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DRAFT FOR REVIEW

Heavy-Duty Diesel Vehicle Idle Reduction Policies

Prepared by the Texas A&M Transportation Institute
Prepared for the Texas Department of Transportation
August 2012

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Air Quality and Conformity Inter-Agency Contract

Subtask 2.3, "Development of Appropriate Heavy-Duty Vehicle Idle Reduction Policies" - FY2012

Prepared for the

Texas Department of Transportation

By the

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1: INTRODUCTION

Overview

The purpose of this sub-task is to provide the Texas Department of Transportation (TxDOT) with an understanding of the impacts of idling emissions, a review of current idling policies and practices in the U.S., and a recommendation for heavy-duty diesel vehicle (HDDV) idle reduction policies in Texas nonattainment (NA) areas, early action compact (EAC) areas, and high-emissions areas such as border crossings. The Texas A&M Transportation Institute (TTI) project staff also measured and examined HDDV idling emissions characteristics using 12 HDDVs, which were tested under a controlled environment inside TTI's Environmental and Emissions Research Facility (EERF). The real-world emissions data collected allowed TTI staff to quantify potential emissions reductions associated with various idle reduction policy scenarios.

HDDV Idling

Vehicle idling is a major concern for air quality, especially within nonattainment metropolitan areas. The Texas Commission on Environmental Quality (TCEQ) defines "idle" in their idling limitation rule as the operation of an engine where the engine is not engaged in gear, where the engine operates at a speed at the revolutions per minute (rpm) specified by the engine or vehicle manufacturer when the accelerator is fully released, and there is no load on the engine.[1] Heavy-duty vehicle (HDV) idling occurs during several different situations such as when stopped in traffic, during the loading/unloading, and for overnight stays at truck stops. Much of the extended idling at truck stops results from mandates of the U.S. Department of Transportation (DOT) specified in guidance of the U.S. Environmental Protection Agency (EPA), that truck drivers must rest 10 hours for every 14 hours of driving.[2]

The focus of this task was on the type of idling that is usually targeted by "5 minute" or "15 minute" idle restrictions (i.e. idling that occurs in stationary vehicles outside of the extended idling during mandated driver rest periods). Thus extended idling, as well as idling during traffic congestion, is not addressed in this report. Furthermore, HDVs in the context of this report are considered to be synonymous with HDDVs, given that almost all HDVs operating in Texas are diesel vehicles.

According to the American Transportation Research Institute (ATRI), 20 states, including California and the District of Columbia, currently enforce idling regulations statewide, and nine other states, including Texas, enforce idling regulations at the regional level (41 cities, 20 counties, and three towns).[3] The maximum idling time allowed varies from 0 minutes (i.e., no

[1] TCEQ. Locally Enforced Motor Vehicle Idling Limitations Rule – Definitions, Texas Administrative Code Title 30 Part 1 Chapter 114 Subchapter J Division 2 Rule §114.510.

[2] EPA. (2004) Guidance for Quantifying and Using Long Duration Truck Idling Emissions Reductions in State Implementation Plans and Transportation Conformity. EPA420-B-04-001.

[3] ATRI. Compendium of Idling Regulations: Updated in July 2012, http://www.atri-online.org/research/idling/ATRI_Idling_Compendium.pdf, accessed August 2012.

idling at all) to 20 minutes depending on the enforcing state, city, and/or local authority. Five minutes are allowed in most states and regions. For conditions such as weather, traffic conditions, and areas/sites, the idling regulations can be exempted and/or the maximum idling time can be extended. For example, the city of South Euclid generally allows 0 minutes for idling (that is, no idling is allowed), but 10 minutes per each hour at loading docks/areas or if ambient temperature is less than 32° F or more than 85° F. Details of the idling regulations can be found in the ATRI's Compendium of Idling Regulation[3] and websites of the enforcing states, cities, counties, and towns therein.

However, there have been no comprehensive studies verifying whether and how effective this "five minute" limit is when compared to others such as 2 minutes or 20 minutes, or continuous idling. Depending on the idling time limitation, frequent engine turn-off and re-starts (especially in cold weather) may increase emissions more than continuous vehicle idling. Thus, while attempting to reduce unnecessary idling in areas suffering from high congestion and poor air quality, it is important for TxDOT to first understand idling emissions characteristics, in order to develop an effective idling restriction policy to reduce harmful emissions from HDDV idling.

TTI project staff measured idling emissions of 12 HDDVs in controlled environments (one cold and one hot test conditions), analyzed, and characterized the idling emissions to support the idling reduction policy recommendations in this report.

The remainder of this report describes idling regulations in Texas and other states to examine current idling limitation practices (Chapter 2); methodologies of testing idling emissions to characterize HDDV idling emissions (Chapter 3); and HDDV idling testing results and conclusions including the idling reduction policy recommendation (Chapter 4). The final chapter (Chapter 5) presents the summary of the findings.

CHAPTER 2: IDLE REDUCTION POLICIES/PRACTICES

The EPA recommends that a 15-minute threshold be used to define idling for extended periods of time where perhaps an HDDV is loading or unloading.[4] However, many state and local governments in the U.S. have their own idle reduction/prevention policies. For example, West Virginia has a 15-minute idling limit, but the restriction time in other states varies from 0 minutes (i.e., no idling allowed at all) to 20 minutes depending on the enforcing states and/or local governments. In this chapter, idling regulations in Texas and other states are discussed.

Policies in Texas

In Texas, 29 cities, two towns, and nine counties currently have signed memoranda of agreement (MOA) to enforce the idling restriction in their jurisdictions.[5] The state idling restriction rule, 30 Texas Administrative Code (TAC) Chapter 114, Subchapter J, Division 2, Locally Enforced Motor Vehicle Idling Limitations, was originally adopted by TCEQ on November 17, 2004. It was for use as a control strategy in the Austin area to maintain attainment with the 1997 eight-hour ozone National Ambient Air Quality Standard (NAAQS).[6] Since the rule's inception, 29 cities, two towns, and nine counties in the North Central Texas Area and the Central Texas Area have signed MOAs to enforce the idling restriction in their jurisdictions. The original 2004 enforcement period was from April 1 to October 31 each year, but the revised rules (on July 20, 2011) expanded the enforcement period to allow for year round enforcement. 6 Table 1 lists the cities, towns, and counties that have signed MOAs.

[4] EPA. (2004) Guidance for Quantifying and Using Long Duration Tuck Idling Emission Reductions in State Implementation Plans and Transportation Conformity. EPA 420-b-04-001, U.S. Environment Protection Agency, Washington, D.C., January 2004., pp. 2

[5] TCEQ. Vehicle Idling Restrictions: Participants that have signed an MOA with the TCEQ. http://www.tceq.texas.gov/airquality/mobilesource/vehicleidling.html, accessed August 2012.

[6] TCEQ. Interoffice Memorandum – Commission Approval for Rulemaking Adoption, Docket No. 2011-1639-RUL.

Table 1. Texas Vehicle Idling Restriction Participants.

Jurisdiction Type	Participants
City	Arlington, Benbrook, Cedar Hill, Celina, Colleyville, Dallas, Duncanville, Euless, Hurst, Keene, Lake Worth, Lancaster, Mabank, McKinney, Mesquite, North Richland Hills, Pecan Hill, Richardson, Rowlett, University Park, and Venus (in the North Central Texas Area) City of Austin, Bastrop, Georgetown, Hutto, Lockhart, Luling, Round Rock, and San Marcos (in the Central Texas Area)
Town	Little Elm and Westlake (in the North Central Texas Area)
County	Collin, Dallas, Kaufman, and Tarrant (in the North Central Texas Area) Bastrop, Caldwell, Hays, Travis, and Williamson (in the Central Texas Area)

Source: TCEQ.[5]

According to the rule (30 TAC §114.512[7]) in those cities, towns, and counties, no person shall cause, suffer, allow, or permit the primary propulsion engine of a motor vehicle to idle for more than five consecutive minutes when the motor vehicle, as defined in 30 TAC §114.5101 (relating to definitions), is not in motion. The rule does not apply to certain vehicles and/or vehicles in certain conditions including a motor vehicle:

- That has a gross vehicle weight rating (GVWR) of 14,000 pounds or less;
- That has a GVWR greater than 14,000 pounds and that is equipped with a 2008 or subsequent model year (MY) heavy-duty diesel engine or liquefied or compressed natural gas engine that has been certified to emit no more than 30 grams of nitrogen oxides (NO_x) emissions per hour when idling;
- When idling is necessary to power a heater or air conditioner while a driver is using the vehicle's sleeper berth for a government-mandated rest period and is not within two miles of a facility offering external heating and air conditioning connections at a time when those connections are available; or
- Forced to remain motionless because of traffic conditions over which the operator has no control.

Exemptions other than the above-mentioned can be found in 30 TAC §114.517.[8]

[7] TCEQ. Locally Enforced Motor Vehicle Idling Limitations Rule – Control Requirements for Motor Vehicle Idling, 30 TAC §114.512.

[8] TCEQ. Locally Enforced Motor Vehicle Idling Limitations Rule – Exemptions, 30 TAC §114.517.

Policies in Other States

As stated in Chapter 1, currently, 28 states, excluding Texas, enforce their idling regulations at the state and/or regional level. Table 2 shows the 20 states enforcing their regulations statewide and the maximum normal allowed idling times.

Table 2. States Enforcing Statewide Vehicle Idling Regulations.

State	Maximum Idling Time (Minutes)
California	5
Connecticut	5
Delaware	3
Hawaii	0
Illinois	10
Maine	5
Maryland	5
Massachusetts	5
Nevada	15
New Hampshire	5
New Jersey	3
New York	5
North Carolina	5
Oregon	5
Pennsylvania	5
Rhode Island	5
South Carolina	10
Virginia	10
Washington, D.C.	3
West Virginia	15

Source: ATRI.[3]

As Table 2 shows, the maximum idling time allowed, in general, ranges from 0 (i.e., no idling is allowed at all) to 15 minutes, with individual state limits of 0, 3, 5, 10, and 15 minutes. Among the 20 states, 11 states set the time as 5 minutes, the same as in Texas. In those states, some local authorities have their own regulations in addition to and/or conjunction with their state rules. Details of such local regulations can be found in the ATRI's Compendium of Idling Regulation[3] and websites of the enforcing states, cities, counties, and towns therein.

In addition, eight states have idling regulations at the local level. Table 3 lists the states. The number of local governments in their states actually enforcing their idling regulations and the maximum idling times allowed are also shown in Table 3.

Table 3. States Enforcing Vehicle Idling Regulations Locally.

State	Number of Cities / Maximum Idling time	Number of Counties / Maximum Idling time	Number of Towns / Maximum Idling time
Arizona		1 / 5 minutes	
Colorado	2 / 5 minutes	1 / 5 minutes	1 / 20 minutes
Georgia	1 / 15 minutes		
Michigan	1 / 5 minutes		
Minnesota	2 / 5 and 15 minutes		
Missouri	1 / 5 minutes	8 / 3 and 5 minutes	
Ohio	3 / 0 and 5 minutes		
Utah	2 / 2 and 3 minutes	1 / 15 minutes	

Source: ATRI.[3]

As Table 3 shows, the maximum idling time allowed, in general, ranges from 0 (i.e., no idling is allowed at all) to 20 minutes (0, 2, 3, 5, 15, and 20 minutes), and the time selected by most of the local authorities is 5 minutes. More detailed information, including exemptions, can be found in the ATRI's Compendium of Idling Regulation[3] and websites of the enforcing states, cities, counties, and towns therein.

Overall, the states and/or local authorities selected the maximum idling time allowed, in general, as 2, 3, 5, 10, 15, and 20 minutes as well as 0 minutes (no idling at all). Most jurisdictions limit idling to 5 minutes. The idling duration limits were incorporated in the testing protocol that TTI project staff developed to examine idling emissions characteristics in the following chapter.

CHAPTER 3: HDDV IDLING EMISSION TEST METHODOLOGIES

As discussed in the previous chapters, an important part of understanding the potential benefits of implementing idling reduction policies is to be able to characterize and examine HDDV idling emissions in a scientific manner. To achieve this, TTI project staff developed an emissions testing protocol that included the measurement of idling emissions under controlled environmental conditions for different idle times and "soak" durations (i.e. the time of which the engine is turned off before being restarted). The test protocol that was submitted to TxDOT for approval prior to conducting the testing is included in Appendix A.

Idling and Soak Time Matrix

As described in Chapter 2, current idling rules in Texas and other states allow maximum idle durations of 2, 3, 5, 10, 15, and/or 20 minutes, or do not allow any idling at all . For the commonly occurring idling restriction durations, Table 4 shows the engine idling time and non-idling time (i.e. "soak" time) for a 1-hour analysis period.

Table 4. Idle and Soak Duration over 1-Hour Period for Common Idle Restriction Rules.

Maximum idling time (min)	2	3	5	10	15	20
Consequent soak time (min)	58	57	55	50	45	40

Based on the idling times in the current rules, TTI project staff developed an idling and soak time matrix, shown in Table 5. Idling emissions testing based on the matrix was used for the evaluation of the most commonly implemented idle-reduction scenarios.

Table 5. Idling and Soak Time Matrix.

Idling time (min)	Soak time (min)							
	5	10	15	40	45	50	59	> 720†
1	✓	✓	✓	✓	✓	✓	✓	✓
2	✓	✓	✓	✓	✓	✓	✓	✓
3	✓	✓	✓	✓	✓	✓	✓	✓
4	✓	✓	✓	✓	✓	✓	✓	✓
5	✓	✓	✓	✓	✓	✓	✓	✓
10	✓	×*	✓	✓	✓	✓	×*	✓
15	✓	×*	✓	✓	✓	✓	×*	✓
20	✓	×*	✓	✓	✓	✓	×*	✓

† Cold start.
* Idling emissions data are unavailable for the marked idling and soak time combinations.

Due to logistical and budgetary constraints, some idling/soak time combinations were excluded from testing as shown in Table 5. In addition to the tested idling/soak time combinations shown in Table 5, TTI project staff also performed additional idling emissions testing for an extended period of time for each vehicle and each test condition to obtain stabilized idling emissions. The extended idling emissions testing was combined with cold start idling (having a soak time of more than 12 hours or 720 minutes) as defined by EPA,[9] by measuring idling emissions continuously after the cold start idling until the measured idling emissions were stabilized. The measured stabilized emissions were then considered as the baseline emissions, and they were used to compare to the measured emissions for the tested idling/soak time combinations.

For idling emissions comparisons (discussed in Chapter 4), TTI project staff selected all of the idling/soak time combination scenarios in Table 4 that are currently practiced in the U.S., except the 2 minute idling/58 minute soak. In addition, TTI project staff added 1 minute idling/59 minute soak to examine emissions characteristics of the first minute idling. TTI project staff dropped the 2 minute idling/58 minute soak scenario, because emissions results for the 2 minute idling/58 minute soak scenario generally fell proportionally between the 1 minute idling/59 minute soak and 3 minute idling/57 minute soak scenarios. The 20-minute cold-start idling scenario was also added to examine cold-start effects.

For the idling emissions testing (ambient) conditions, TTI project staff selected 100° F with 70 percent relative humidity (RH) for a hot test condition and 30° F for a cold test condition. The RH for the cold test condition was not applicable because the RH effects and control are not meaningful at such a low temperature. TTI project staff selected those temperature and/or RH conditions because they represent a typical weather condition that the vehicle would encounter during the year in Texas (winter in Dallas and summer in Houston). During the testing, test vehicles idled with their air conditioning (A/C) systems operating for hot tests or heaters operating for cold tests, to replicate real-world conditions, where it is expected that drivers would operate either the heating or A/C systems in their vehicles.

