Characterizing Vehicular Contributions to PM2.5 in Fairbanks, Alaska

Dynamometer-Based Emissions Measurements, Vehicle Keep-Warm Activities and MOVES Analysis

In the fall of 2009, DEC engaged Sierra Research to perform several studies to better characterize vehicular emissions in Fairbanks. The study included four main elements: repeated chassis dynamometer testing of more than 30 vehicles, on-road sampling of more than 1000 vehicles plume using an instrumented vehicle, sampling and recording of in-use engine coolant temperatures of the vehicles to document the state of engine warm-up, and an examination of EPA's mobile emissions model "MOVES" in consideration of the possible need for low-temperature adjustments to the conditions present in Fairbanks Alaska.

Dynamometer Pilot Study:

Sierra Research conducted a pilot dynamometer-based exhaust emission measurement of $PM_{2.5}$ and criteria pollutants during the winter of 2009-2010 on a set of four "normal emitter" and two "high emitter" gasoline powered vehicles, one of which had induced defects. The main purpose of the pilot study was;

1. To upgrade the Fairbanks Cold Temperature Test Facility to provide dilution tunnel-based chassis dynamometer measurement of exhaust $PM_{2.5}$ sampling;
2. To test a selected sample of vehicles to determine the impacts of temperature and plug-in upon $PM_{2.5}$ emissions for the same vehicle at different ambient temperatures; and
3. To assess how well the measured Fairbanks test results compare to the emission estimated from the US EPA's MOVES emissions model based on the Kansas City Study.

The testing was performed when the temperatures ranged from -24^{o}F to 23^{o}F, with and without overnight block heater operation and/or 5-minute warm-up idle, both of which are normal activities in Fairbanks during winter.

Main findings of the pilot study showed that;

1. $PM_{2.5}$ emissions for the COLD Alaska Drive Cycle (ADC) increased exponentially with decreasing ambient temperature by 31% for every 10^{o}F drop in temperature whereas the Kansas City study reported a $PM_{2.5}$ emission increase of 58% for the same temperature drop.
2. For the warm (hot start) phase of testing, both Fairbanks and KC vehicles showed as expected, much lower base emissions than the cold start phase.
3. Based on the Fairbanks testing, block heater plug-in during overnight soaks and a 5-minute warm up idling reduced cold start $PM_{2.5}$ emissions by 74%.

4. Fairbanks winter test results aided in developing a series of modeling equations to predict average $PM_{2.5}$ emission factors.

This study formed the model upon which additional dynamometer studies were performed for other light duty vehicles.

Dynamometer – Based Emissions Measurements

In winter of 2011, the chassis dynamometer-based exhaust emission measurements of $PM_{2.5}$ and criteria pollutant gases were conducted on 32 Fairbanks based light-duty diesel vehicles. The test was to determine the effect of ambient temperature and block heater plug-in upon exhaust emission as performed during the pilot study but with a bigger sample size. Using a chassis dynamometer, equipped with dilution tunnel, and upgraded CVS sampling system, both integrated filter and continuous analyzer-based measurements of $PM_{2.5}$ and other gaseous pollutants were made. Test vehicles were recruited through phone surveys and all accepted vehicles were Alaska-licensed, street legal, and in-use vehicles that were driven during winter. The table below summarized information about the targeted and actual vehicles sampled.

Table 1 .Targeted and Actual Vehicle Samples for Dyno Testing

Vehicle Category	Targeted sample (n>=30)	Actual Sample (n=33)
Trucks	60%	22(67%)
Passenger Cars	40%	11(33%)
MY ≥ 2004	33%	10(30%)
1987-2003	33%	17(52%)
MY ≤ 1986	33%	4(12%)

The procedures and equipments used in testing complied with those specified in the Federal Code of Regulations, with adaption of low temperatures. The testing was conducted at the Fairbanks Cold Temperature Test Facility between January 12 and March 26, 2011, over a range of ambient temperatures from -30° F to 44° F. The selected sample of 32 Fairbanks light-duty diesel vehicles received three tests: one test with block heater plug-in, and two non-plug-in tests targeted for different ambient temperatures. Each test included two phases, referred to as a Cold Alaska Drive Cycle (ADC) and Hot ADC, separated by 10-minute soak (engine off). The Cold

ADC drive was preceded by a 5-minute warm-up idle, which is common practice in Fairbanks. The Alaska Drive Cycle is a time speed driving pattern designed to represent on-road driving in Alaska in winter. It is 816 seconds in duration and 4.7 miles long. Following overnight soak, more than 100 cold start tests were successfully completed on each of the vehicle.

