2014	10,745	18.4%
		2015	6,011	10.3%
		2016	6,250	10.7%
		2017	19,504	33.3%
Blended	Ford CMAX Energi	2013	12,664	2.9%
		2014	6,019	1.4%
		2015	6,328	1.5%
		2016	6,396	1.5%
		2017	4,867	1.1%
	Ford Fusion Energi	2013	27,149	6.3%
		2014	36,102	8.4%
		2015	23,859	5.5%
		2016	42,888	10.0%
		2017	40,073	9.3%
	Toyota Prius	2012	65,846	15.3%
		2013	75,403	17.5%
		2014	66,478	15.4%
		2017	16,867	3.9%

Results

The data were processed to estimate three start activity distributions for EMFAC: starts per day, start temporal distribution, and soak time distribution.

Starts per Day

With engine-on events defined as starts as outlined above, weighted starts per vehicle-day for the four PHEV analysis categories are show in Table 2. For comparison, the number of total non-first engine-on events are shown, reflecting the large number of these events that occurs within minutes of the previous event (and thus not defined as a "start" for the purpose of this analysis). Analysis of engine-on events with soaks less than 5 minutes shows that roughly 90 percent occur within one minute the preceding event.

Table 2. Starts/Vehicle-Day by Analysis Category

Category	First Starts	Non-First Starts	All Non-First Events
Non-Blended	2.46	1.56	29.4
Blended	4.16	1.65	92.4

Start Hour Distribution

The distribution of daily starts by hour of the day were calculated for each analysis group, shown in Figure 2. These were populated into the EMFAC *start hour distribution* input table format and delivered to ARB.

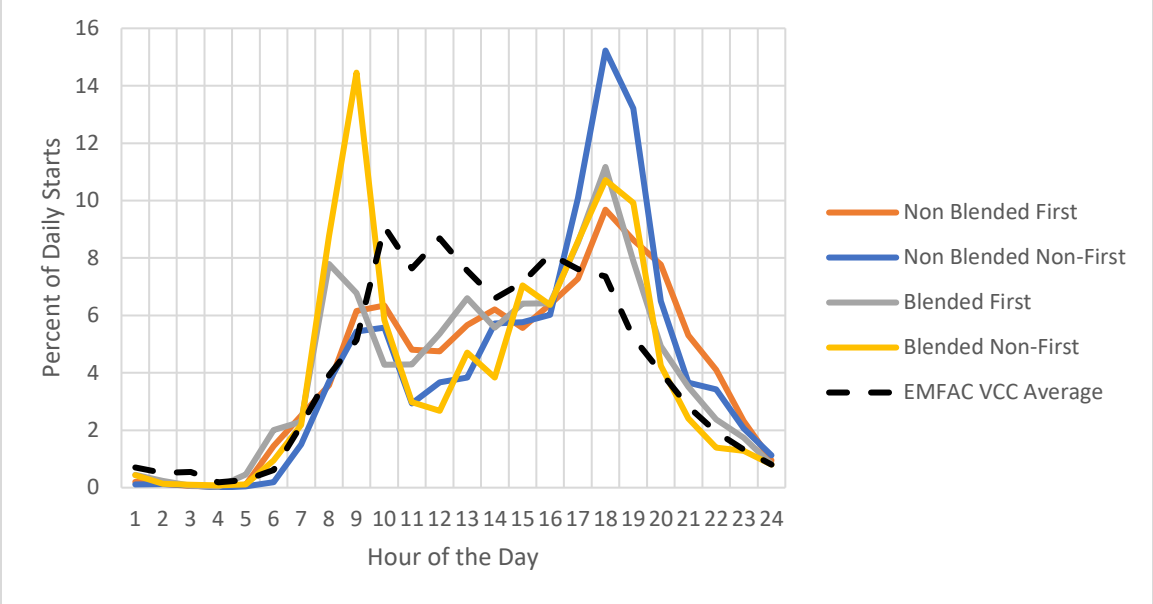

Figure 2. PHEV Start Hour Distributions

Soak Time Distribution

The percentage of soak period lengths for each hour (referred to in EMFAC as "time off" distributions) were summarized for the four analysis groups, per soak period bins from EMFAC2017 Technical Documentation, Appendix 6.14. These were populated into the EMFAC *soak time distribution* input table format and delivered to ARB. Results are shown in Figures 3 for first starts, and Figure 4 for non-first starts, summarized across all hours. For first starts the soak times encompass when the vehicle is off (as with conventional vehicles) plus time between when the vehicle begins operation and the engine is on (unique to PHEVs), and resembles conventional vehicles, since vehicle-off time dominates for longer parked events (such as overnight). Soak bins shown in Figure 3 are aggregated for soak bins less than 60 minutes, and over 720 minutes, for brevity. For first starts, differences between non-blended vs. blended vehicles appear in the higher percentage of long soaks for non-blended vehicles. This follows from differences in engine-on strategy between the two types of vehicles, with non-blended vehicles traveling longer without turning on the engine, until state-of-charge necessitates it.

