On-Road Testing of an LPG Delivery Truck on R-LPG

Final Report

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September 2020

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Acknowledgements

The authors express appreciation to Propane Education and Research Council for funding this project. The authors also thank the following UCR personnel Dr. Ling Cobb, Mr. Mark Villela, Mr. Cavan McCaffery, and Mr. Tianbo Tang, who were involved with setting up and running the field testing with the portable emission measurement system (PEMS).

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Executive Summary

As governmental agencies continue to look for ways to reduce emissions from heavy-duty vehicles, liquefied petroleum gas (LPG) fueled heavy-duty vehicles offer the potential for both improved air quality and reduced greenhouse gas (GHG) emissions. The Propane Education and Research Council (PERC) has sponsored research that demonstrates superior in-use emissions of LPG fueled heavy-duty vehicles as compared to diesel vehicles that conform to the same emissions standards in the lab (especially for urban and stop/go duty cycles). The use of renewable LPG (RLPG) could provide additional benefits in GHG emissions. Specifically, while CARB has assigned a carbon intensity (CI) for conventional LPG (83.19 gCO_2eq/MJ) that is similar to that for average grid electricity (82.92 gCO_2eq/MJ), they have approved a temporary fuel pathway for RLPG (45 and 65 gCO2eq/MJ of fuel depending on the feedstock) that is significantly below that for the grid electric. If renewable propane emits in-use criteria pollutants at the same levels as conventional propane, then heavy-duty vehicles burning RLPG (from the proper feedstocks) could be plausibly marketed as an alternative to electric heavy-duty vehicles being recharged from California's electric grid. PERC research has shown that laboratory emissions from engines burning propane with a high butane component (like renewable propane) are similar to emissions from conventional propane. However, the emissions equivalence of renewable and conventional propane has not yet been demonstrated in-use (in the "real world" outside of the lab).

The objective of this project was to determine whether or not renewable LPG produces criteria emissions that are of any practical difference from conventional LPG. Testing was conducted over a typical in-use operation of a heavy-duty delivery truck. The delivery vehicle was Ford F-750 box truck equipped with a Roush 6.8 liter, near-zero emission (0.02 g-NOx/bHP-hr) LPG engine. This delivery truck was operated by Nestle Waters of Colton, CA over a typical day of operation. The vehicle was tested for three days using a conventional LPG fuel and three days using renewable LPG fuel.

A summary of the PEMS data results is provided below.

- NOx emissions for the truck on the baseline LPG fuel averaged 0.1 on a g/mi basis, 0.029 on a g/bhp basis, 0.4 on a g/gal/fuel basis, 1.68 on g/hour basis, and 1.97 on a g/day basis. For the truck on RLPG, NOx emissions averaged 0.1 on a g/mi basis, 0.027 on a g/bhp basis, 0.42 on a g/gal/fuel basis, 1.69 on g/hour basis, and 2.09 on a g/day basis. Overall, the NOx emissions for the truck were slightly greater, but comparable to the 0.02 g/bhp-hr certification level of the engine. The differences in the average NOx emissions between the conventional and renewable LPG fuels were relatively minor, and were not statistically significant.
- THC emissions for the truck on the baseline LPG fuel averaged 0.04 on a g/mi basis, 0.013 on a g/bhp basis, 0.17 on a g/gal/fuel basis, 0.73 on g/hour basis, and 0.86 on a g/day basis. For the truck on RLPG, THC emissions averaged 0.04 on a g/mi basis, 0.01 on a g/bhp basis, 0.15 on a g/gal/fuel basis, 0.60 on g/hour basis, and 0.75 on a g/day basis. The differences in the average THC emissions between the conventional and renewable LPG fuels were relatively minor, and were not statistically significant.
- CO emissions for the truck on the baseline LPG fuel averaged 3.72 on a g/mi basis, 1.09 on a g/bhp basis, 14.8 on a g/gal/fuel basis, 62.7 on g/hour basis, and 73.6 on a g/day

basis. For the truck on RLPG, CO emissions averaged 3.4 on a g/mi basis, 0.91 on a g/bhp basis, 14.1 on a g/gal/fuel basis, 56.4 on g/hour basis, and 69.7 on a g/day basis. The differences in the average CO emissions between the conventional and renewable LPG fuels were relatively minor, and were not statistically significant.

- CO_2 emissions for the truck on the baseline LPG fuel averaged 1873.6 on a g/mi basis, 553.7 on a g/bhp basis, 7525.1 on a g/gal-fuel basis, 31713.4 on g/hour basis, and 37322.7 on a g/day basis. For the truck on RLPG, CO_2 emissions averaged 1820.9 on a g/mi basis, 491.2 on a g/bhp basis, 7527.8 on a g/gal/fuel basis, 30260.1 on g/hour basis, and 37493.7 on a g/day basis. The differences in the average CO_2 emissions between the conventional and renewable LPG fuels were relatively minor, and were not statistically significant, except for the differences in g/bhp-hr.
- Fuel economy values for the truck on the baseline LPG and RLPG averaged 4.64 and 4.78 miles per gallon, respectively. The differences in the average fuel economy between the conventional and renewable LPG fuels were relatively minor, and was not statistically significant.

Based on the results of this and other studies, the following recommendations are suggested.