Findings from the dynamometer-based testing showed that use of block heaters, heated garages and extended warm-up idle for light duty vehicles are normal activities in Fairbanks during winter which significantly affects $PM_{2.5}$ emissions. The block heater plug-in during overnight soak and 5-minute warm-up idle after engine start for vehicles parked outside reduced cold start $PM_{2.5}$ emissions by 74%. Based on the filter calibrated continuous analyzer measurements from non-plug in Cold ADC dynamometer drives, most of the $PM_{2.5}$ was emitted within the first 2 minutes after the engine start. In addition to startup, $PM_{2.5}$ emissions tended to spike during the high power accelerations. Graphical presentations of the vehicle test data is displayed below showing the basic trends in emissions for the Cold and Hot ADC cycles. $PM_{2.5}$ emissions from the Cold ADC test fleet are shown in logarithmic form in figures 2 and 3 respectively.

Figure 1: $PM_{2.5}$ Emissions for Cold and Hot Alaska Drive Cycles

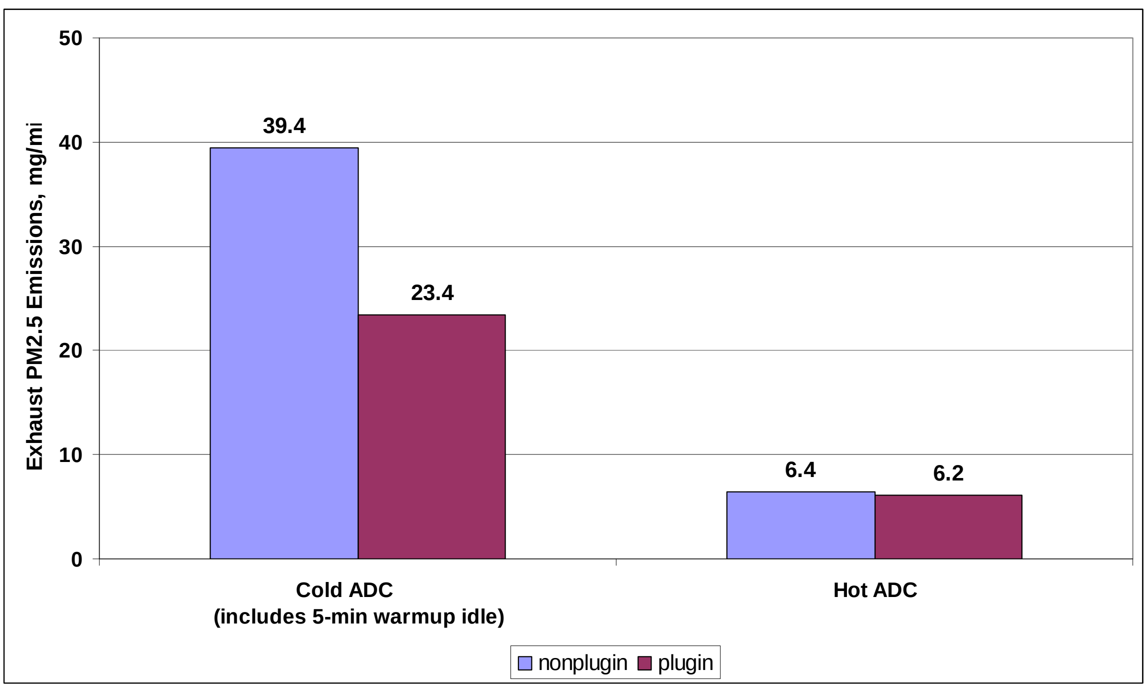


Figure 2: $PM_{2.5}$ Emissions vs. Ambient Temperature, Tests Without Plug-in (n=62) Cold Start + 5-min Warm-Up Idle + ADC (unweighted) with Exponential Trendline