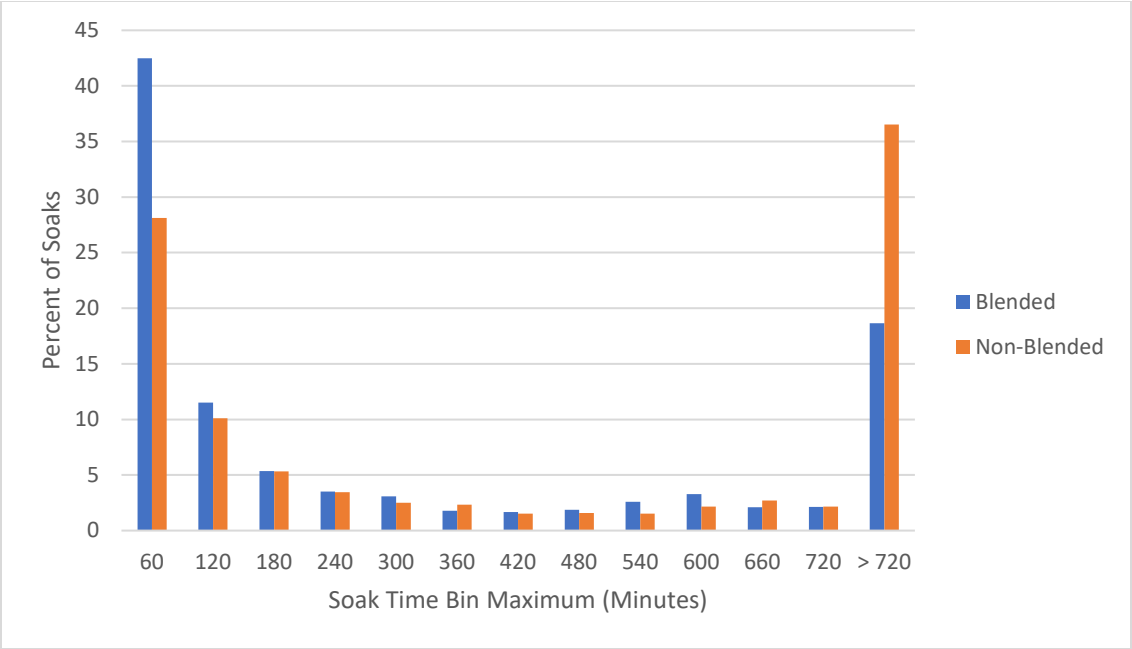

Figure 3. Soak Distributions for First Starts

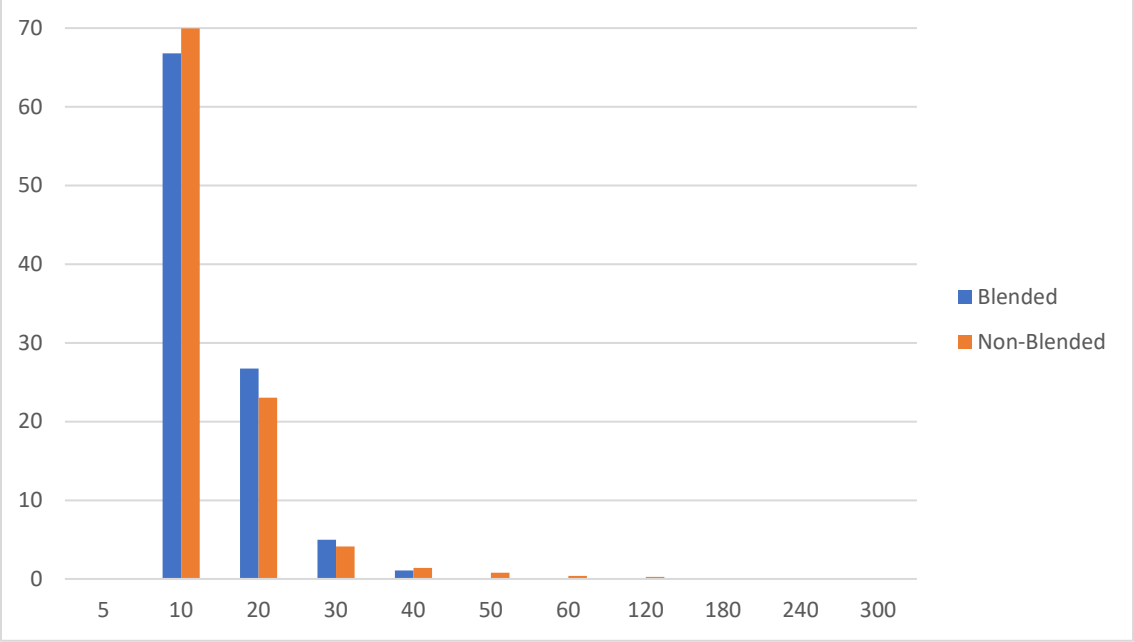

Figure 4. Soak Distributions for Non-First Starts

As shown in Figure 4, the profile for non-first starts much different; note the x-axis soak bins are not aggregated and include only bins under 300 minutes, which include 99.9 percent of non-first soak duration. About 2/3 of soaks are between 5-10 minutes (by definition these data do not include soak times < 5 minutes). For non-first starts there are no discernable differences in soak time between blended and non-blended vehicles, as with the number of events per day, though as illustrated earlier the number of total engine-on events per day is about three times higher for non-blended vehicles.