- While the in-use emissions for the vehicle were relatively low, being only slightly above the certification standard, it is important to test a broader range of vehicles to provide a more robust evaluation of the in-use emission rates of these vehicles. this should include vehicles representing a wider range of mileages to characterize any deterioration effects.
- It is suggested that additional parameters be added to the ECM output, such that the vehicle performance can be more readily evaluated via data logging. This could include the addition of parameters such as engine torque or fuel consumption.
- It is suggested that a more comprehensive study be conducted to evaluate the potential benefits of more widespread adoption of near-zero emission LPG vehicles. This could include an evaluation of emission inventory benefits as well, as well-to-wheel benefits in greenhouse gases, particularly in the case of renewable LPG.
- In addition to characterizing direct tailpipe emissions, the emissions of secondary organic aerosols (SOA) could also be evaluated to provide a more complete picture of the potential air quality benefits of near-zero emission LPG vehicles.

1 Introduction

1.1 Background

As governmental agencies continue to look for ways to reduce emissions from heavy-duty vehicles, LPG fueled heavy-duty vehicles offer the potential for both improved air quality and reduced greenhouse gas (GHG) emissions. The PERC has sponsored research that demonstrates superior in-use emissions of LPG fueled heavy-duty vehicles as compared to diesel vehicles that conform to the same emissions standards in the lab (especially for urban and stop/go duty cycles).[1] The use of renewable LPG (RLPG) could provide additional benefits in GHG emissions. Specifically, while CARB has assigned a carbon intensity (CI) for conventional LPG (83.19 gCO_2eq/MJ) that is similar to that for average grid electricity (82.92 gCO_2eq/MJ),[2] they have approved a temporary fuel pathway for RLPG (45 and 65 gCO2eq/MJ of fuel depending on the feedstock)[3] that is significantly below that for the grid electric. If renewable propane emits in-use criteria pollutants at the same levels as conventional propane, then heavy-duty vehicles burning RLPG (from the proper feedstocks) could be plausibly marketed as an alternative to electric heavy-duty vehicles being recharged from California's electric grid. PERC research has shown that laboratory emissions from engines burning propane with a high butane component (like renewable propane) are similar to emissions from conventional propane.[4,5] However, the emissions equivalence of renewable and conventional propane has not yet been demonstrated in-use (in the "real world" outside of the lab).

1.2 Project objective

The purpose of this project is to determine whether or not renewable LPG produces criteria emissions that are of any practical difference from conventional LPG. A practical difference in this case would be in the +/- 20% range or larger. Due to the sample sizes for this project and the low inherent emissions from this engine, large differences will be detectable and small ones will not be. Confidence intervals on the average triplicate result for each fuel will be determined by assuming a Normal distribution for the inter-replicate differences.

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[1] Ryskamp, R., 2019, In-Use Emissions and Performance Testing of Propane-Fueled Engines - PERC Docket 20893 - School Bus Results, Final report by West Virginia University for the Propane Education & Research Council, June.

[2] California Air Resources Board, 2020, Low Carbon Fuel Standard Annual Updates to Lookup Table Pathways - California Average Grid Electricity Used as a Transportation Fuel in California and Electricity Supplied under the Smart Charging or Smart Electrolysis Provision, January.

[3] California Air Resources Board, 2019, Low Carbon Fuel Standard Proposed New Temporary Fuel Pathway - Renewable Propane, May.

[4] Koehler,E., Beier, F., Trebing, J., 2016, P312593 CleanFuel USA 6.0l Report with different Fuel Blends - 6.0L LPG Engine Fuel Blend Testing, Final Report by FEV for CleanFuel USA/Agility, Auburn Hills, MI, August.

[5] Koehler,E., Beier, F., Trebing, J., 2016, P312593 CleanFuel USA 6.0l LPG Engine Certification Report, Final Report by FEV for CleanFuel USA/Agility, Auburn Hills, MI, August.

2 Experimental Approach

This section describes the test approach of the PEMS testing of the LPG delivery on conventional and renewable LPG. The delivery vehicle was Ford F-750 box truck equipped with a Roush 6.8 liter, near-zero emission (0.02 g-NOx/bHP-hr) LPG engine. This delivery truck was operated by Nestle Waters of Colton, CA over a typical day of operation. The vehicle was tested for three days using a conventional LPG fuel and three days using renewable LPG fuel.

2.1 Test Vehicle and Test Fuel

2.1.1 Test Vehicle

The test vehicle was a box truck (Ford F-750) powered by the Roush 6.8 liter, near-zero emission (0.02 g-NOx/bHP-hr) LPG engine. This vehicle was certified to the near-zero emission 0.02 g/bhp-hr NOx standard. The specifications of the vehicle and engine are provided in **Table 2-1**.

Table 2-1. Specifications of LPG 0.02 g/bhp-hr NOx Delivery Vehicle

LPG Vehicle & Engine Specifications	
Manufacturer	Ford Motor Company
Model Year	2018
Model Type	F750
Class	8
Engine Manufacturer	Ford Motor Company
Engine Year	2019
Engine Model	V10 3V
Engine Size	6.8L
Engine Family	KFMXE06.8BW6
HP Rating	320 hp
Torque Rating	460 lb-ft
Transmission	Automatic
GVWR	Up to 33,000 lbs
LPG Vessel Capacity	74 usable liquid gallons at full
LPG Range	Up to 380 miles of range

2.1.2 Test Fuel

The vehicle was tested on a conventional LPG fuel and a Renewable LPG. Typical properties for conventional and renewable LPG are provided in Table 2-2.

Table 2-2. Specifications of the Test Fuels (volume %)

Fuel Component	Conventional LPG[6]	Renewable LPG (RLPG)
Ethane	2.5	3.0
Propane	96.1	90.0
Propylene	0.3	0.0
i-Butane	1.0	3.1
n-Butane	0.2	3.4
i-Pentane	0.0	0.2
n-Pentane	0.0	0.3

[6] Note adds up to 100.1% due to rounding.