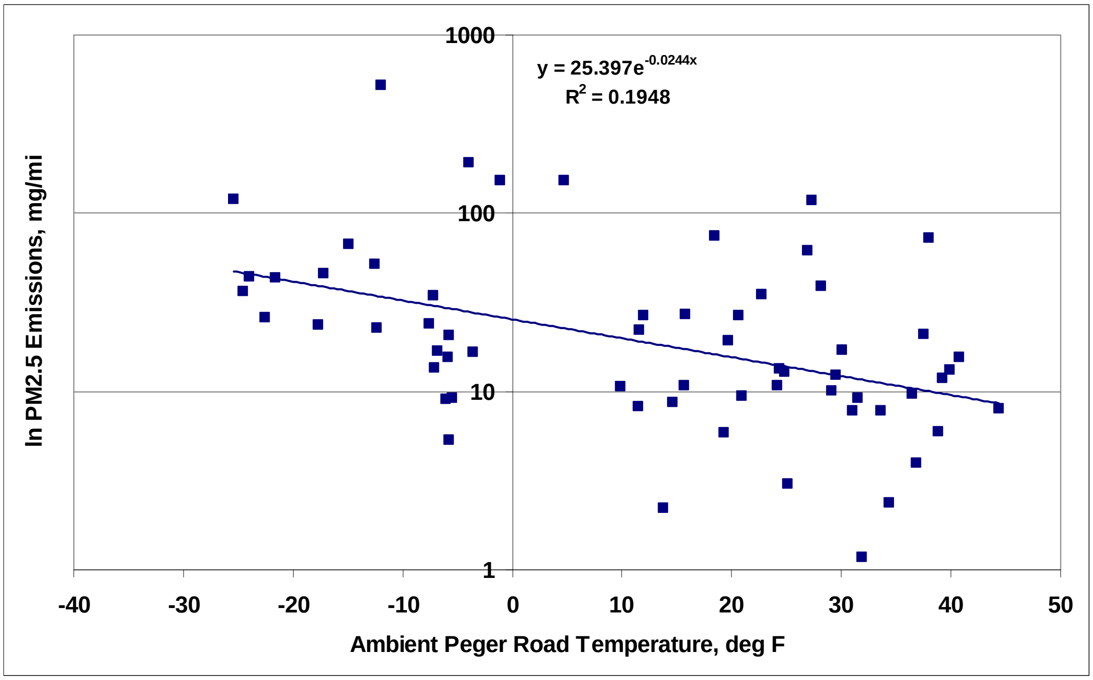
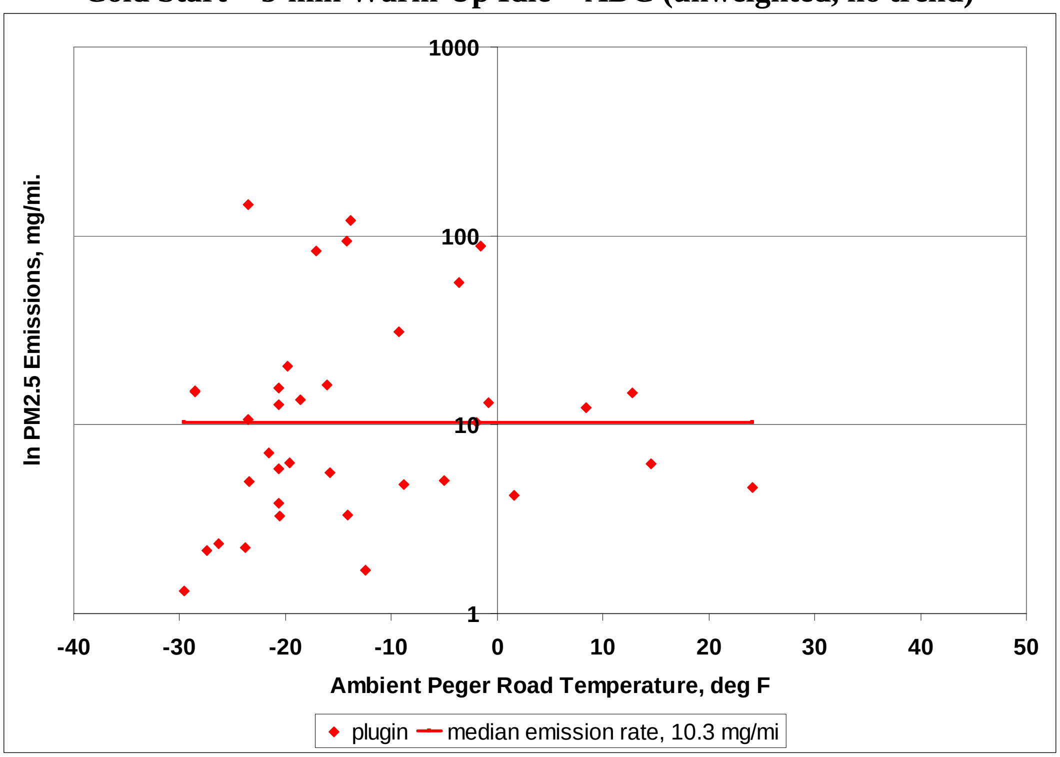