Test Vehicles

TTI project staff tested a total of 12 HDDVs. Table 6 shows the specifications of the 12 vehicles. Figure 1 shows pictures of a test truck. The trucks were assigned numbers are the order in which they were tested - that is, Truck #1 was tested first, and Truck #12 was tested last.

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[9] EPA. Modeling and Inventories: MOVES, http://www.epa.gov/otaq/models/moves/index.htm, accessed in August 2011.

Table 6. Test Vehicle Specifications.

Truck Number	Make	Model	MY	Engine Make	Engine Model	Horsepower @ governed engine speed (rpm)	Displacement	Odometer
1	Freightliner	Colombia	2006	Caterpillar	C15	466 @ 1800	15.2 L	484550
2	International	94001 SBA 6x4	2007	Cummins	ISX 450	450@2000 RPM	15 L	505964
3	International	Prostar	2008	Cummins	ISX 450ST	450 @ 1800 RPM	N/A*	406740
4	International	Prostar+ 122 6x4	2011	MaxxForce	GDT430B	430 @ 1700 RPM	12.4 L	73030
5	Navistar	8600 SBA 6x4	2011	MaxxForce	A410	410 @ 1700	12.4 L	57814
6	International	ProStar+ 122 6x4	2011	MaxxForce	A475	475 @ 1700 RPM	12.4 L	10724
7	Mack	CHU613	2012	Mack	MP8-415C	338 @ 2100 RPM	N/A*	82976
8	Peterbilt	N/A*	2008		ISM 425V	425 @ 1800 RPM	N/A*	353945
9	Mack	CHU 613	2010	Mack	MP8-415C	415 @ 1500	N/A*	89469
10	Mack	CHU 613	2009	Mack	MP8-415C	338 @ 2100 RPM	12.8 L	96409
11	Volvo	N/A*	2012	Volvo	VE-D12-465	465 @ 1800 RPM	N/A*	640341
12	Mack	CHU 613	2011	Mack	MP8-445C	445 @ 1500 RPM	12.8 L	95169

* N/A – Certain specifications of some vehicles were not available.

(a) **(b)**

Figure 1. A Test Vehicle (a) and Sampling Lines Installed on Exhaust of a Test Vehicle (b).

Note that some newer vehicles have features for cold ambient protection (CAP); that is, features to safeguard engines from damage caused by prolonged idling at no load during cold weather. The presence of CAP may impact the idling characteristics and resultant emissions. For example, Truck #5 increased its engine speed (rpm) to a programmed value when the ambient air temperature was below 50° F, coolant temperature was below 167° F, and the engine had been idling at no load for over five minutes. The truck continued to increase or decrease its engine speed automatically to maintain a coolant temperature between 158° F and 176° F until the following situations occurred: any pedal actuated, engine load increase over 45 percent, temperature sensor malfunctioning, etc.[10] TTI project staff observed these CAP features for some other trucks during their testing, but the parameters such as pre-programmed engine speeds and pre-set temperature and idling time seemed to be different among the vehicles. The different parameters seemed to affect idling emissions, which are briefly discussed in Chapter 4. Investigations of newer HDDVs would have benefitted this study by including the effects of CAP features. However, such investigations were beyond the scope of this task.

Test Equipment/Test Location

TTI Environmental and Emissions Research Facility (EERF)

The idling emission testing was conducted in TTI's EERF. TTI's EERF is located at Texas A&M University's Riverside Campus (A&M RC) in Bryan, Texas. The EERF includes an environmentally controlled test chamber with dimensions of 75 ft. long × 23 ft. wide × 22 ft. high where the test vehicles were placed one at a time for the idling testing. The chamber can control both temperature and humidity. The chamber can control temperatures from -40° F to 131° F. Figure 2 shows the test chamber.

[10] Navasota, Inc. MaxxForce 11 and 13 (2010) Overview: Cold Ambient Protection, http://evalue.internationaldelivers.com/service/bodybuilder/general/engine_feature/documents/NAVI_BB_CAP_090111_MY2010_REV6.pdf, accessed August 2012.

Figure 2. TTI's EERF Test Chamber.

SEMTECH-DS

The SEMTECH-DS is a portable emissions measurement system (PEMS), which complies with the EPA's Code of Federal Regulations (CFR) Title 40 Part 1065 (40 CFR 1065) emissions testing instrument requirements and is used for emissions testing during the idling tests. It consists of a set of gas analyzers to measure gaseous emissions of NO_x (both nitrogen oxide [NO] and nitrogen dioxide [NO_2]), hydrocarbon (HC), carbon monoxide (CO), carbon dioxide (CO_2), and oxygen (O_2) in the exhaust. The SEMTECH-DS is used in conjunction with the SEMTECH electronic flow meter (EFM), which measures the vehicle exhaust flow rate. This allows for the calculation of exhaust mass emissions from all measured gasses. Figure 3 shows the SEMTECH-DS and EFM installed on a HDDV during the testing.

Figure 3. SEMTECH-DS and EFM.

Axion

The PEMS used to collect particulate matter (PM) was the Axion system (Axion) manufactured by Clean Air Technologies International, Inc. The Axion consists of gas analyzers, a PM measurement system, an engine diagnostic scanner, a GPS, and an on-board computer. For this study only the PM measurement system was used. The PM measurement capability includes a laser light scattering detector and a sample conditioning system. The PM concentrations are converted to PM mass emissions using concentration rates measured by the Axion and the exhaust flow rates collected by the SEMTECH EFM. Figure 4 shows the Axion system. The measurement results are described in Chapter 4.

Figure 4. Axion System.

CHAPTER 4: IDLING EMISSION TEST RESULTS AND DISCUSSIONS

TTI project staff performed HDDV idling emissions testing using 12 HDDVs based on the idling/soak time matrix described in Chapter 3. Prior to testing each vehicle, the SEMTECH-DS and EFM, Axion, and other required equipment were installed on the test vehicle. Then, for each vehicle, exhaust emissions were measured while the test vehicle was idling under the different combinations of idling and soak time for hot and cold test conditions. The test results are presented and discussed in the following sections.

Stabilized Idling Emissions

Stabilized (continuous) emissions were measured for comparison with idling emissions under the different idling/soak time combinations described in Chapter 3. Table 7 shows the stabilized emissions rates (grams per hour, g/h) of CO_2, CO, NO_x, and total HC (THC) for each test vehicle for the hot test condition and Table 8 shows the rates for the cold test condition. For PM, the measured emissions were all under the detection limits. For test vehicles # 9, 10, 11, and 12, THC emissions results were not available due to a malfunctioning HC analyzer. The TTI project staff investigated options to repair the analyzer, but it was found that the entire PEMS unit would need to be sent to the manufacturer for repair. The TTI project staff attempted repairs on-site with assistance from the manufacturer, but were unsuccessful. Due to the availability of the test trucks, TTI staff made the decision not to send the PEMS out for repair. In addition, the THC emissions were not significant for HDDVs, as shown in Table 7 and Table 8 and Figure 5, and are of less concern than NO_x emissions in Texas.

Table 7. Stabilized Idling Emissions Results for the Hot Test Condition.

Truck number	MY	Stabilized Idling Emissions Rate (g/h)				
		CO_2	CO	NO_x	THC	PM
#1	2006	7565	52.1	105	13.9	Ng*
#2	2007	8385	31.7	151	17.0	Ng*
#3	2008	9017	31.0	19.3	5.97	Ng*
#4	2011	6717	12.9	64.2	5.44	Ng*
#5	2011	6029	13.2	57.1	5.22	Ng*
#6	2011	7226	17.8	25.6	5.40	Ng*
#7	2012	6110	74.7	199	10.2	Ng*
#8	2008	5741	66.7	5.25	13.6	Ng*
#9	2010	6656	35.0	21.3	N/A**	Ng*
#10	2009	6960	57.6	251	N/A**	Ng*
#11	2012	7385	33.5	94.1	N/A**	Ng*
#12	2011	8464	50.1	78.5	N/A**	Ng*

* Ng: Negligible because the measure values were under the detection limit.
** N/A: Not available due to malfunctioning of the HC measurement instrument.

Table 8. Stabilized Idling Emissions Results for the Cold Test Condition.

Truck number	MY	Stabilized Idling Emissions Rate (g/h)				
		CO_2	CO	NO_x	THC	PM
#1	2006	8360	51.8	115	10.5	Ng*
#2	2007	8236	47.2	137	8.57	Ng*
#3	2008	8205	33.3	33.4	5.45	Ng*
#4	2011	6094	18.1	25.4	4.07	Ng*
#5	2011	11610	17.4	73.1	2.57	Ng*
#6	2011	5647	14.8	16.6	3.61	Ng*
#7	2012	7697	127	189	9.98	Ng*
#8	2008	5008	46.1	23.0	6.94	Ng*
#9	2010	8205	33.3	33.4	N/A**	Ng*
#10	2009	7762	155	129	N/A**	Ng*
#11	2012	5767	34.7	90.1	N/A**	Ng*
#12	2011	7532	52.0	100	N/A**	Ng*

* Ng: Negligible because the measure values were under the detection limit.

** N/A: Not available due to malfunctioning of the HC measurement instrument.

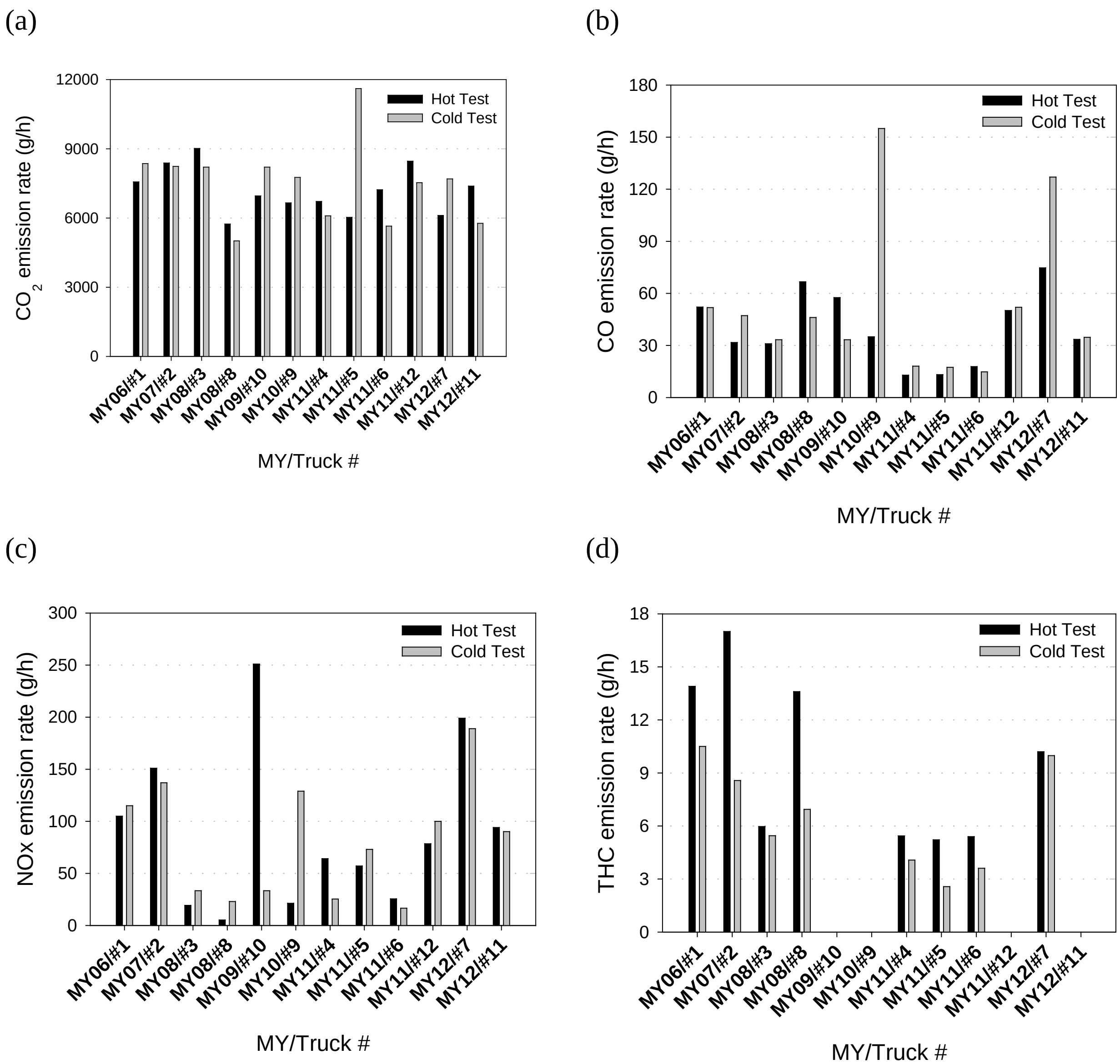


Figure 5. Stabilized Idling Emissions Results; (a) CO_2, (b) CO, (c) NO_x, (d) THC.

In general, it was expected that newer trucks would produce lower idling emissions for all the measured pollutants. Additionally, TTI project staff expected that idling emissions for cold tests would be higher than those for hot tests, especially for NO_x and CO, as shown in other studies.[11] As shown in Table 7 and Table 8 and Figure 5, however, the stabilized emissions show mixed results with respect to MY, between hot and cold tests, and among the measured pollutants. For example:

[11] TTI. (2001) Development of a NO_x Verification Protocol and Actual Testing of Onboard Idle Reduction Technologies. Submitted to the Houston Advanced Research Center.

- The MY 2008 trucks produced both the highest (Truck #3) and the lowest (Truck #8) CO_2 emissions for hot tests; the stabilized CO_2 emissions rate for Truck #3 was 57 percent more than the rate for Truck #8;
- One of the newest MY (2012) trucks, Truck #7, produced the highest CO emissions for hot tests; the emissions rate was 4.8 times higher than the lowest truck, Truck #4, which was the second newest truck (MY 2011); and
- Truck #5 (MY 2011) produced the lowest THC emissions for the hot test condition while the truck's CO_2 emissions for the cold test condition were the highest.

Different HDDVs (especially, newer MY HDDVs such as the test trucks) used different engine and emissions controls. Additionally, the controls vary for different ambient conditions, such as different ambient temperature. TTI project staff believes that the mixed emissions results could be explained through additional analyses using detailed information from emissions reduction devices and idling control strategies such as CAP along with all the parameters such as temperature at emissions reduction devices and pre-programmed and pre-set parameters for CAP features. However, such analyses are beyond the scope of this task. Stabilized emissions results are used in this task for comparisons with different idling/soak time scenarios and identification of "break-even" points, where the emissions reduction due to idling restrictions becomes greater than the emissions due to the vehicle start-ups, to examine effects of idling limitations compared to continuous (stabilized) idling. Note that a few vehicles showed NO_x emissions rates less than 30 g/h in Table 7 and Table 8:

- For hot tests: Truck #3, #6, #8, and #9; and
- For cold tests: Truck #4, #6, and #8.

Because HDDVs having NO_x emissions of 30 g/h or less are exempted from the idling rules in Texas (as well as other states), Truck #6 and Truck #8 could be idled for both cold and hot test conditions as long as their actual emissions are the same or lower than the measured stabilized emissions (25.6 g/h, 16.6 g/h, 5.25 g/h, and 23.0 g/h for Truck #6 hot, Truck #6 cold, Truck #8 hot, and Truck #8 cold tests, respectively) shown in Table 7 and Table 8. The emission rates of Trucks #3 and #9 were under the threshold for hot test conditions only (19.3 and 21.3 g/h, respectively), while that of Truck #4 (25.4 g/h) was under the threshold for the cold test condition only.