2.2 PEMS testing

This section discusses the PEMS Test set up and the Test Routes.

2.2.1 PEMS Test Set Up

The PEMS used for this study were SEMTECH-DS gas-phase analyzers that UCR obtains from the EPA via its CRADA. This system is both capable of 1065 compliance and measurement of carbon monoxide (CO), carbon dioxide (CO_2), total hydrocarbon (THC), and total NOx emissions. These systems measure NO_x using a non-dispersive ultraviolet (NDUV) analyzer, THC using a heated flame ionization detector (HFID), and CO and CO_2 using a non-dispersive infrared (NDIR) analyzer. THC emissions are collected through a line heated to 190°C consistent with the conditions for regulatory measurements. The analyzer provides measurements of the concentration levels in the raw exhaust. Figure 2-1 shows the SEMTECH-DS unit.

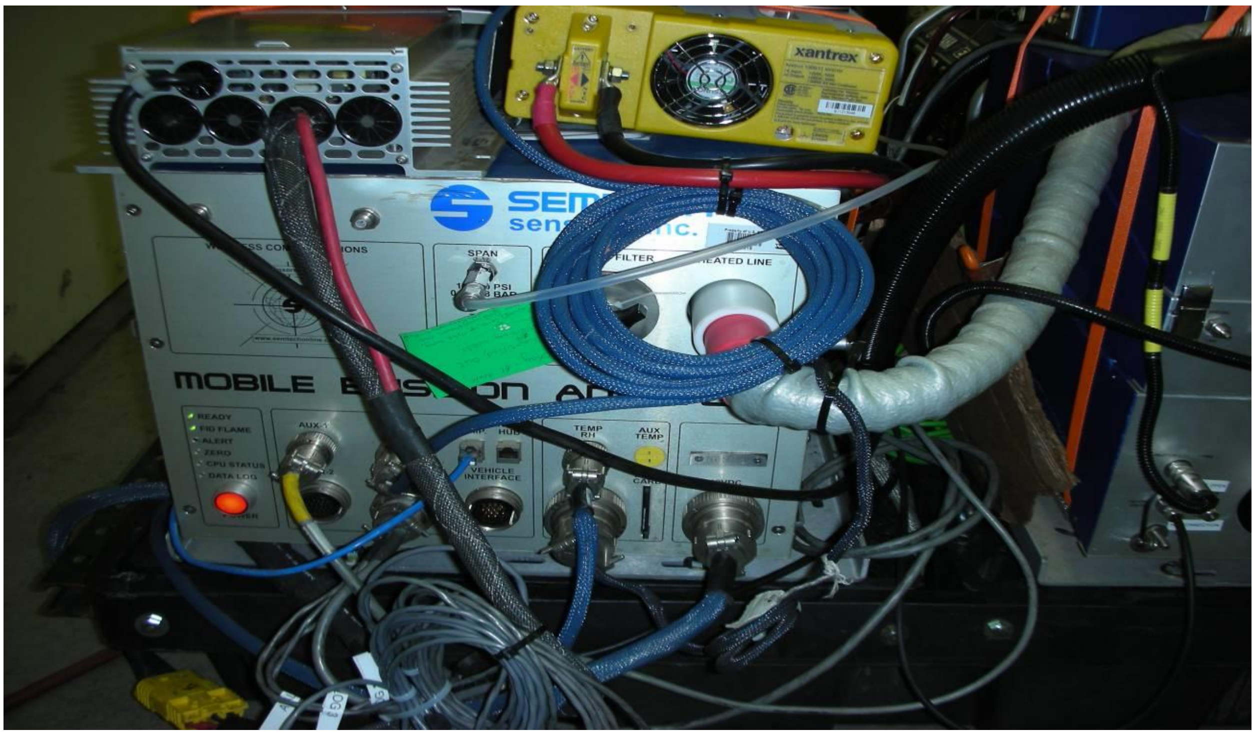

Figure 2-1: Picture of Semtech DS PEMS

A 40 CFR 1065 capable flow meter manufactured by Sensors, Inc. was used for the exhaust flow measurements. This flow meter is compatible with a wide range of PEMS systems. The flow meter uses an averaging pitot tube and temperature to measure exhaust velocity via the Bernouli principle. The flow meter is housed in a 3”, 4”, or 5” diameter pipe that is placed in line with the engine tailpipe exhaust for the equipment being tested. Combining the known cross-sectional area of the tube with the measured exhaust velocity gives the volumetric flow rate, which is converted to mass flow rate using the Ideal Gas Law, known fuel properties and measured properties/constituents of the exhaust. Figure 2-2 is a picture of the exhaust flow meter. The exhaust flow rates are multiplied by the concentration levels for the various emission components to provide emission rates in grams per second. A picture of the set-up of the PEMS on the LPG delivery truck is provided in Figure 2-3.