Figure 3
$PM_{2.5}$ Emissions vs. Ambient Temperature for Tests with Plug-in (n=37)
Cold Start + 5-min Warm-Up Idle + ADC (unweighted, no trend)

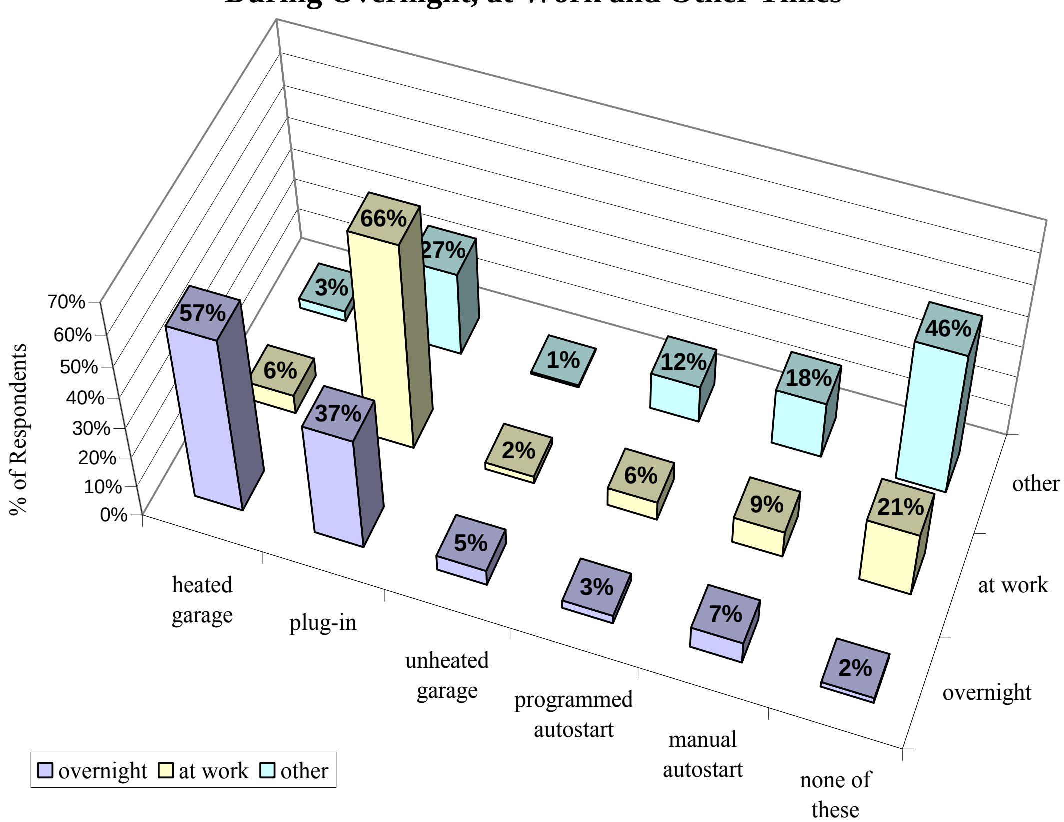


Vehicle Keep Warm Activities

To validate how the public keeps their vehicle warm during winter, a random phone survey of 300 households in 2005 was conducted. The survey showed that plug-in engine block heaters are widely used during Fairbanks winter months to keep the vehicle engine warm if the vehicles are parked outside for more than a few hours. For overnight parking at home, heated garage is the most common "keep warm" strategy and plug in the second most common. For vehicles parked at work, plug-in is the most common keep-warm activity. Figure 4 shows the methods used by Fairbanks residents to keep the vehicles warm. A portion of dynamometer testing was conducted with a CarChipPro datalogger installed in the test vehicles to document the effect of plug-in and engine temperatures. The device logged various vehicle perimeters such as speed, coolant temperature and acted as surrogate for engine temperature.