Emissions Results Regarding Idling Time and Cold Starts

As described in Chapter 3, idling emissions were measured for different combinations of idling and soak times with both hot and cold starts. These emissions were compared against stabilized emissions. TTI project staff found that, in general:

- All reductions in emissions from the stabilized level are in approximate proportion to the percent idling time; and
- Total idling emissions increased approximately in proportion to idle time;
- Cold-start emissions were higher than non-cold start emissions.

For example, Figure 6 shows the cold test CO_2, CO, NO_x, and HC emissions results for Truck #1 compared to its continuous one-hour (stabilized) emissions. The cold-test emissions results for Truck #1 in Figure 6 show that emissions increased almost proportionally as idling time increased, and cold-start emissions for the 20(cold)/40 scenario were higher than non-cold start emissions (20/40 scenario). Similar results were observed for Truck #2 hot and cold tests, Truck #4 hot tests, and Truck #11 hot and cold tests. Appendix B contains the detailed results.

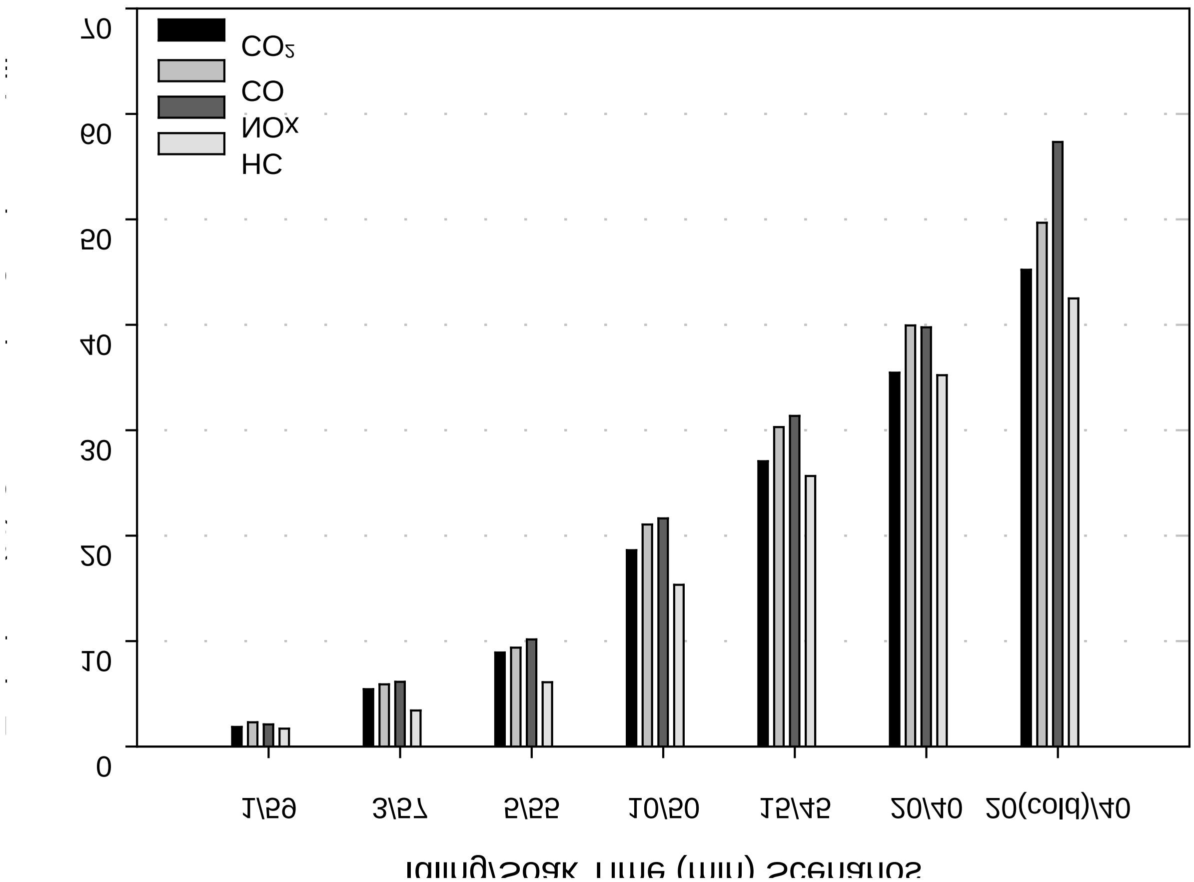


Figure 6. Truck #1 Idling Cold Test Emissions Results.

Table 9 shows cold-start idling emissions reduction percentages compared to stabilized (continuous) one-hour idling emissions for Truck #1. Idling emissions reductions increase with shorter idling time. Idling emissions reductions for cold-start idling are smaller than for hot starts although the reductions are still around, or more than, 50 percent. Results were similar for Truck #2 hot and cold tests, Truck #4 hot tests, and Truck #11 hot and cold tests (see Appendix C).

Table 9. Idling Emissions Reductions Results for Different Idling/Soak Time Scenarios for Truck #1 for Cold Tests.

Idling/Soak Time Scenario	Idling Emission Reduction (%) compared to One-Hour Continuous (Stabilized) Idling Emissions			
	CO_2	CO	NO_x	THC
1/59	98	98	98	98
3/57	95	94	94	97
5/55	91	91	90	94
10/50	81	79	78	85
15/45	73	70	69	74
20/40	65	60	60	65
20(cold)/40	55	50	43	58

For PM, emissions were observed during the first few minutes of cold-start idling for a few trucks. For example, for cold start idling during hot tests, Truck #1 produced 0.15g of PM during the first minute, and 0.33g and 0.42g during the first minute and three minutes, respectively, for cold tests. In general, the Truck #1 PM emissions were higher and were observed longer for cold tests than for hot tests. For other idling/soak tests, PM emissions were not observed, or if any, were lower than those for cold-start idling tests. Appendix D shows all of the cold-start idling results, including the Truck#1 PM emission results.

For test results from other trucks and/or test conditions (i.e., Truck #1 hot tests, Truck #3 hot and cold tests, Truck #4 cold tests, and Truck #5, 6, 7, 8, 9, 10, and 12 hot and cold tests), TTI project staff found slight to significant different trends from the general trends. These different trends are discussed in the following by Truck number.

For the Truck #1 hot tests, emissions results were similar to those for other hot tests discussed previously (i.e., general trends), except for HC emissions for the 20(cold)/40 scenario. As shown in

Figure 7, HC emissions for the 20(cold)/40 scenario are lower than those for the 20/40 and the 15/45 scenarios for unknown reasons. Additional tests beyond the scope of this project possibly might unveil the reason(s). Due to malfunctioning of the PEMS during the 5/55 tests, emissions results are not available for that scenario. Table 10 shows the corresponding idling emissions reduction percentages compared to stabilized emissions; emissions reductions for all scenarios are 60 percent or more. In general, similar to the results for cold tests, shorter idling times produce fewer emissions.

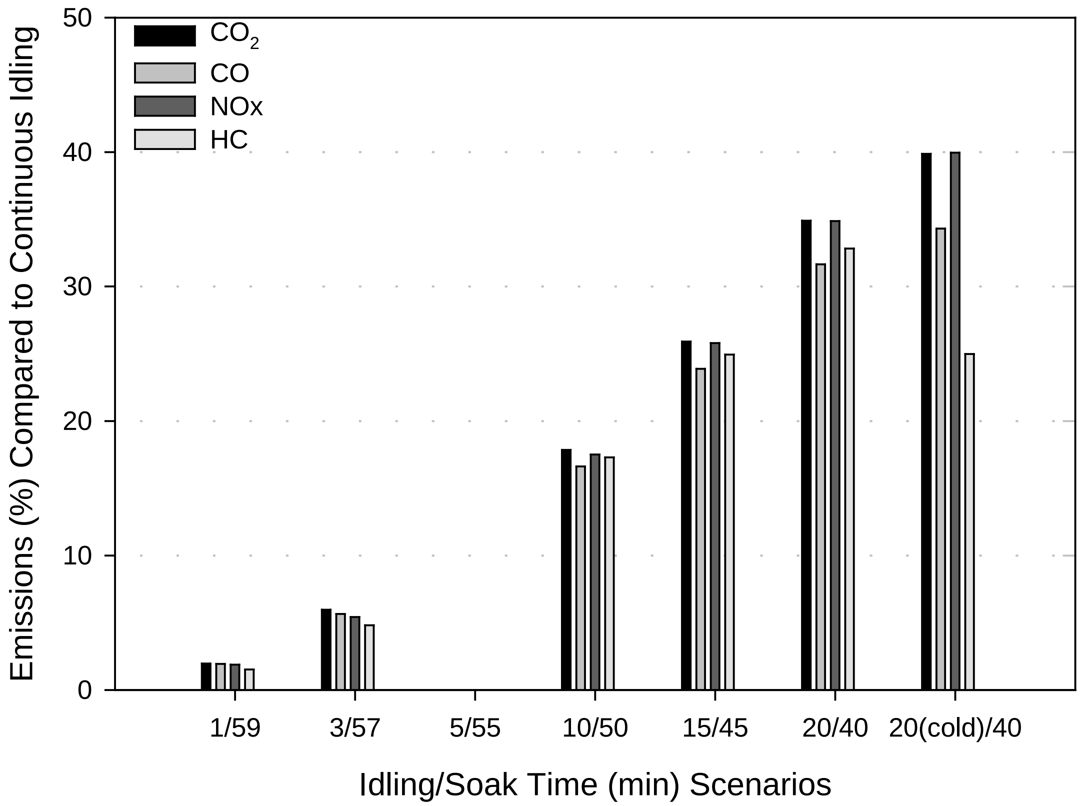


Figure 7. Truck #1 Idling Hot Test Emissions Results.

Table 10. Idling Emissions Reductions Results for Different Idling/Soak Time Scenarios for the Truck #1 Hot Tests.

Idling/Soak Time Scenario	Idling Emissions Reduction (%) compared to One-Hour Continuous (Stabilized) Idling Emissions			
	CO_2	CO	NO_x	THC
1/59	98	98	98	98
3/57	94	94	95	95
5/55	N/A*	N/A*	N/A*	N/A*
10/50	82	83	82	83
15/45	74	76	74	75
20/40	65	68	65	67
20(cold)/40	60	66	60	75

* N/A: Not available due to malfunctioning of the instruments.

For the Truck #3 hot and cold tests, emissions results were similar to those for the Truck #1 hot tests. Truck #3 emissions results in Figure 8 (for hot tests) and Figure 9 (for cold tests) show that all of the idling emissions increase as idling time increases except for NO_x emissions for the 20(cold)/40 scenario. For the Truck #1 hot tests, the only exception was for HC. As shown in Figure 8 and Figure 9, NO_x emissions for the 20(cold)/40 scenario are lower than those for the 20/40 scenario for unknown reasons. Additional tests beyond the scope of this task might provide the reasons. For the Truck #3 tests, emissions for the hot tests were higher than those for the cold tests. Similar to the Truck #1 cold test results, idling emissions for the Truck #3 hot tests are still approximately 50 percent or lower compared to the stabilized idling emissions. Table 11 and Table 12, respectively, show the Truck #3 resulting idling emission reduction percentages compared to the stabilized idling emissions for both hot and cold tests. Similar to other emissions results discussed earlier, shorter Truck #3 idling times generally produces fewer emissions.

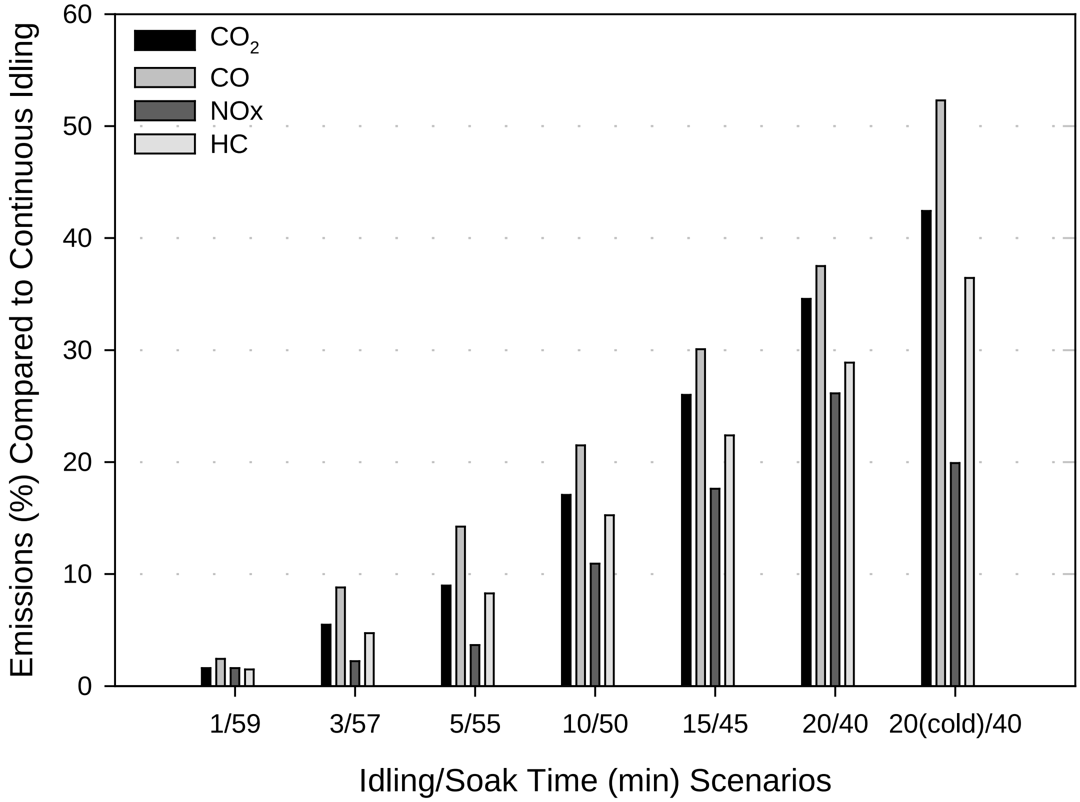


Figure 8. Truck #3 Idling Hot Test Emissions Results.