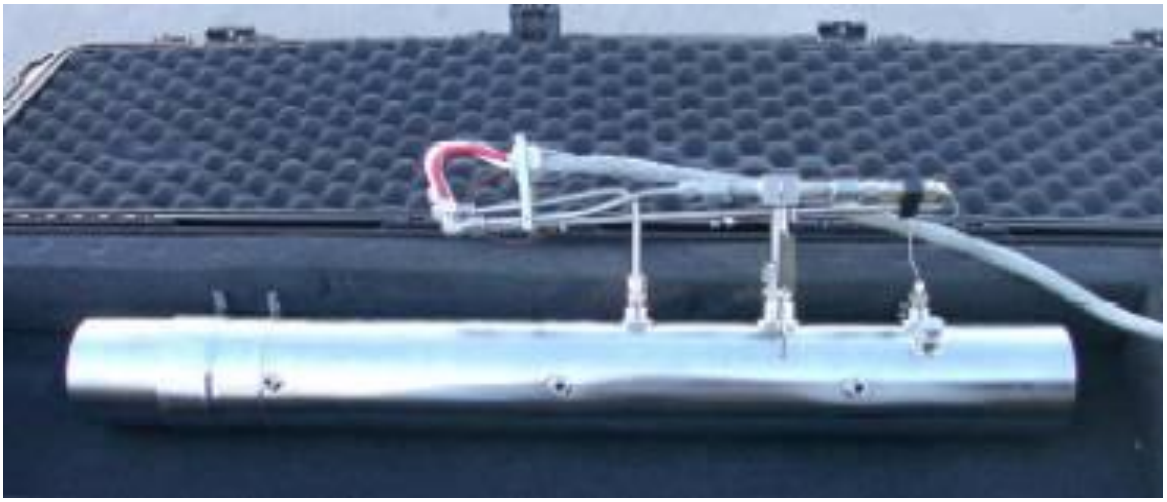

Figure 2-2: Exhaust Flow Meter Used by UCR CE-CERT

Figure 2-3: Picture of the Test Set-up on the LPG Delivery Truck

2.2.2 *Engine Control Module (ECM) Parameters*

In addition to the emissions measurements, ECM parameters were logged with a HEM data logger. The data logger was used to obtain information about the vehicles locations with a Global Positioning System (GPS), the vehicle speed, and the engine speed and horsepower. The brake horsepower hour value was calculated based on the lug curve for this specific engine model and engine RPM and % load information from the engine control module (ECM). The lug curve provides information on the maximum power over the full range of engine RPM values. The power for a given second is determined by multiplying the maximum power at the engine RPM at that second from the lug curve by the % load to get the absolute engine power.

2.2.3 *Test Route*

The test route for the testing was based on a typical day of operation for a delivery truck with the Nestle Water fleet. The testing focused on the delivery route within the Riverside neighborhood. The driving from the fleet yard in Colton, CA to the starting point, and the return drive to the fleet yard after completing the deliveries were not included, as it was expected that they might be more impacted by traffic and other related issues. The test route is approximately 20.5 miles in length, and included 6 delivery stops. The test route typically took 1.1 hours to complete for each test day including six-stopping point for 5 min each. A picture of the test route is provided in Figure 2-4.

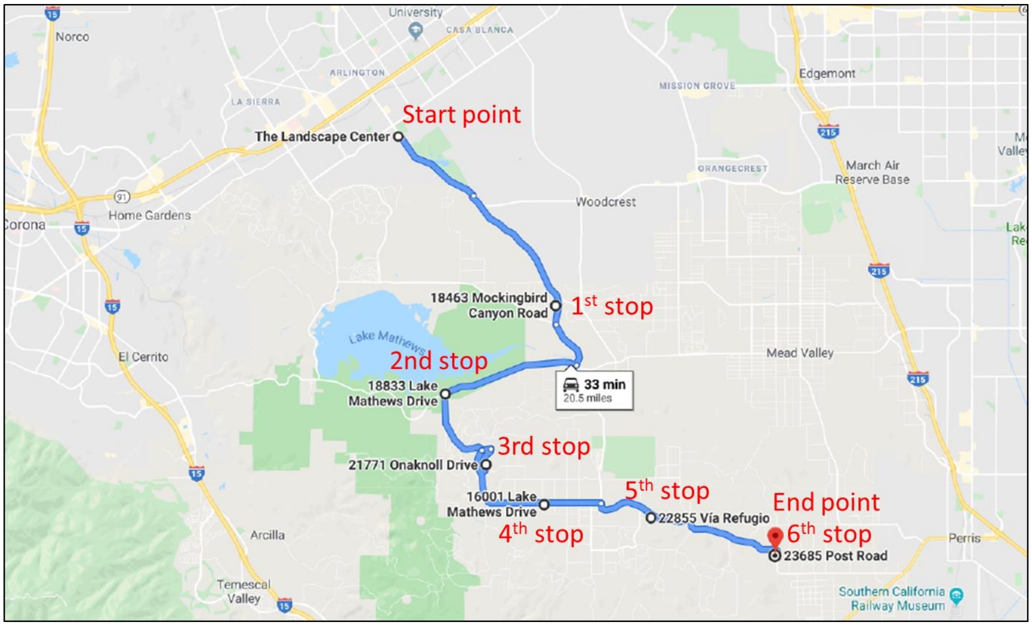

Figure 2-4: Picture of the Test Route

3 PEMS Results

This section discusses the emissions results for the LPG delivery truck over the test route on conventional LPG and renewable LPG. For each pollutant, the results are presented on a g/mi, g/bhp-hr, g/gal/fuel, g/hour, and g/day basis. The error bars represent the standard deviation of the average for the three test days on each fuel type.

3.1 NOx Results

NOx emissions for the delivery truck with LPG and RLPG fuel are shown on a g/mi, g/bhp-hr, g/gal-fuel, g/hour, and g/day basis in Figure 3-1. NOx emissions for the truck on the baseline LPG fuel averaged 0.1 on a g/mi basis, 0.029 on a g/bhp basis, 0.4 on a g/gal/fuel basis, 1.68 on g/hour basis, and 1.96 on a g/day basis. For the truck on RLPG, NOx emissions averaged 0.1 on a g/mi basis, 0.027 on a g/bhp basis, 0.42 on a g/gal/fuel basis, 1.69 on g/hour basis, and 2.08 on a g/day basis. Overall, the NOx emissions for the truck were slightly greater, but comparable to the 0.02 g/bhp-hr certification level of the engine. The differences in the average NOx emissions between the conventional and renewable LPG fuels were relatively minor, and were not statistically significant.