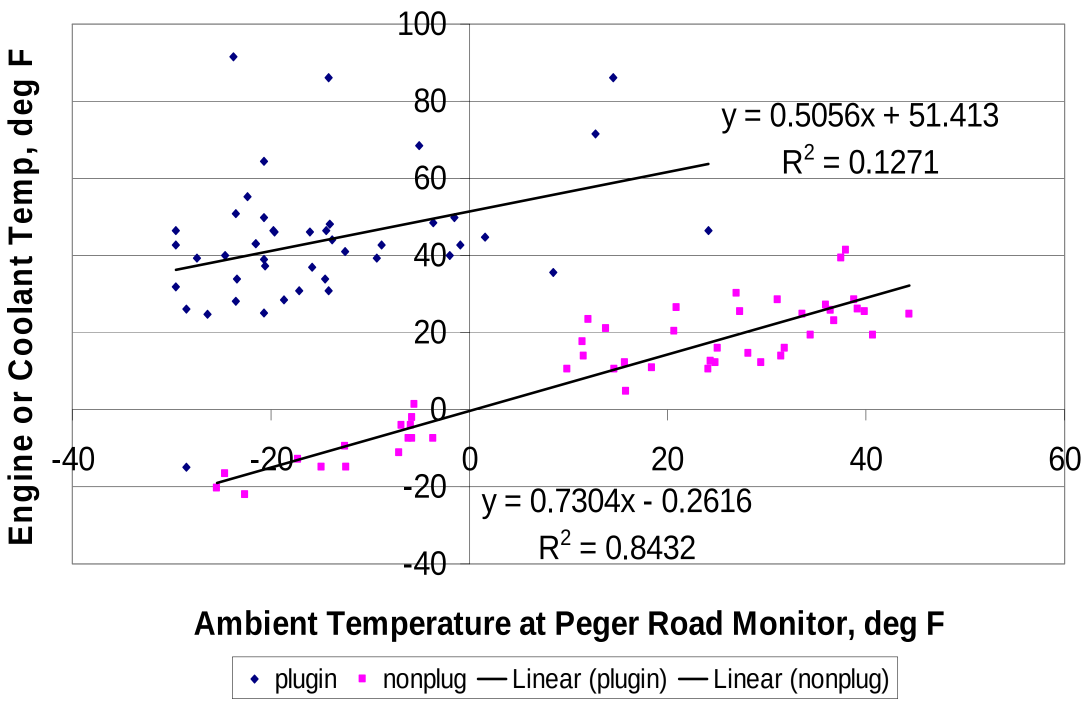
According to the instrumented vehicle data, the coolant temperature was significantly elevated at engine start after extended soaks suggesting that the efforts by the owners/operators to keep the vehicle warm is the key factor in elevated temperatures. The instrumented data also suggested that except for very short soak periods, plug-in is used almost universally for engine starts at ambient temperature below -20°F and plug-in is not used at ambient temperatures above 20°F.

Figure 4
Methods for Vehicle "Keep Warm" and Warm-up During Overnight, at Work and Other Times



The results from engine and coolant temperature measurements are summarized in Figure 5, which shows the corresponding ambient temperature measurements collected by FNSB at its Peger Road monitoring station. Both trend lines are statistically significant, and a comparison of the two shows that plug-in increased engine temperatures by about 50°F over non-plug-in engine temperatures. The plug-in helps in the reduction of $PM_{2.5}$ emissions.