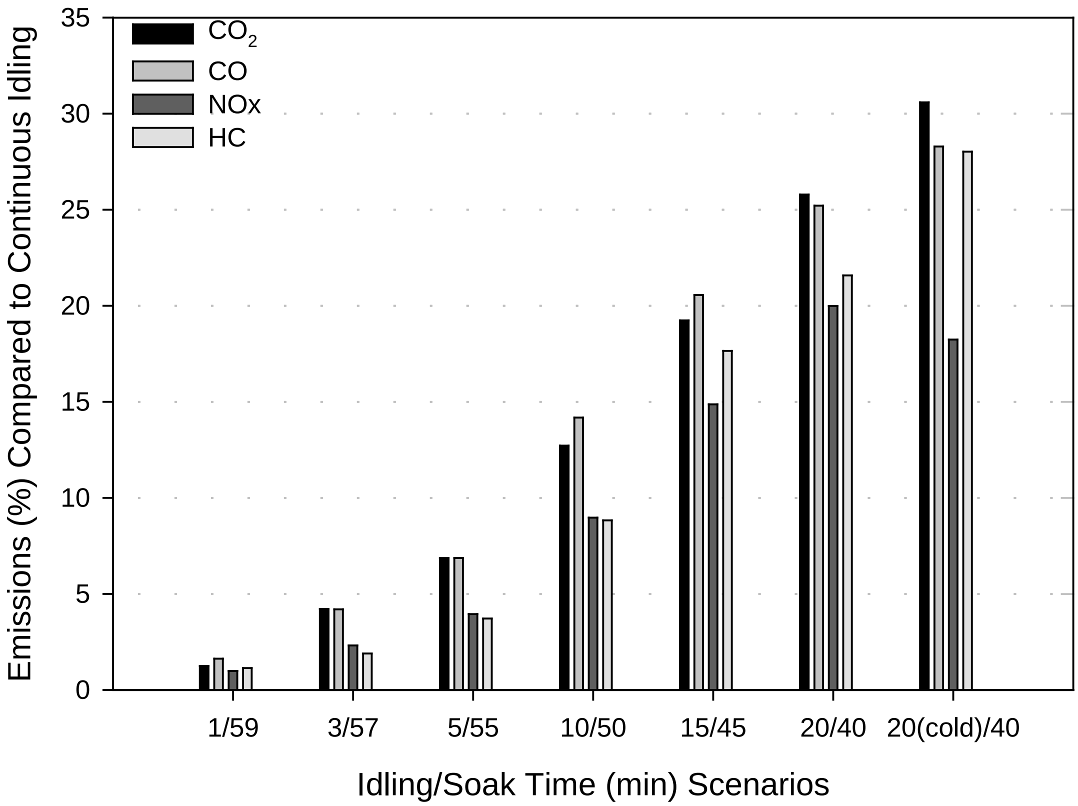


Figure 9. Truck #3 Idling Cold Test Emissions Results.

Table 11. Idling Emissions Reductions Results for Different Idling/Soak Time Scenarios for the Truck #3 Hot Tests.

Idling/Soak Time Scenario	Idling Emissions Reduction (%) compared to One-Hour Continuous (Stabilized) Idling Emissions			
	CO_2	CO	NO_x	THC
1/59	98	98	98	99
3/57	95	91	98	95
5/55	91	86	96	92
10/50	83	79	89	85
15/45	74	70	82	78
20/40	65	63	74	71
20(cold)/40	58	48	80	64

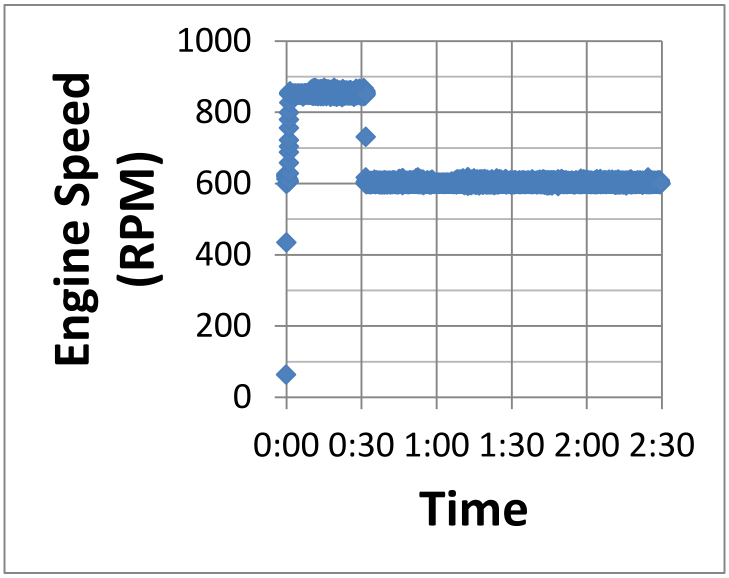
Table 12. Idling Emissions Reductions Results for Different Idling/Soak Time Scenarios for the Truck #3 Cold Tests.

Idling/Soak Time Scenario	Idling Emissions Reduction (%) compared to One-Hour Continuous (Stabilized) Idling Emissions			
	CO_2	CO	NO_x	THC
1/59	99	98	99	99
3/57	96	96	98	98
5/55	93	93	96	96
10/50	87	86	91	91
15/45	81	79	85	82
20/40	74	75	80	78
20(cold)/40	69	72	82	72

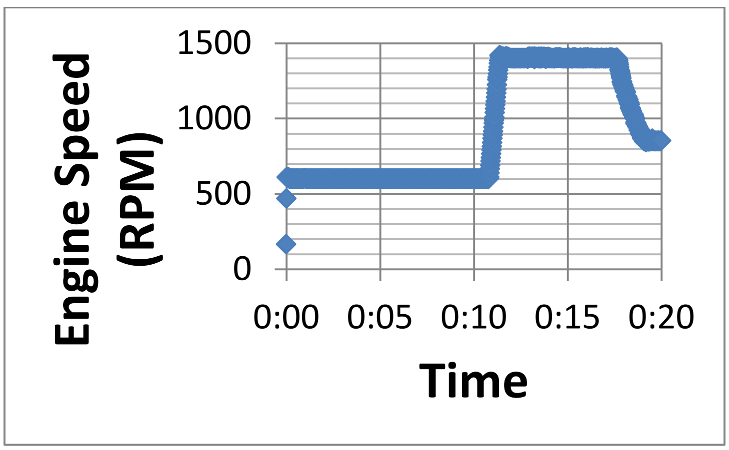
Similar trends in idling emissions were observed with few exceptions for Truck #5 hot, Truck #9 hot and cold tests, and Truck #10 cold tests. Emissions and emissions reduction results for these tests are shown in Appendices B and C, respectively. For Truck #10 cold tests, the NO_x emissions from the 20(cold)/40 scenario were higher than the stabilized emissions.

When total emissions of any pollutants for any idle/soak time scenarios exceed the (one-hour) stabilized emissions, TTI project staff calculated break-even times for the scenarios and pollutants for which the total emissions of the scenarios are same as the stabilized emissions. For the Truck #10 20/40 scenario, the break-even idling time for NO_x is 19.3 minutes, which indicates that idling time needs to be less than 19.3 minutes for the vehicle start-up emissions to be lower than continuous idling emissions.

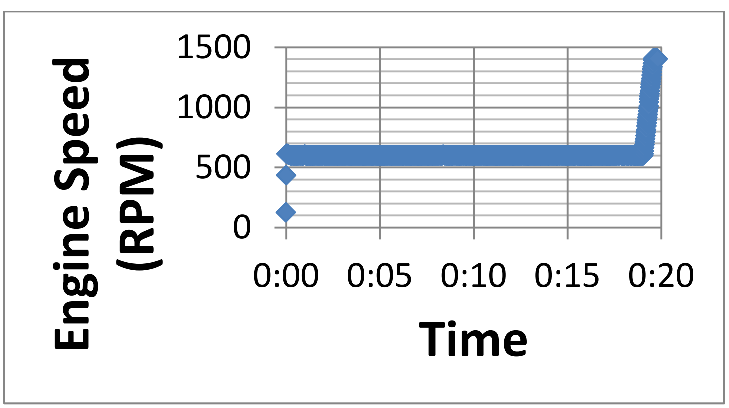
For the Truck #4 cold tests, TTI project staff observed CAP operations. For cold-start emissions testing, the engine speed increased to 850 rpm at the beginning of the testing and remained at 850 rpm for about 30 minutes, then, decreased to its normal idling engine speed of 600 rpm as shown in Figure 10 (a). For different test conditions, TTI project staff observed different engine speed profiles as shown in Figure 10 (b) and (c). For the 20-minute idle and 40-minute soak condition, engine speeds increased at around the 11-minute mark to 1400 rpm, maintained that speed, and then gradually decreased to 850 rpm from about 17.5 minutes as shown in Figure 10 (b). For the 15/45 scenario testing, the engine speeds increased to 1400 rpm at the end of the testing as shown in Figure 10 (c).



(a)



(b)



(c)

Figure 10. Engine Speed Profiles for the Truck #4 Cold Tests; (a) Cold-Start Idling, (b) 20/40 Scenario, and (c) 15/45 Scenario.

The different engine speeds for different test conditions caused different emissions results as Figure 11 shows. The elevated engine speed (850 rpm) for cold-start idling emissions for 20 minutes (20[cold]/40 scenario) increased CO_2 and NO_x emissions about three times those for 15 minutes idling (15/45 scenario with 600 rpm) although the idling time for the former is only 33% more. Emissions comparisons between the 20(cold)/40 and 20/40 scenarios (same idling time – 20 minutes) — in Figure 11 show that about 7.5 minutes of higher engine speed (1400 rpm) for the 20/40 scenario produced more emissions for all pollutants measured. The HC emissions for the 20/40 scenario were about 5.5 times that for the 20(cold)/40 scenario.

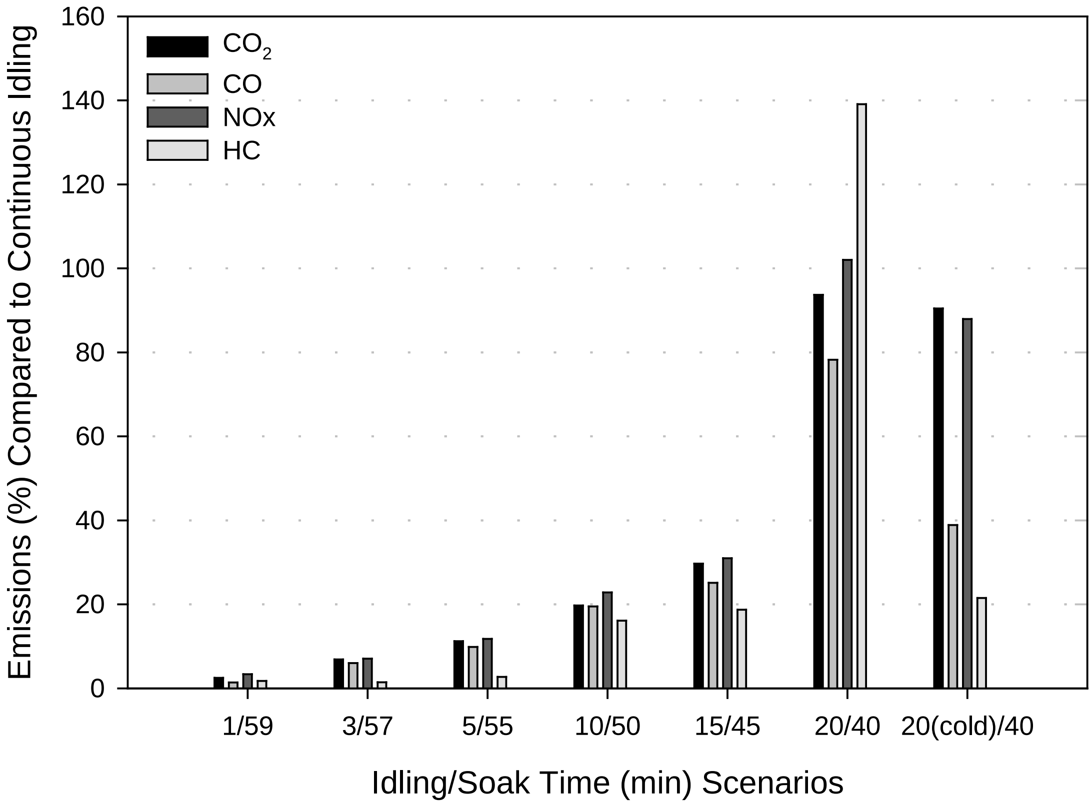


Figure 11. Truck #4 Idling Cold Test Emissions Results.

NO_x and HC emissions for the 20/40 scenario were higher than the stabilized emissions as shown in Figure 11. For the 20/40 scenario, the break-even time for NO_x is 19.6 minutes and the break-even time for HC is 18 minutes. Twenty minutes of idling after 40 minutes of soak time would produce more NO_x and HC emissions than continuous stabilized (one-hour) idling when the same CAP operations occur. Table 13 shows the emission increases (2 percent of NO_x and 39 percent of HC). For all other scenarios including the 20(cold)/40 scenario, the corresponding emissions are still less than the stabilized idling emissions shown in Table 13. Idling for up to 15 minutes would reduce idling by 70 percent or more compared to continuous idling emissions, while five minutes of idling would reduce emissions by almost 90 percent or more.

Table 13. Idling Emissions Reductions Results for Different Idling/Soak Time Scenarios for the Truck #4 Cold Tests.

Idling/Soak Time Scenario	Idling Emissions Reduction (%) compared to One-Hour Continuous (Stabilized) Idling Emissions			
	CO_2	CO	NO_x	THC
1/59	98	99	97	98
3/57	93	94	93	99
5/55	89	90	88	97
10/50	80	80	77	84
15/45	70	75	69	81
20/40	6	22	-2*	-39*
20(cold)/40	10	61	12	78

* Negative ("-") reductions mean emission increases.

TTI project staff also observed CAP operations during the Truck #5 cold test, Truck #6 hot and cold test, Truck #7 hot and cold test, Truck #10 hot test, and Truck #12 hot and cold test. Depending on the test vehicles, conditions, and/or scenarios, emissions and emissions reduction results varied. Those results are shown in Appendices B and C. Emissions for all idle/soak test scenarios are less than the corresponding continuous idling emissions except for:

- Truck #5 cold test HC emissions for the 20(cold)/40 scenario;
- Truck #6 hot test NO_x emissions for the 20(cold)/40 scenario;
- Truck #6 cold test NO_x emissions for the 20(cold)/40 scenario; and
- Truck #7 hot test CO_2 emissions for the 20/40 scenario.

The corresponding break-even times are 16, 17, 15, and 16 minutes for the Truck #5 cold test HC, the Truck #6 hot test and cold test NO_x, and Truck #7 hot test CO_2 emissions, respectively. That is, less than 15 minutes of idling for each hour – even after a cold start – would reduce emissions compared to continuous (stabilized) idling for those trucks for those conditions.

For the Truck #8 hot tests, three minutes or more of idling produced more NO_x emissions than the stabilized (continuous) idling NO_x emissions, as Figure 12 shows. For these tests, NO_x emissions increased rapidly from the beginning as Figure 12 shows. The corresponding break-even time for NO_x for the 3/57, 5/55, 10/50, 15/45, and 20/40 scenarios is about three minutes, while it is 1.4 minutes for the 20(cold)/40 scenario. This shows that non-cold start idling of three minutes or longer would produce more NO_x emissions when compared to the corresponding stabilized (continuous) NO_x emissions. The same is true for cold-start idling of 1.4 minutes or longer. TTI project staff believes that these different emissions characteristics for Truck #8, compared to those of other test trucks discussed earlier in this section, were due to different emissions control features for Truck # 8. Investigations of the relationships between the control features and consequent idling emissions are beyond the scope of this task.