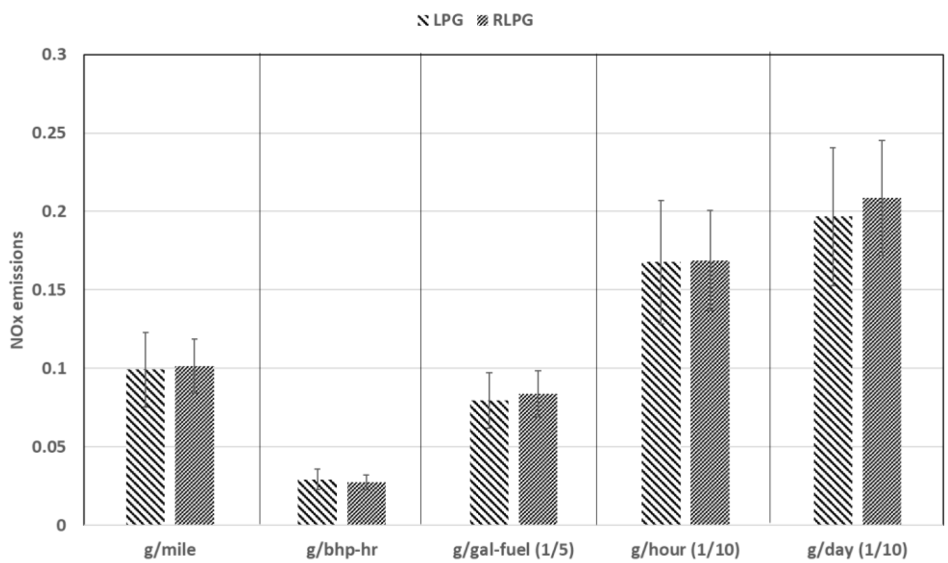

Figure 3-1: Average NO_x Emissions for Delivery Truck Operated on Conventional and Renewable LPG in g/mi, g/bhp, g/kg-fuel, and a g/day Units

3.2 THC Results

THC emissions for the delivery truck with LPG and RLPG fuel are shown on a g/mi, g/bhp-hr, g/gal-fuel, and g/day basis in Figure 3-2. THC emissions for the truck on the baseline LPG fuel averaged 0.04 on a g/mi basis, 0.013 on a g/bhp basis, 0.17 on a g/gal/fuel basis, 0.73 on g/hour basis, and 0.86 on a g/day basis. For the truck on RLPG, THC emissions averaged 0.04 on a g/mi basis, 0.01 on a g/bhp basis, 0.15 on a g/gal/fuel basis, 0.60 on g/hour basis, and 0.75 on a g/day basis. The differences in the average THC emissions between the conventional and renewable LPG fuels were relatively minor, and were not statistically significant.

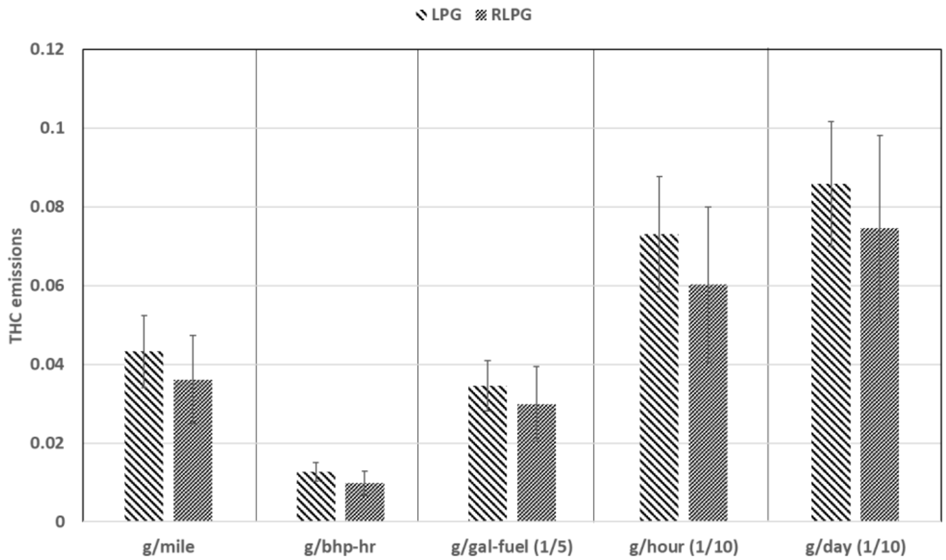

Figure 3-2: Average THC Emissions for Delivery Truck Operated on Conventional and Renewable LPG in g/mi, g/bhp, g/kg-fuel, and a g/day Units

3.3 CO Results

CO emissions for the LPG delivery truck are shown on a g/mi, g/bhp-hr, g/gal-fuel, and g/day basis in Figure 3-3. CO emissions for the truck on the baseline LPG fuel averaged 3.72 on a g/mi basis, 1.09 on a g/bhp basis, 14.8 on a g/gal/fuel basis, 62.7 on g/hour basis, and 73.6 on a g/day basis. For the truck on RLPG, CO emissions averaged 3.4 on a g/mi basis, 0.91 on a g/bhp basis, 14.1 on a g/gal/fuel basis, 56.4 on g/hour basis, and 69.7 on a g/day basis. The differences in the average CO emissions between the conventional and renewable LPG fuels were relatively minor, and were not statistically significant.