Figure 5
Coolant Temperature vs. Peger Road Ambient Temperature at Start of Test for Plug-in (Upper Points) & Nonplug (Lower Points & Best-Fit Linear Regressions)

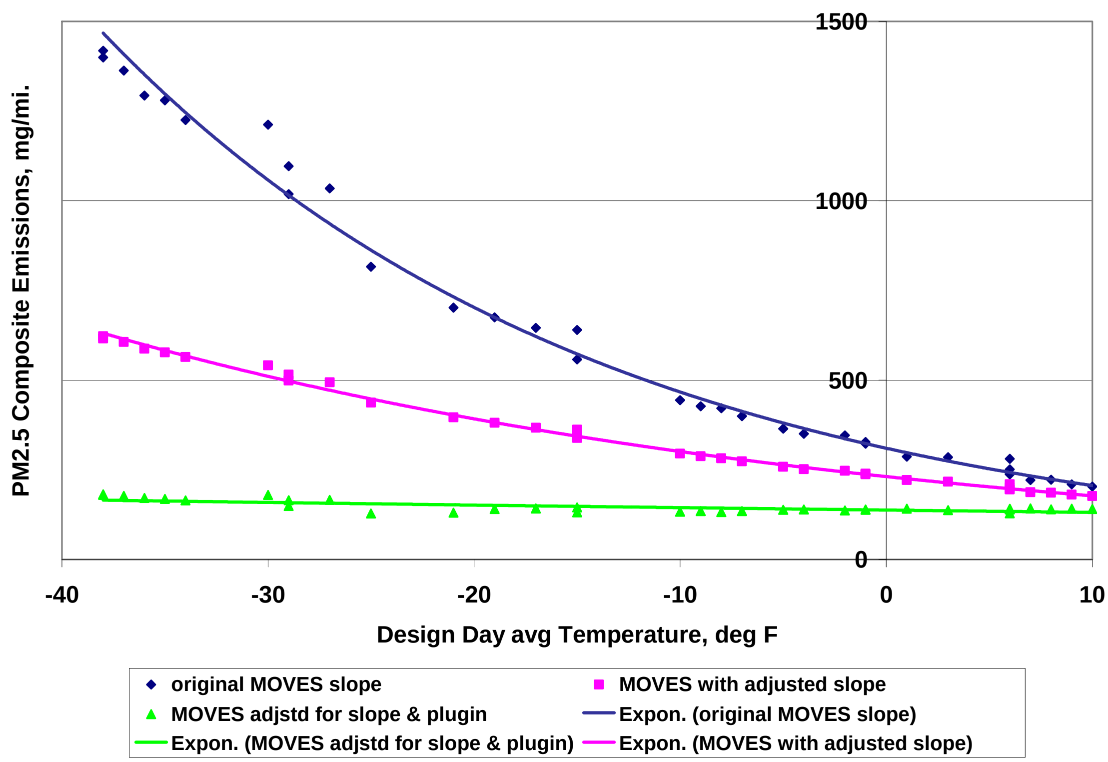


MOVES Analysis

The EPA's latest emission factor model MOVES is programmed to characterize emissions based on the Kansas City PM emission study and does not include the critical issues present in Fairbanks. The PM emissions factors in MOVES, including the temperature corrections of those emissions, are derived from measurements made in Kansas City, where minimum temperature for testing was 12°F and did not account for the impacts of block heaters which are universally used in Fairbanks at temperatures below -20° F. As a result of above limitations, any modeling of Fairbanks PM emissions using MOVES must rely on extrapolation of temperature effects outside the range in which the data were collected. The results from emission testing in Fairbanks in the winter of 2011 confirmed that such extrapolation and assumptions are not technically supportable and could result in overestimating the $PM_{2.5}$ and secondary components emissions for conditions in Fairbanks.

To provide an informed estimate of the effect of several theoretical emissions adjustments to MOVES outputs for Fairbanks, composite emissions for 35 tentatively selected Fairbanks $PM_{2.5}$ design days from 2008 were estimated and compared. Figure 6 shows composite emissions versus average design day temperatures for three alternative emission estimates. The first, and highest curve shown, is a MOVES-based estimate of composite emissions. It is based on the temperature coefficient that is currently in MOVES and is not adjusted for plug-in. The second curve is another MOVE-like estimate but using the lower temperature slope derived from Fairbanks testing (with Kansas City sample weightings). The third estimate is the same as second, except that the effect of plug-in has been factored in.

Figure 6: Composite Emissions vs. Average Daily $PM_{2.5}$ Design Day Temperature for 3 Theoretical Emission Estimates



The figure shows that if corrections to the MOVES model are not taken into account for the conditions present in Fairbanks, than the estimates from the gasoline-powered on-road vehicles will be overestimated for the lowest temperature day by about 680%. Thus, to correctly model the conditions in Fairbanks, the MOVES model had to be modified with Alaska conditions.