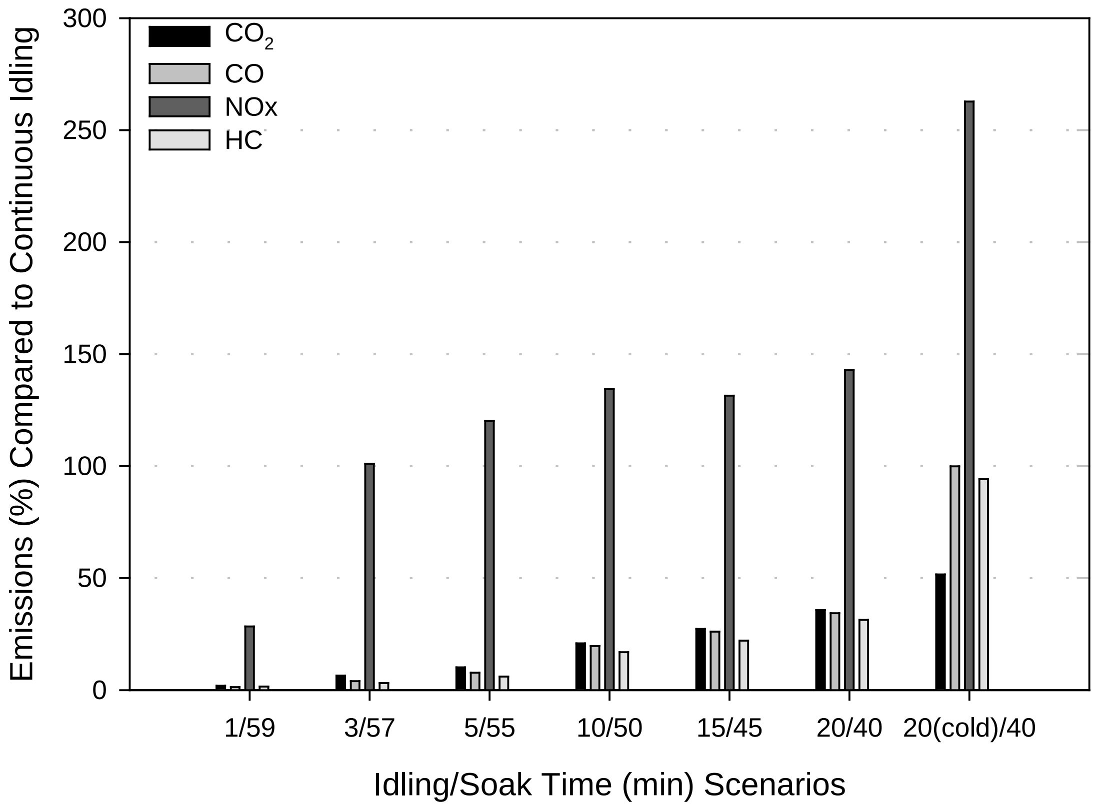


Figure 12. Truck #8 Idling Hot Test Emissions Results.

Note that NO_x emissions for the 20(cold)/40 scenario (13.8 g/h), which is 163 percent of the stabilized emission (5.25 g/h shown in Table 7), is still less than 30g/h of NO_x emissions rate that is the criterion for exemption from the idling rules described in Chapter 2. However, continuous (stabilized) idling would obviously reduce NO_x emissions more than start-up idling of three minutes or more for this truck. Table 14 shows the idling reduction results.

Table 14. Idling Emissions Reductions Results for Different Idling/Soak Time Scenarios for the Truck #8 Hot Tests.

Idling/Soak Time Scenario	Idling Emissions Reduction (%) compared to One-Hour Continuous (Stabilized) Idling Emissions			
	CO_2	CO	NO_x	THC
1/59	98	99	72	98
3/57	94	96	-1*	97
5/55	90	92	-20*	94
10/50	79	80	-34*	83
15/45	73	74	-31*	78
20/40	64	66	-43*	69
20(cold)/40	48	0	-163*	6

* Negative (“-“) reductions mean emission increases.

For other pollutants, the emissions results in Figure 12 and Table 14 show that they are approximately 50 percent or less than the corresponding stabilized (continuous) emissions, but CO and HC emissions for the 20(cold)/40 scenario are 100 percent and 94 percent, respectively.

Truck #8 showed similar trends in the cold tests as Figure 13 shows. NO_x emissions increased rapidly from the beginning while emissions of other pollutants did not. (For the 20(cold)/40 scenario, emissions results are not available because the corresponding data were missing due to the instrument malfunction.) Compared to the stabilized emissions, cold test start-up emissions were lower than 50 percent as Figure 13 and Table 15 show.

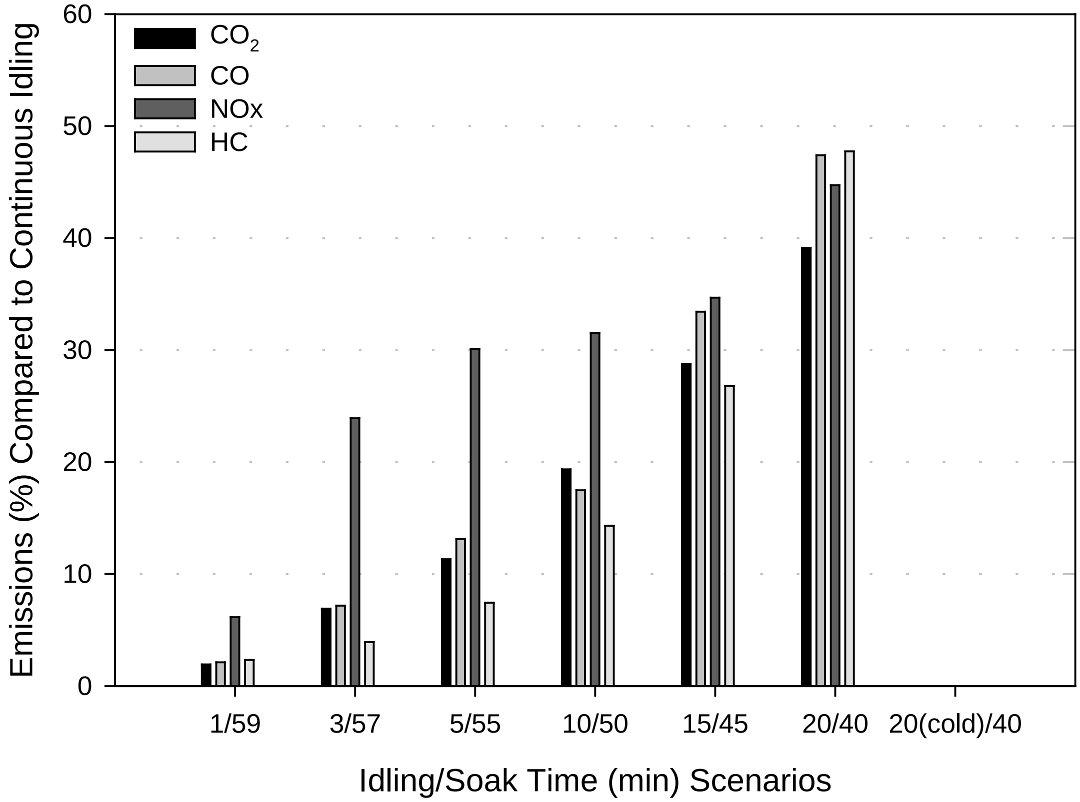


Figure 13. Truck #8 Idling Cold Test Emissions Results.

Table 15. Idling Emissions Reductions Results for Different Idling/Soak Time Scenarios for the Truck #8 Cold Tests.

Idling/Soak Time Scenario	Idling Emissions Reduction (%) compared to One-Hour Continuous (Stabilized) Idling Emissions			
	CO_2	CO	NO_x	THC
1/59	98	98	94	98
3/57	93	93	76	96
5/55	89	87	70	93
10/50	81	83	68	86
15/45	71	67	65	73
20/40	61	53	55	52
20(cold)/40	N/A*	N/A*	N/A*	N/A*

* N/A: Not available due to malfunctioning of the instruments.

Emissions with Regard to Soak Time

For light-duty gasoline vehicles, start-up emissions are considered to be significant. For example, Zietsman et al. found that close to zero NO_x emissions were produced due to the idling of a warmed-up vehicle. However, NO_x emissions were produced during all re-start scenarios making re-starts the worst case for NO_x; emissions were more than two orders of magnitude higher.[12] However, in this study of HDDVs, TTI project staff found that HDDV idling emissions were not greatly affected by restart scenarios, that is, different soak times ranging up to a cold start (> 720 minutes of soak time).

For example, Figure 14 shows Truck #1 emissions rates of CO_2, CO, NO_x, and THC during the first minute of idling with different soak times ranging from 0 minutes (continuous stabilized idling) to over 720 minutes (cold start idling). Soak time effects on the idling emissions of Truck #1 were not as great as for LDVs from the Zietsman et al. study.[12] The greatest soak time effects were for cold-start idling with a range of -20 percent-to200 percent increases, where a -20 percent increase means a 20 percent decrease. For other soak times (from five minutes to 59 minutes), the soak time effects were much smaller compared to those for the cold-start idling.

[12] Zietsman, J, T. L. Forrest, D. G. Perkinson, and L. R. Rilett. (2004) Emissions of Light Duty Gasoline Vehicles Due to Idling and Restarts: A Comparative Study.

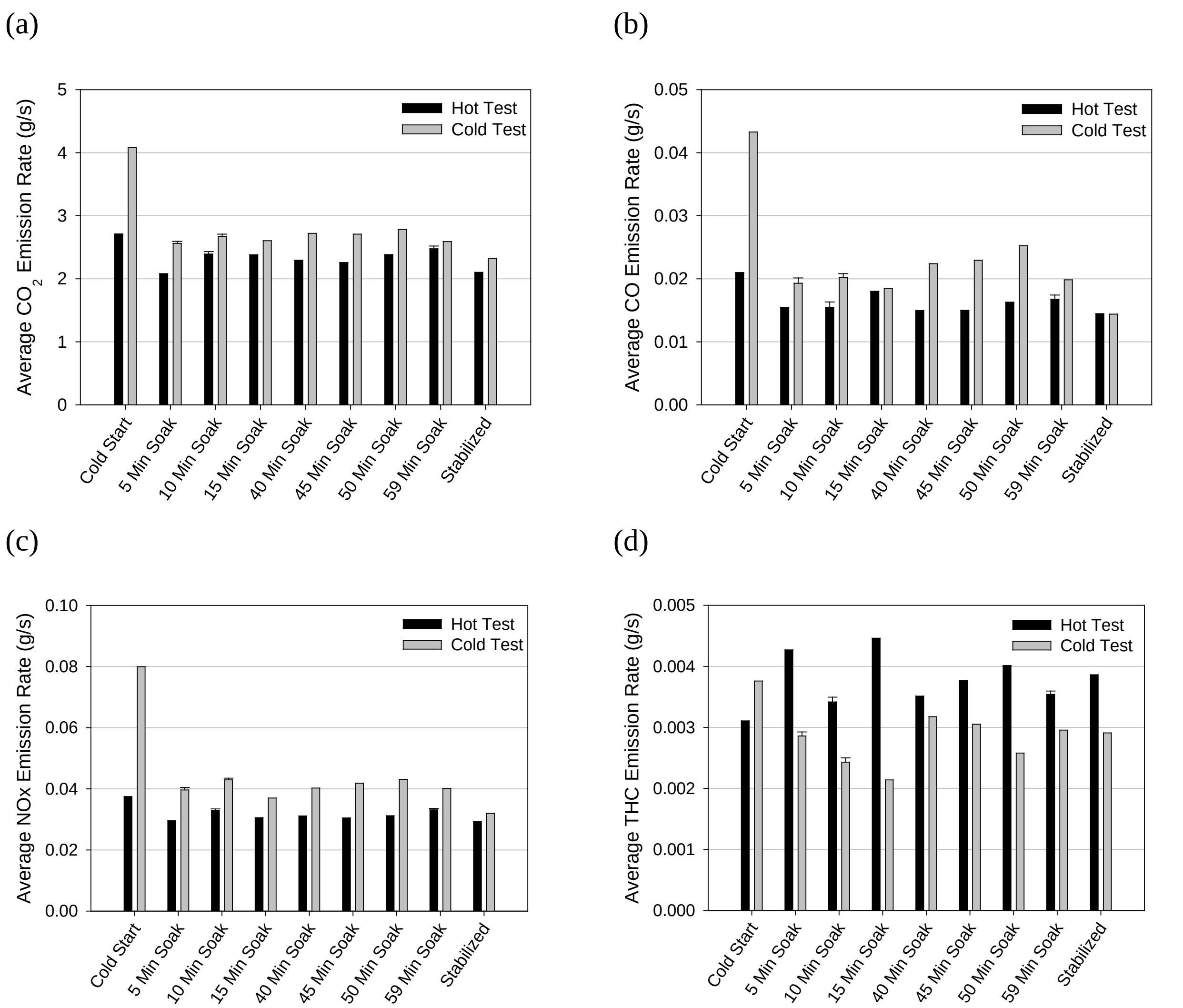


Figure 14. Truck#1 Emission Rates for 1 Minute Idling with Different Soak Time; (a) CO2, (b) CO, (c) NO_x, and (d) THC.

When the idling duration increases, the soak time effects become even smaller. Figure 15 shows the Truck #1 emissions rates for 20 minutes of idling with different soak times. The greatest soak time effects for the 20-minute idling were still shown for cold-start idling. However, the greatest emissions rate increase was only 72 percent.

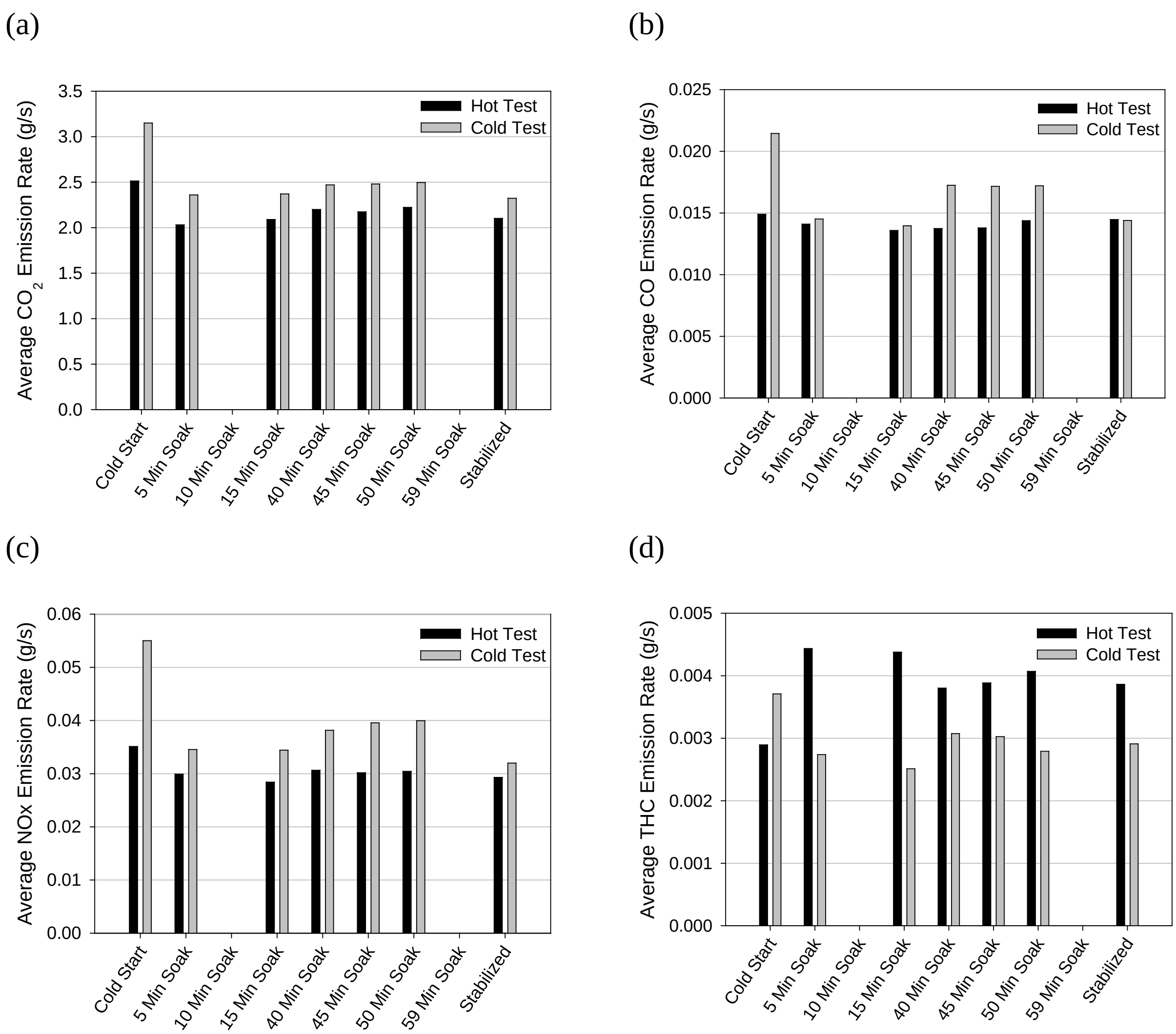


Figure 15. Truck#1 Emissions Rates for 20 Minutes of Idling with Different Soak Times; (a) CO_2, (b) CO, (c) NO_x, and (d) THC.