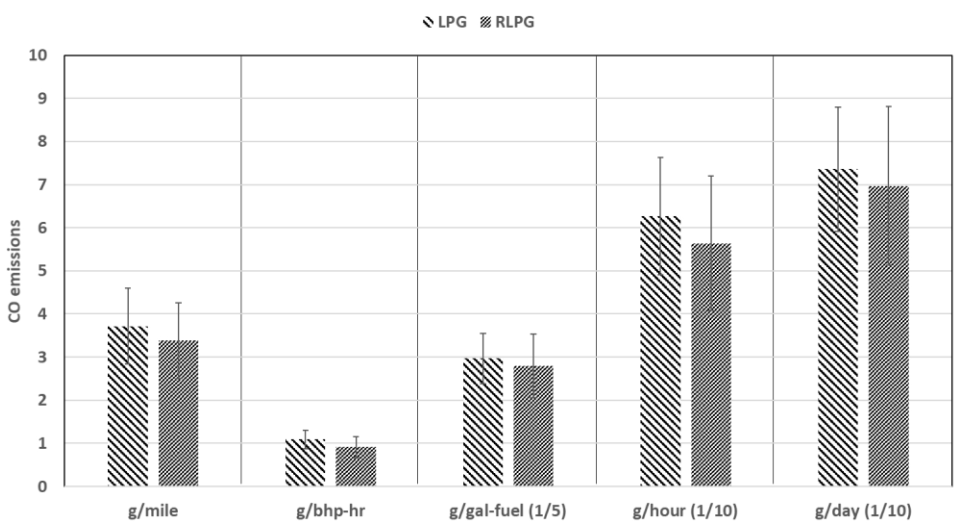

Figure 3-3: Average CO Emissions for Delivery Truck Operated on Conventional and Renewable LPG in g/mi, g/bhp, g/kg-fuel, and a g/day Units

3.4 CO_2 Results

CO_2 emissions for the LPG delivery truck are shown on a g/mi, g/bhp-hr, g/kg-fuel, and g/day basis in Figure 3-4. CO_2 emissions for the truck on the baseline LPG fuel average 1,873.6 on a g/mi basis, 553.7 on a g/bhp basis, 7,525.1 on a g/gal-fuel basis, 31,713.4 on g/hour basis, and 37,322.7 on a g/day basis. For the truck on RLPG, CO_2 emissions averaged 1,820.9 on a g/mi basis, 491.2 on a g/bhp basis, 7,527.8 on a g/gal/fuel basis, 30,260.1 on g/hour basis, and 37,493.7 on a g/day basis. The differences in the average CO_2 emissions between the conventional and renewable LPG fuels were relatively minor, and were not statistically significant, except for the differences in g/bhp-hr.

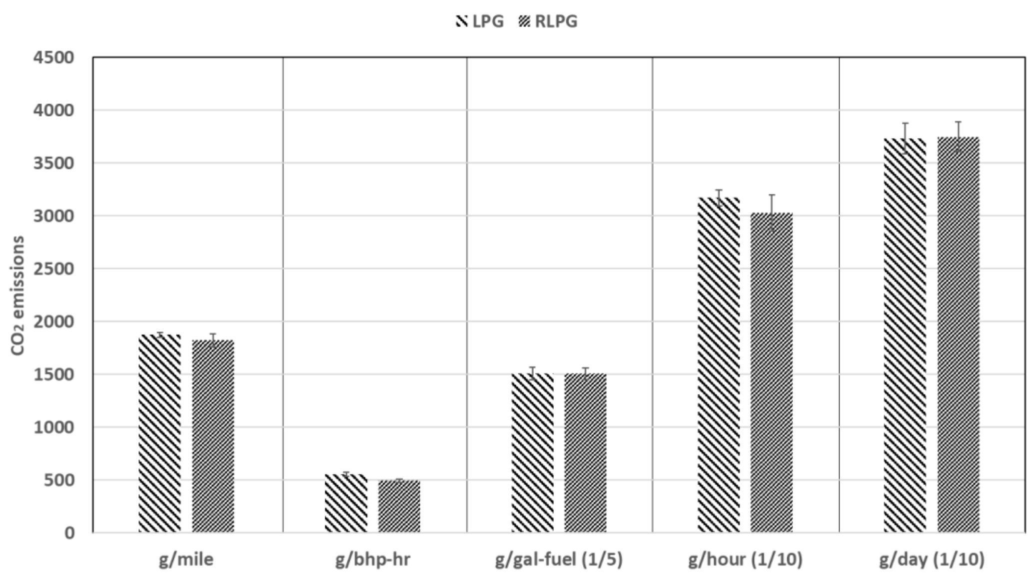

Figure 3-4: Average CO_2 Emissions for Delivery Truck Operated on Conventional and Renewable LPG in g/mi, g/bhp, g/kg-fuel, and a g/day Units

3.5 Fuel Economy Results

Fuel economy results for the delivery truck with LPG and RLPG fuel are shown in Figure 3-5 on a mile/gallon basis. Fuel economy values for the truck on the baseline LPG and RLPG averaged 4.64 and 4.78 miles per gallon, respectively. The differences in the average fuel economy between the conventional and renewable LPG fuels were relatively minor, and were not statistically significant.

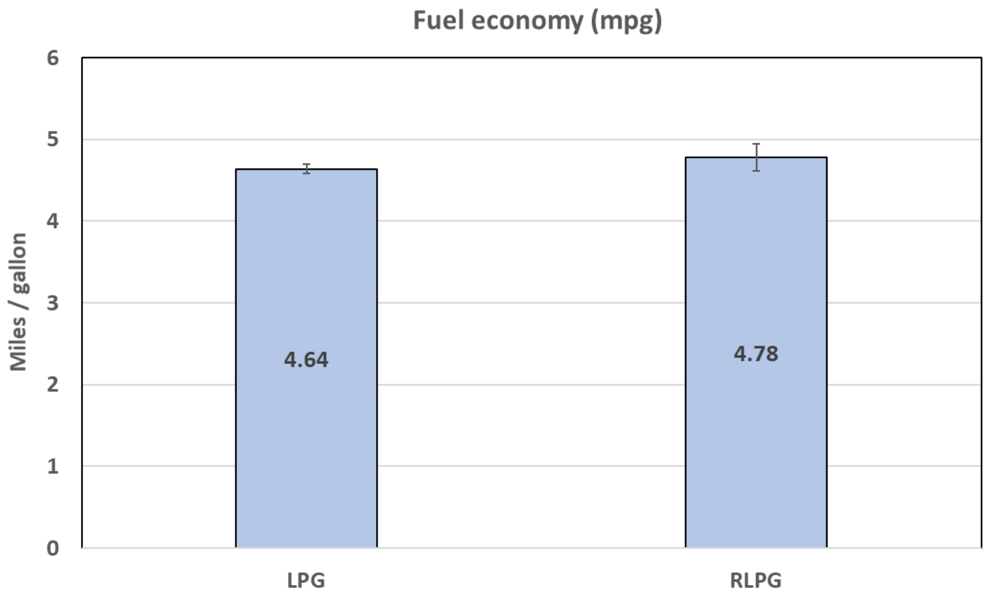

Figure 3-5: Average Fuel Economy for Delivery Truck Operated on Conventional and Renewable LPG

4 Conclusions

The objective of this project was to determine whether or not renewable LPG produces criteria emissions that are of any practical difference from conventional LPG. Testing was conducted over a typical in-use operation of a heavy-duty delivery truck. The delivery vehicle was Ford F-750 box truck equipped with a Roush 6.8 liter, near-zero emission (0.02 g-NOx/bHP-hr) LPG engine. This delivery truck was operated by Nestle Waters of Colton, CA over a typical day of operation. The vehicle was tested for three days using a conventional LPG fuel and three days using renewable LPG fuel.

A summary of the PEMS data results is provided below.

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- Fuel economy values for the truck on the baseline LPG and RLPG averaged 4.64 and 4.78 miles per gallon, respectively. The differences in the average fuel economy between the conventional and renewable LPG fuels were relatively minor, and were not statistically significant.

Based on the results of this and other studies, the following recommendations are suggested.

- While the in-use emissions for the vehicle were relatively low, being only slightly above the certification standard, it is important to test a broader range of vehicles to provide a more robust evaluation of the in-use emission rates of these vehicles. this should include vehicles representing a wider range of mileages to characterize any deterioration effects.

- It is suggested that additional parameters be added to the ECM output, such that the vehicle performance can be more readily evaluated via data logging. This could include the addition of parameters such as engine torque or fuel consumption.
- It is suggested that a more comprehensive study be conducted to evaluate the potential benefits of more widespread adoption of near-zero emission LPG vehicles. This could include an evaluation of emission inventory benefits as well, as well-to-wheel benefits in greenhouse gases, particularly in the case of renewable LPG.
- In addition to characterizing direct tailpipe emissions, the emissions of secondary organic aerosols (SOA) could also be evaluated to provide a more complete picture of the potential air quality benefits of near-zero emission LPG vehicles.

Appendix A – Detailed Test Results

Fuel	mile	CO2 (g/mi)	CO (g/mi)	NO (g/mi)	NO2 (g/mi)	NOx (g/mi)	THC (g/mi)
LPG	19.922	1873.568	3.717	0.093	0.006	0.099	0.043
RLPG	20.590	1820.853	3.382	0.100	0.001	0.101	0.036
Fuel	gal	CO2 (g/gal)	CO (g/gal)	NO (g/gal)	NO2 (g/gal)	NOx (g/gal)	THC (g/gal)
LPG	4.960	7525.115	14.838	0.371	0.025	0.397	0.173
RLPG	4.981	7527.809	13.995	0.415	0.004	0.419	0.150
Fuel	hour	CO2 (g/hour)	CO (g/hour)	NO (g/hour)	NO2 (g/hour)	NOx (g/hour)	THC (g/hour)
LPG	1.177	31713.386	62.713	1.570	0.106	1.676	0.731
RLPG	1.240	30260.053	56.369	1.670	0.025	1.686	0.602
Fuel	day	CO2 (g/day)	CO (g/day)	NO (g/day)	NO2 (g/day)	NOx (g/day)	THC (g/day)
LPG	1.000	37322.727	73.592	1.842	0.125	1.967	0.858
RLPG	1.000	37493.742	69.703	2.065	0.021	2.086	0.745
Fuel	bhp-hr	CO2 (g/bhp-hr)	CO (g/bhp-hr)	NO (g/bhp-hr)	NO2 (g/bhp-hr)	NOx (g/bhp-hr)	THC (g/bhp-hr)
LPG	68.982	553.671	1.092	0.027	0.002	0.029	0.013
RLPG	74.907	491.186	0.913	0.027	0.000	0.027	0.010