The soak time effects for other test vehicles were similar to those for Truck #1. Based on these results (of which other trucks are not shown), TTI project staff concluded that re-start effects on HDDV idling emissions are not significant compared to those for LDVs, and idling time itself is more significant.

Comparisons of Idling Emissions with Driving Emissions

Comparisons of idling emissions with driving emissions benefit understanding of the impacts of idling emissions in metropolitan areas. MY 2011 is selected for comparison because the number of MY 2011 trucks (4) in the study sample was the highest. From Table 7 and Table 8, MY 2011 HDDV average emissions rates were calculated:

- CO_2: 7415 g/h;
- CO: 24.5 g/h;
- NOx: 55.0 g/h; and
- THC: 4.39 g/h.

Idling emissions for five minutes, which is the most common maximum idling time allowed under current idling rules, were calculated using the 90 percent reduction assumption based on the results previously discussed (that is, 10 percent of the stabilized emissions). Table 16 lists the calculated emissions for comparisons with the driving emissions. For driving emissions, MY 2011 HDDV driving emissions results from a previous TTI study,[13] were used:

- CO_2: 1602 g/mi;
- CO: 0.42 5 g/mi;
- NOx: 0.97 g/mi; and
- THC: 0.13 g/mi.

Considering that speed limits of most intra-city local roads are approximately 35 mph, TTI project staff assumed an average driving speed of 35 miles per an hour for the comparisons with the idling emissions. Table 16 summarizes the estimated idling and driving emissions.

Table 16. Idling and Driving Emissions (One HDD Vehicle Hour).

	CO_2	**CO**	**NO_x**	**THC**
	Emissions (g)			
MY 2011 HDDV emissions for 5 min idling (as 90% reduction)	741	2.45	5.5	0.44
MY 2011 HDDV Driving (for 35 miles)	56070	14.7	34.0	4.55
	Percentage Ratio of Idling Emissions Over Driving Emissions			
Idling vs. Driving Emission	1.3%	16.7%	16.2%	9.6%

As Table 16 shows, the calculated five-minute idling emissions are 17 percent or less than for a 35-mile drive; 1.3 percent, 16.7 percent, 16.2 percent, and 9.6 percent for CO_2, CO, NO_x, and THC, respectively. When 10 minutes of idling is considered, with the assumption of 70 percent reductions found in this study, (i.e., 30 percent of the stabilized emissions), the calculated idling emissions reaches to 50 percent of the driving emissions; 4.0 percent, 50.1 percent, 48.6 percent, and 28.9 percent for CO_2, CO, NO_x, and THC, respectively.

[13] Johnson, J. D.-W. Lee, R. Farzaneh, J. Zietsman, and L. Yu. (2011) Characterization of Exhaust Emissions from Heavy-Duty Diesel Vehicles in the HGB Area – Final Report.

CHAPTER 5: CONCLUSIONS

Currently, 20 states enforce idling regulations state-wide, and nine other states, including Texas, enforce regulations at the regional level. The maximum idling time allowed under these regulations range from no idling at all to 20 minutes of idling, with five minute idle restriction being the most common. Texas also allows five minutes of idling.

To provide TxDOT with an understanding of the characteristics and impacts of idling emissions, TTI project staff performed idling emissions testing using 12 HDDVs for the hot (100° F and 70 percent relative humidity) and cold (30° F) test conditions. During the testing, a range of idling times and soak times (including cold start) were tested. Following is a summary of the findings from the testing.

- In general, idling emissions increase almost proportionally as idling time increases, though idling emissions from trucks vary quite significantly depending on model years, idling controls, and emissions control devices on the HDDVs.
- Different trucks with different engine and emissions control strategies, such as CAP, showed differing emissions characteristics. Additional studies collecting more information, such as temperature at emissions control devices and CAP parameters, would explain the different emissions characteristics. Cold-start emissions are usually higher than re-start emissions for intervening soak times of up to 59 minutes.
- Cold-start effects of HDDVs are not significant when compared to those of light-duty gasoline vehicles, and it was found that re-starts of HDDVs did not increase emissions significantly.

The findings above indicate that any idling restriction or idle reduction rule will result in an emissions benefit. When compared to an hour of stabilized idling, even implementing a 20 minute idle reduction policy will be beneficial from an emissions perspective. Compared to continuous stabilized one-hour idling, the 15-minute idle scenario (15 minute idle/45 minute “soak” scenario) is found to reduce idling emissions by approximately 50 percent or more, while the 10-minute and 5-minute scenarios reduce emissions by approximately 70 percent or more and 90 percent or more, respectively. TTI project staff also compared the idling emissions results with equivalent driving emissions results for MY 2011 HDDVs, to provide a comparative basis for evaluating the impact of emissions reductions due to idling restrictions. Based on the findings, it is seen that reducing the Texas idling limit from five minutes to zero would result in a NO_x emissions reduction of approximately $1/6^{th}$ of an hour’s driving, for each idling stop made.

Overall, the findings indicate that the current Texas idling limitation time of five minutes seems to be effective (resulting in about 90 percent emissions reduction when compared to an hour of idling) and is the most commonly used limit through the U.S. Idling of HDDVs can generate emissions comparable to driving/operating emissions, and the reduction of idling in Texas can help contribute to overall emissions reduction actions in the State.

APPENDIX A

SUMMARY OF TESTING PROTOCOL

Subtask Scope (From Contract)

The Performing Agency will provide the Receiving Agency with an understanding of the impacts of idling emissions, review of current practices in Texas, and recommendations on implementing heavy-duty idling reduction policies in nonattainment areas, early action compact areas, and areas such as border crossings. The Performing Agency will investigate idling emissions characteristics to identify the "break-even" point where the emissions reduction due to idling becomes greater than the emissions due to the vehicle startups.

Summary of Testing Protocol

- TTI developed a test protocol for the measurement of idle emissions as part of the subject task, and conducted a few pre-test runs using TTI's Model Year (MY) 2006 truck.
- The testing will be conducted for a total of 10 heavy-duty diesel trucks, two trucks in the pre-MY2007 category, four trucks in the MY2007-MY2010 category, and four trucks in the MY2011 and newer category.
- Testing will be conducted for two ambient test conditions: one for hot tests – 100° F and 70 percent relative humidity (RH) and the other for cold tests – 30° F. The temperature and RH conditions for the hot tests were based on average ambient conditions in the Houston area in the summer. The temperature for the cold tests was based on average ambient conditions in the Dallas area in the winter.
- TTI project staff investigated current idling restrictions and practices in Texas and other states, and found that the common restrictions on maximum idle durations were 2, 3, 5, 10, 15, or 20 minutes, depending on the location and other factors. Therefore, if the enforcement of these restrictions is considered for a vehicle that would normally idle over a one-hour period, the time engine idling time and the engine non-idling time (i.e., "soak" time) would be as shown in the following table.

Idle Duration and Soak Duration over One-Hour Period for Common Idle Restriction Policies

Maximum idling time (min)	2	3	5	10	15	20
Consequent soak time (min)	58	57	55	50	45	40

- TTI, therefore, developed the test protocol to report findings from idle emissions for 1-, 2-, 3-, 4-, 5-, 10-, 15-, and 20-minute durations over a one-hour period, along with the measurement of cold-start and extended-idling emissions. This test protocol will allow for the evaluation of the most commonly-implemented idle reduction scenarios, as well as provide flexibility for the analysis of certain other scenarios.
- Per the test protocol, the measurement of idle emissions will be performed through two sets of tests – the first to cover scenarios of 10, 15, and 20 minutes of idling, and the other to cover scenarios of 1, 2, 3, 4, and 5 minutes of idling.

- Grouping the various scenarios into two sets of tests allows for more testing to be accommodated within the task budget. The pre-testing conducted on TTI's test truck confirmed that this grouping was reasonable, as the emissions rates observed over these groups of durations were very similar. Additionally, this grouping splits up idle durations for which start-up emissions were significant (for test durations of five minutes or less), and negligible (for test durations 10 minutes or more).
- Emissions measurements will be repeated three times in each set of testing to allow for statistically meaningful data. The soak times are varied between the measurements to allow for replication of various idle time/soak time combinations.
- Steps for the first set of testing.
  - Turn off the warm engine, and allow for a 50-minute soak time for cooling the engine.
  - Turn on the engine, idle it for 20 minutes, and collect emissions data. This data will cover the 10-, 15-, and 20-minute idling emissions scenarios (as verified by pre-testing).
  - Repeat the above steps, first with a 45-minute soak time, and then with a 40-minute soak time. Collect emissions data for 20 minutes each time.
  - The data collected in this set of testing will allow for the following scenarios to be evaluated: 10 min idle/50 min soak, 15min idle/45min soak, and 20min idle/40min soak.
- Steps for the second set of testing.
  - After the first set of testing, allow for a 59-minute soak time.
  - Check the engine oil/ coolant temperature (T_1), turn on the engine, and collect emissions data for five minutes. This data will cover the 1-, 2-, 3-, 4-, and 5-minute idling emissions scenarios, as verified by pre-testing.
  - Turn off the engine, and allow the engine to cool until its temperature is around T_1 (pre-tests indicate this will take approximately 10 minutes).
  - Turn on the engine, idle it for five minutes, and collect emissions data.
  - Repeat the above two steps to collect a total of three five-minute idle intervals.
  - The data collected in this set of testing will allow for the scenarios of 1, 2, 3, 4, and 5 minutes of idling in a one-hour period to be evaluated.
- In addition to the two sets of tests described above, an extended idling/cold-start emissions test will be conducted, as follows:
  - Emissions data will be collected for two hours of continuous idling for both cold and hot conditions.
  - This extended idling test will be conducted with an engine that has a soak time of 12 hours or longer (i.e., to replicate a cold start).
  - The data collected for the first 20 minutes of this test will be compared to the emissions collected in the two sets of idle-emissions testing. These cold-start emissions values will represent the worst case scenario in the analyses based on the collected emissions data.
  - Emissions from the final 20 minutes of the two-hour idle duration (representing stabilized emissions) will be considered as the baseline emissions, and compared to the emissions collected in the two sets of idle emissions testing.

APPENDIX B

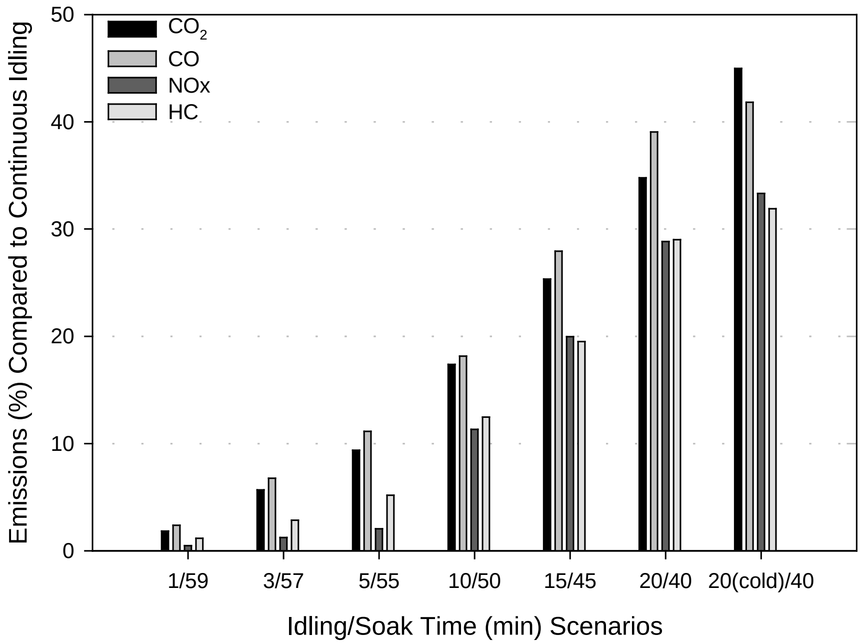


Figure 1. Truck #2 Idling Hot Test Emissions Results.

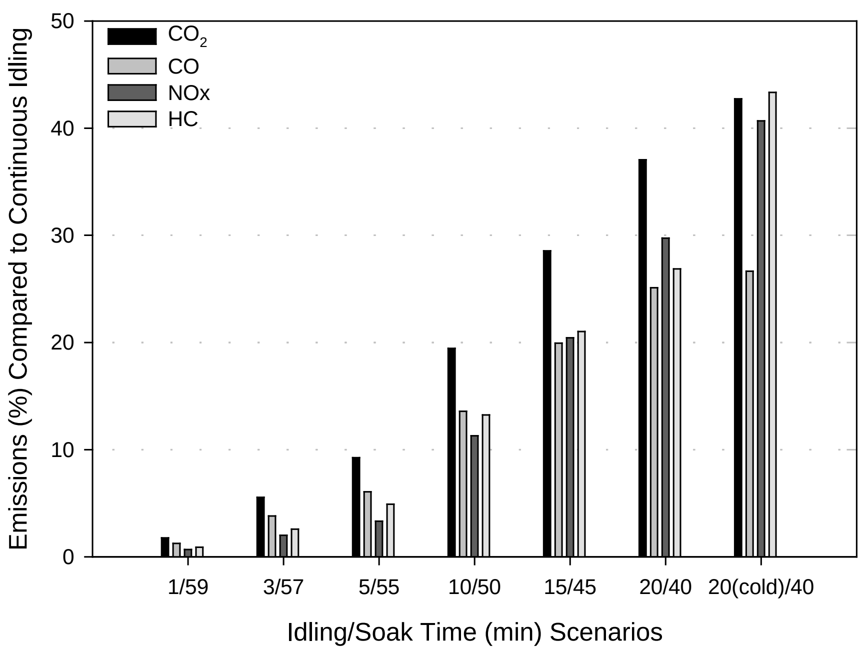


Figure 2. Truck #2 Idling Cold Test Emissions Results.

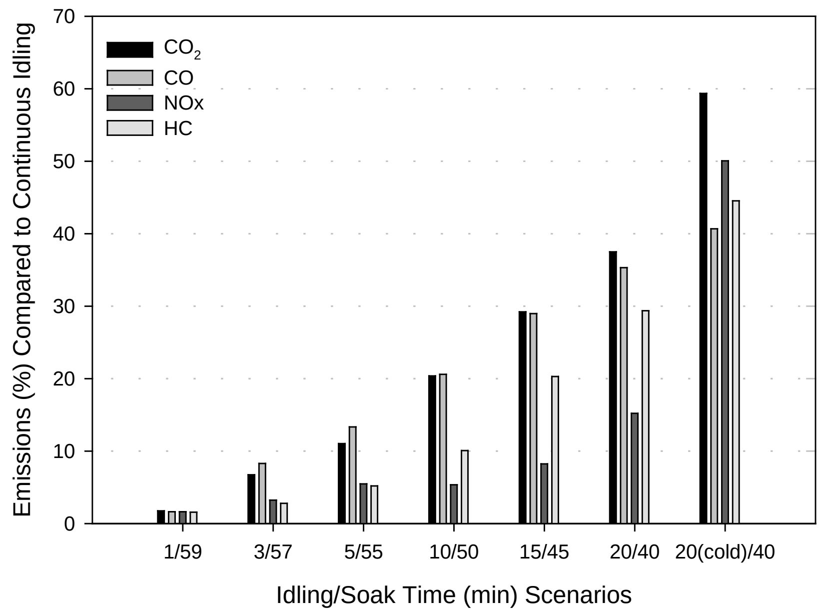


Figure 3. Truck #4 Idling Hot Test Emissions Results.

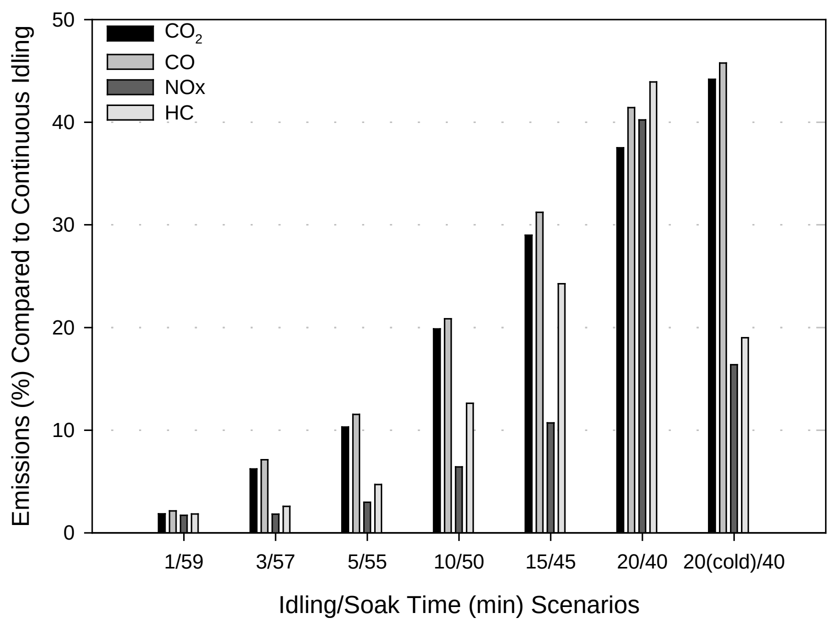


Figure 4. Truck #5 Idling Hot Test Emissions Results.

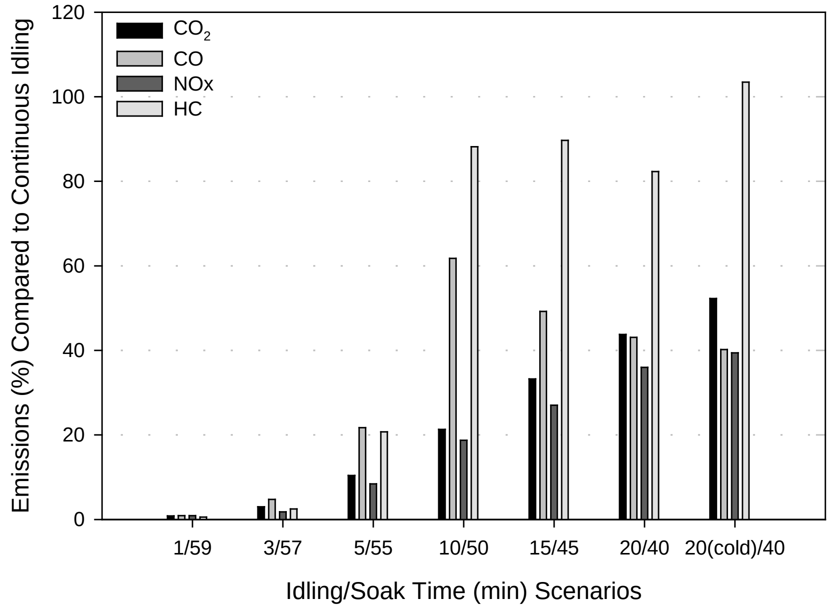


Figure 5. Truck #5 Idling Cold Test Emissions Results.

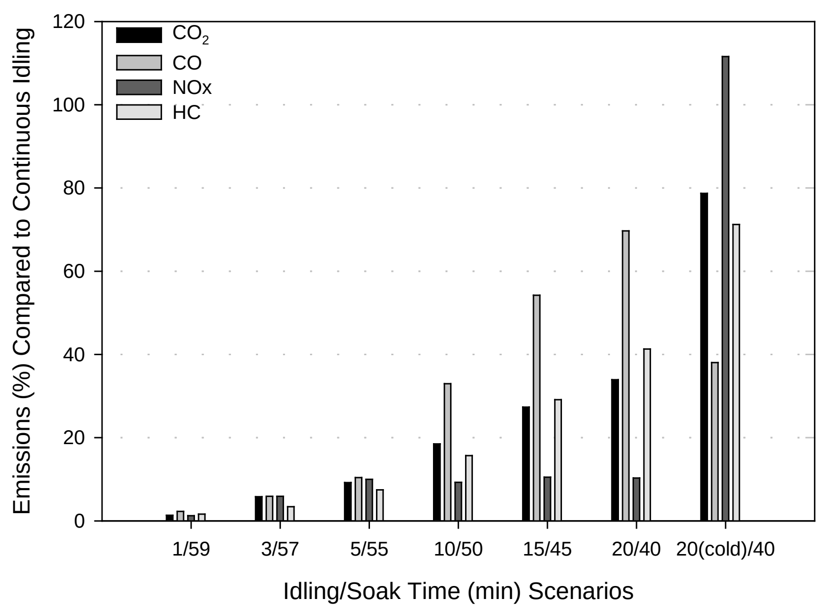


Figure 6. Truck #6 Idling Hot Test Emissions Results.

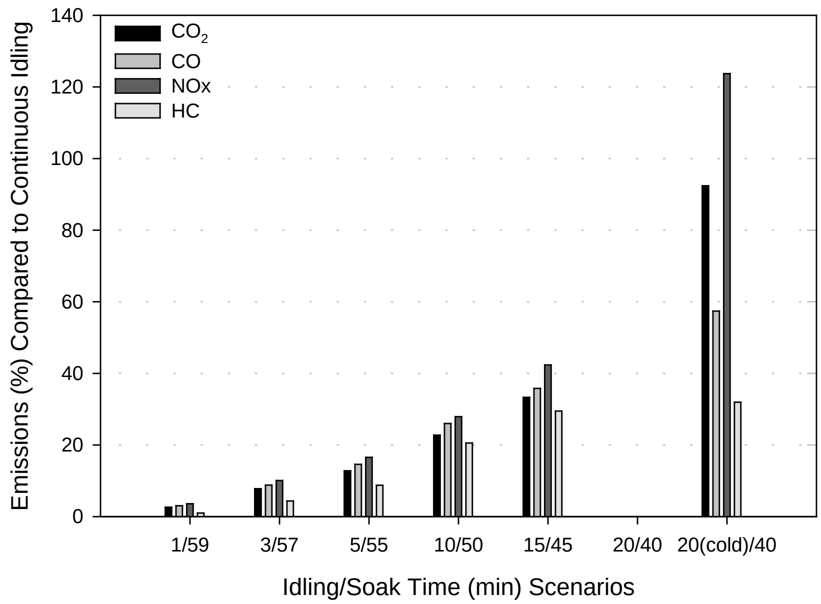


Figure 7. Truck #6 Idling Cold Test Emissions Results.

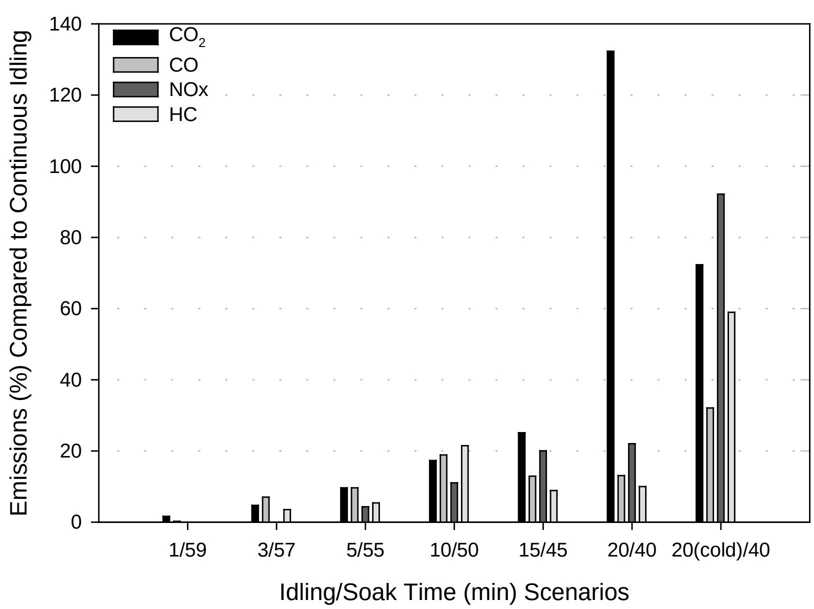


Figure 8. Truck #7 Idling Hot Test Emissions Results.

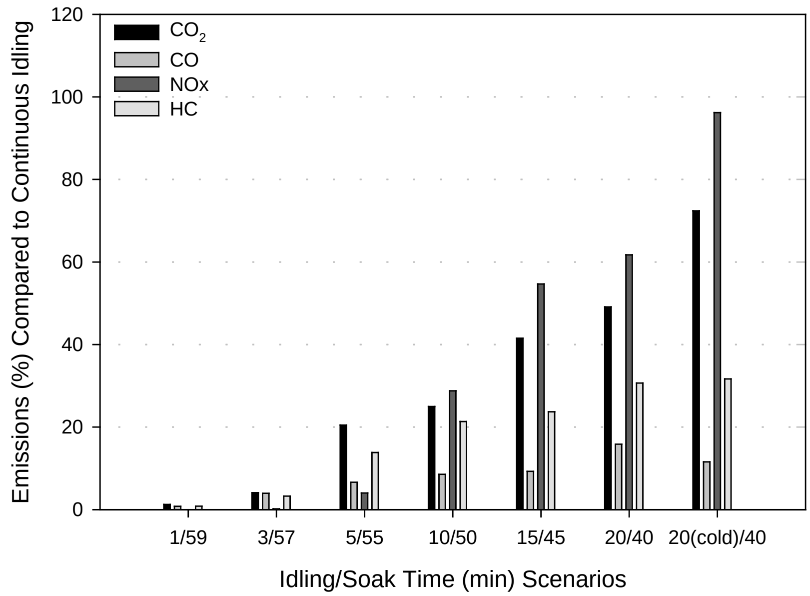


Figure 9. Truck #7 Idling Cold Test Emissions Results.

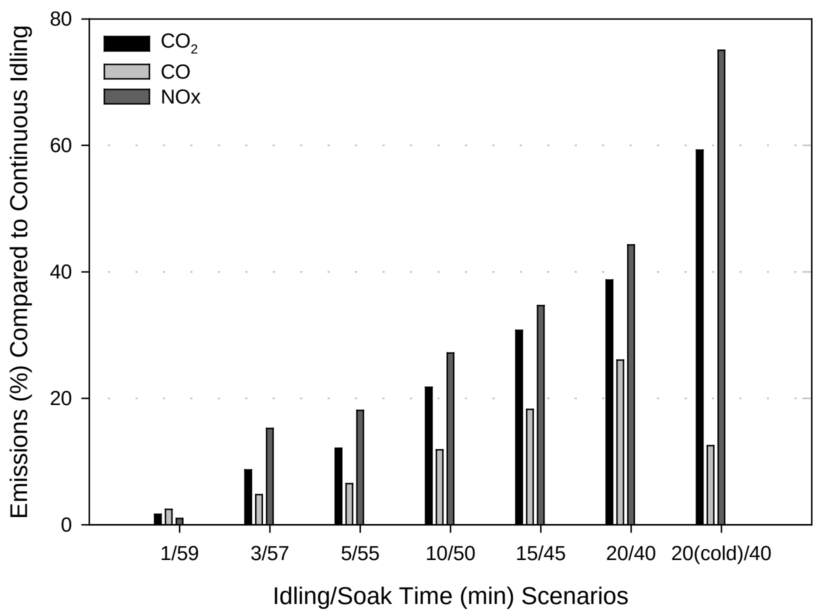


Figure 10. Truck #9 Idling Hot Test Emissions Results.

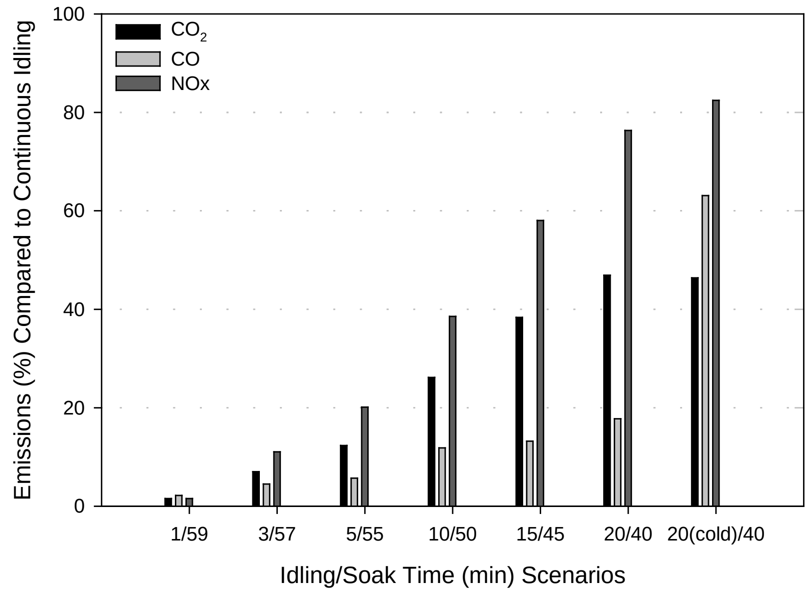


Figure 11. Truck #9 Idling Cold Test Emissions Results.

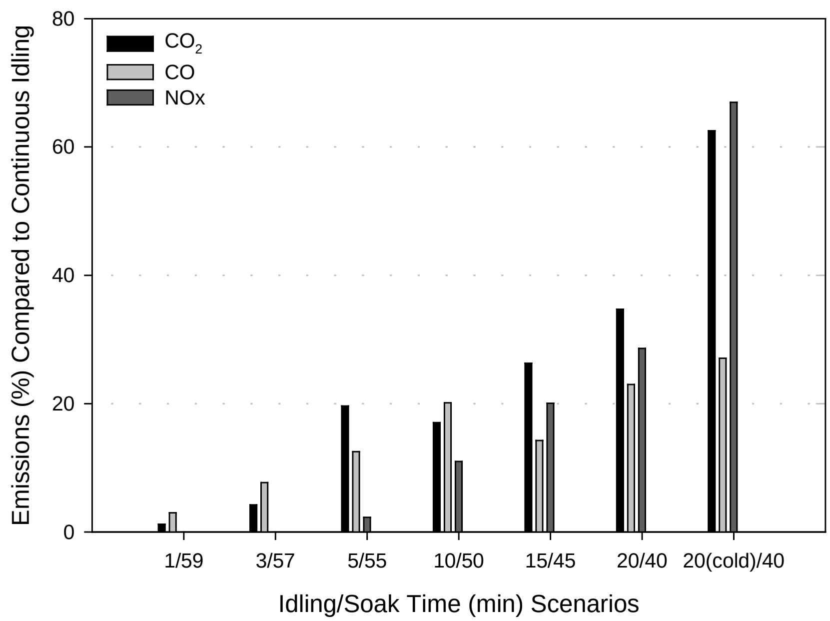


Figure 12. Truck #10 Idling Hot Test Emissions Results.