Table A-1 Detailed Test Results for each Test Day

Test results_LPG fuel							
Cycle	mile	CO2 (g/mi)	CO (g/mi)	NO (g/mi)	NO2 (g/mi)	NOx (g/mi)	THC (g/mi)
RP_1	19.020	1874.187	4.736	0.111	0.000	0.111	0.050
RP_2	20.535	1848.765	3.274	0.072	0.000	0.072	0.033
RP_3	20.212	1897.753	3.140	0.096	0.019	0.115	0.046
Ave	19.922	1873.568	3.717	0.093	0.006	0.099	0.043
STDV	0.798	24.500	0.885	0.020	0.011	0.024	0.009
Cycle	gal	CO2 (g/gal)	CO (g/gal)	NO (g/gal)	NO2 (g/gal)	NOx (g/gal)	THC (g/gal)
RP_1	4.735	7187.342	18.162	0.427	0.000	0.426	0.193
RP_2	5.112	7654.353	13.554	0.298	0.000	0.297	0.136
RP_3	5.032	7733.650	12.798	0.389	0.077	0.467	0.189
Ave	4.960	7525.115	14.838	0.371	0.025	0.397	0.173
STDV	0.199	295.195	2.904	0.067	0.045	0.089	0.032
Cycle	hour	CO2 (g/hour)	CO (g/hour)	NO (g/hour)	NO2 (g/hour)	NOx (g/hour)	THC (g/hour)
RP_1	1.150	30997.789	78.329	1.842	0.000	1.839	0.834
RP_2	1.200	31636.430	56.019	1.230	0.000	1.227	0.563
RP_3	1.180	32505.939	53.791	1.637	0.325	1.961	0.795
Ave	1.177	31713.386	62.713	1.570	0.106	1.676	0.731
STDV	0.025	757.015	13.570	0.311	0.189	0.393	0.146
Cycle	day	CO2 (g/day)	CO (g/day)	NO (g/day)	NO2 (g/day)	NOx (g/day)	THC (g/day)
RP_1	1.000	35647.457	90.079	2.118	0.000	2.115	0.959
RP_2	1.000	37963.716	67.223	1.476	0.000	1.472	0.676
RP_3	1.000	38357.008	63.474	1.932	0.383	2.315	0.938
Ave	1.000	37322.727	73.592	1.842	0.125	1.967	0.858
STDV	0.000	1464.093	14.401	0.330	0.223	0.440	0.158
Cycle	bhp-hr	CO2 (g/bhp-hr)	CO (g/bhp-hr)	NO (g/bhp-hr)	NO2 (g/bhp-hr)	NOx (g/bhp-hr)	THC (g/bhp-hr)
RP_1	67.410	528.819	1.336	0.031	0.000	0.031	0.014
RP_2	73.607	563.180	0.997	0.022	0.000	0.022	0.010
RP_3	65.930	569.014	0.942	0.029	0.006	0.034	0.014
Ave	68.982	553.671	1.092	0.027	0.002	0.029	0.013
STDV	4.073	21.719	0.214	0.005	0.003	0.007	0.002

Test results_RLPG fuel							
Cycle	mile	CO2 (g/mi)	CO (g/mi)	NO (g/mi)	NO2 (g/mi)	NOx (g/mi)	THC (g/mi)
RP_1	20.720	1867.934	4.310	0.118	0.001	0.119	0.049
RP_2	20.514	1844.710	3.273	0.102	0.000	0.101	0.033
RP_3	20.535	1749.915	2.564	0.080	0.004	0.084	0.027
Ave	20.590	1820.853	3.382	0.100	0.001	0.101	0.036
STDV	0.113	62.522	0.879	0.019	0.003	0.017	0.011
Cycle	gal	CO2 (g/gal)	CO (g/gal)	NO (g/gal)	NO2 (g/gal)	NOx (g/gal)	THC (g/gal)
RP_1	5.012	7770.750	17.932	0.492	0.002	0.495	0.202
RP_2	4.962	7597.809	13.482	0.420	0.000	0.414	0.137
RP_3	4.968	7214.869	10.570	0.331	0.017	0.348	0.110
Ave	4.981	7527.809	13.995	0.415	0.004	0.419	0.150
STDV	0.027	284.474	3.708	0.081	0.011	0.074	0.047
Cycle	hour	CO2 (g/hour)	CO (g/hour)	NO (g/hour)	NO2 (g/hour)	NOx (g/hour)	THC (g/hour)
RP_1	1.230	31466.466	72.613	1.994	0.009	2.003	0.818
RP_2	1.220	31018.352	55.041	1.716	0.000	1.692	0.559
RP_3	1.270	28295.340	41.452	1.298	0.065	1.363	0.430
Ave	1.240	30260.053	56.369	1.670	0.025	1.686	0.602
STDV	0.026	1288.074	16.789	0.366	0.052	0.333	0.215
Cycle	day	CO2 (g/day)	CO (g/day)	NO (g/day)	NO2 (g/day)	NOx (g/day)	THC (g/day)
RP_1	1.000	38703.753	89.314	2.453	0.011	2.464	1.006
RP_2	1.000	37842.390	67.150	2.094	0.000	2.064	0.682
RP_3	1.000	35935.082	52.644	1.649	0.083	1.731	0.546
Ave	1.000	37493.742	69.703	2.065	0.021	2.086	0.745
STDV	0.000	1416.881	18.467	0.403	0.057	0.367	0.236
Cycle	bhp-hr	CO2 (g/bhp-hr)	CO (g/bhp-hr)	NO (g/bhp-hr)	NO2 (g/bhp-hr)	NOx (g/bhp-hr)	THC (g/bhp-hr)
RP_1	76.333	507.038	1.170	0.032	0.000	0.032	0.013
RP_2	75.188	495.754	0.880	0.027	0.000	0.027	0.009
RP_3	73.200	470.767	0.690	0.022	0.001	0.023	0.007
Ave	74.907	491.186	0.913	0.027	0.000	0.027	0.010
STDV	1.585	18.562	0.242	0.005	0.001	0.005	0.003