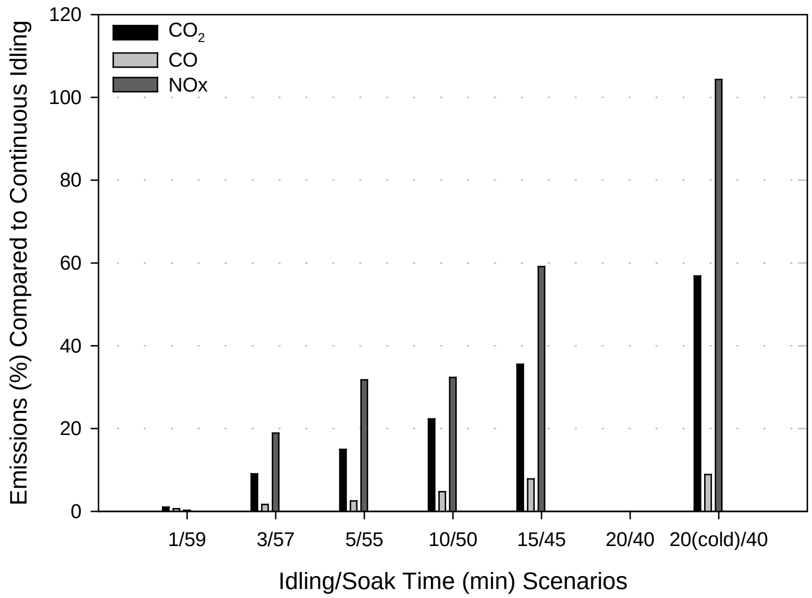


Figure 13. Truck #10 Idling Cold Test Emissions Results.

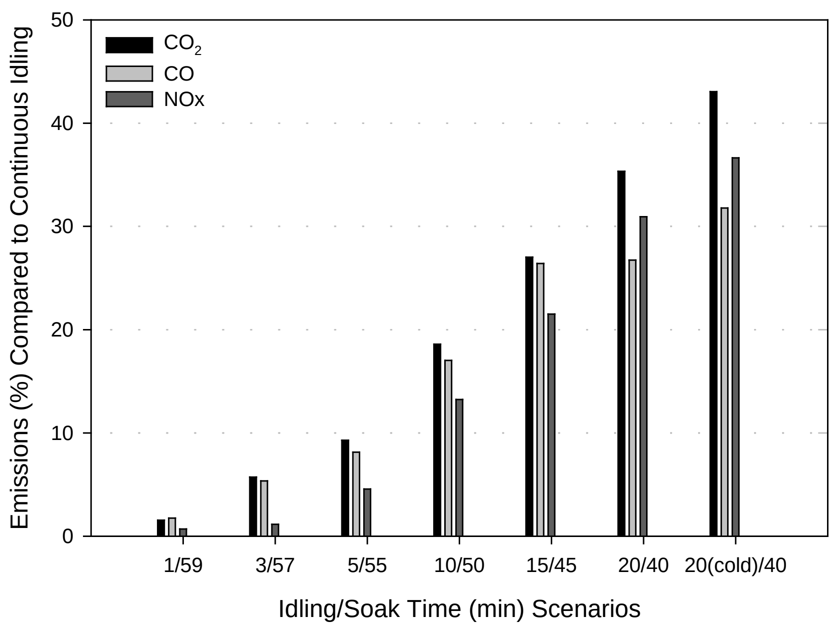


Figure 14. Truck #11 Idling Hot Test Emissions Results.

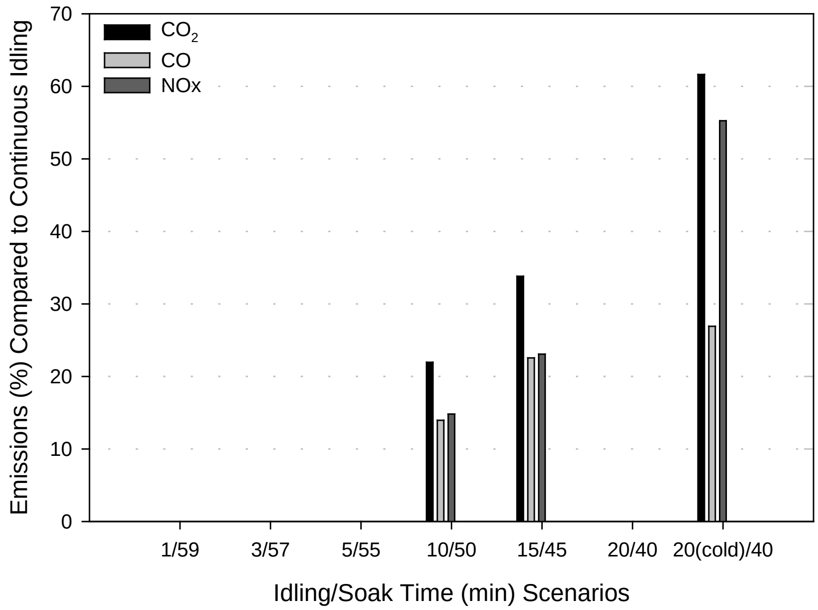


Figure 15. Truck #11 Idling Cold Test Emissions Results.

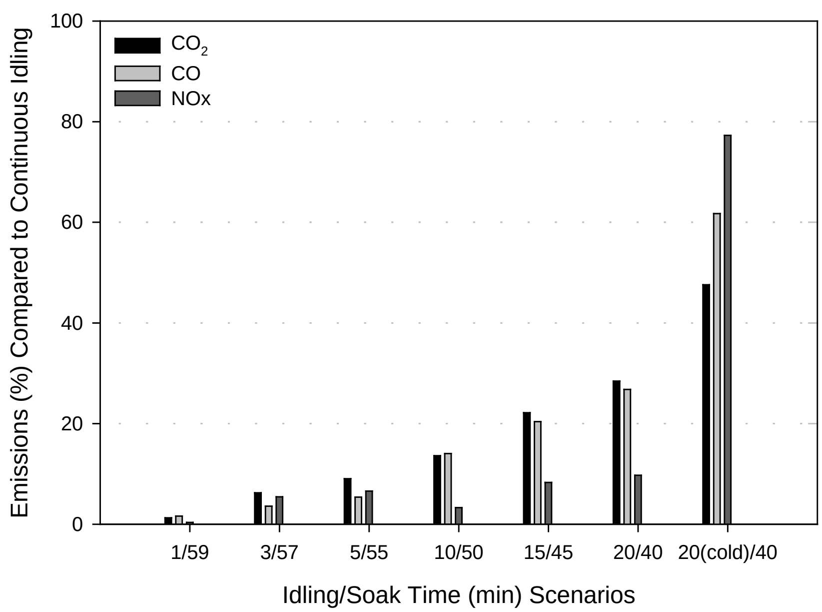


Figure 16. Truck #12 Idling Hot Test Emissions Results.

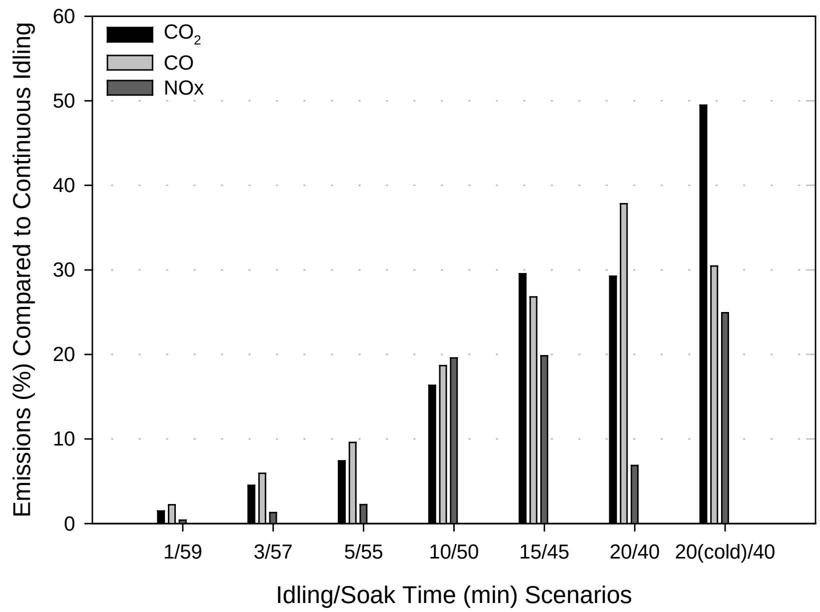


Figure 17. Truck #12 Idling Cold Test Emissions Results.

APPENDIX C

Table 1. Idling Emissions Reductions Results for Different Idling/Soak Time Scenarios for the Truck #2 Hot Tests.

Idling/Soak Time Scenario	Idling Emissions Reduction (%) compared to One-Hour Continuous (Stabilized) Idling Emissions			
	CO_2	CO	NO_x	THC
1/59	98	98	100	99
3/57	94	93	99	97
5/55	91	89	98	95
10/50	83	82	89	88
15/45	75	72	80	80
20/40	65	61	71	71
20(cold)/40	55	58	67	68

Table 2. Idling Emissions Reductions Results for Different Idling/Soak Time Scenarios for the Truck #2 Cold Tests.

Idling/Soak Time Scenario	Idling Emissions Reduction (%) compared to One-Hour Continuous (Stabilized) Idling Emissions			
	CO_2	CO	NO_x	THC
1/59	98	99	99	99
3/57	94	96	98	97
5/55	91	94	97	95
10/50	81	86	89	87
15/45	71	80	80	79
20/40	63	75	70	73
20(cold)/40	57	73	59	57

Table 3. Idling Emissions Reductions Results for Different Idling/Soak Time Scenarios for the Truck #4 Hot Tests.

Idling/Soak Time Scenario	Idling Emissions Reduction (%) compared to One-Hour Continuous (Stabilized) Idling Emissions			
	CO_2	CO	NO_x	THC
1/59	98	98	98	98
3/57	93	92	97	97
5/55	89	87	95	95
10/50	80	79	95	90
15/45	71	71	92	80
20/40	63	65	85	71
20(cold)/40	41	59	50	55

Table 4. Idling Emissions Reductions Results for Different Idling/Soak Time Scenarios for the Truck #5 Hot Tests.

Idling/Soak Time Scenario	Idling Emissions Reduction (%) compared to One-Hour Continuous (Stabilized) Idling Emissions			
	CO_2	CO	NO_x	THC
1/59	98	98	98	98
3/57	94	93	98	97
5/55	90	88	97	95
10/50	80	79	94	87
15/45	71	69	89	76
20/40	62	59	60	56
20(cold)/40	56	54	84	81

Table 5. Idling Emissions Reductions Results for Different Idling/Soak Time Scenarios for the Truck #5 Cold Tests.

Idling/Soak Time Scenario	Idling Emissions Reduction (%) compared to One-Hour Continuous (Stabilized) Idling Emissions			
	CO_2	CO	NO_x	THC
1/59	99	99	99	99
3/57	97	95	98	98
5/55	90	78	92	79
10/50	79	38	81	12
15/45	67	51	73	10
20/40	56	57	64	18
20(cold)/40	48	60	61	-3*

* Negative (“-“) reductions mean emissions increases.

Table 6. Idling Emissions Reductions Results for Different Idling/Soak Time Scenarios for the Truck #6 Hot Tests.

Idling/Soak Time Scenario	Idling Emissions Reduction (%) compared to One-Hour Continuous (Stabilized) Idling Emissions			
	CO_2	CO	NO_x	THC
1/59	99	98	99	98
3/57	94	94	94	97
5/55	91	90	90	93
10/50	82	67	91	84
15/45	73	46	89	71
20/40	66	30	90	59
20(cold)/40	21	62	-12*	29

* Negative (“-“) reductions mean emissions increases.

Table 7. Idling Emissions Reductions Results for Different Idling/Soak Time Scenarios for the Truck #6 Cold Tests.

Idling/Soak Time Scenario	Idling Emissions Reduction (%) compared to One-Hour Continuous (Stabilized) Idling Emissions			
	CO_2	CO	NO_x	THC
1/59	97	97	96	99
3/57	92	91	90	96
5/55	87	85	83	91
10/50	77	74	72	79
15/45	67	64	58	71
20/40	N/A*	N/A*	N/A*	N/A*
20(cold)/40	8	43	-24*	68

* N/A: Not available due to malfunctioning of instruments.
** Negative (“-“) reductions mean emission increases.

Table 8. Idling Emissions Reductions Results for Different Idling/Soak Time Scenarios for the Truck #7 Hot Tests.

Idling/Soak Time Scenario	Idling Emissions Reduction (%) compared to One-Hour Continuous (Stabilized) Idling Emissions			
	CO_2	CO	NO_x	THC
1/59	98	100	100	100
3/57	95	93	100	96
5/55	90	90	96	95
10/50	83	81	89	79
15/45	75	87	80	91
20/40	-32*	87	78	90
20(cold)/40	28	68	8	41

* N/A: Not available due to malfunctioning of instruments.

Table 9. Idling Emissions Reductions Results for Different Idling/Soak Time Scenarios for the Truck #7 Cold Tests.

Idling/Soak Time Scenario	Idling Emissions Reduction (%) compared to One-Hour Continuous (Stabilized) Idling Emissions			
	CO_2	CO	NO_x	THC
1/59	99	99	100	99
3/57	96	96	100	97
5/55	80	93	96	86
10/50	75	91	71	79
15/45	58	91	45	76
20/40	51	84	38	69
20(cold)/40	28	88	4	68

Table 10. Idling Emissions Reductions Results for Different Idling/Soak Time Scenarios for the Truck #9 Hot Tests.

Idling/Soak Time Scenario	Idling Emissions Reduction (%) compared to One-Hour Continuous (Stabilized) Idling Emissions			
	CO_2	CO	NO_x	THC
1/59	98	98	99	N/A*
3/57	91	95	85	N/A*
5/55	88	93	82	N/A*
10/50	78	88	73	N/A*
15/45	69	82	65	N/A*
20/40	61	74	56	N/A*
20(cold)/40	41	87	25	N/A*

* N/A: Not available due to malfunctioning of instruments.

Table 11. Idling Emissions Reductions Results for Different Idling/Soak Time Scenarios for the Truck #9 Cold Tests.

Idling/Soak Time Scenario	Idling Emissions Reduction (%) compared to One-Hour Continuous (Stabilized) Idling Emissions			
	CO_2	CO	NO_x	THC
1/59	98	98	98	N/A*
3/57	93	95	89	N/A*
5/55	88	94	80	N/A*
10/50	74	88	61	N/A*
15/45	62	87	42	N/A*
20/40	53	82	24	N/A*
20(cold)/40	54	37	18	N/A*

* N/A: Not available due to malfunctioning of instruments.

Table 12. Idling Emissions Reductions Results for Different Idling/Soak Time Scenarios for the Truck #10 Hot Tests.

Idling/Soak Time Scenario	Idling Emissions Reduction (%) compared to One-Hour Continuous (Stabilized) Idling Emissions			
	CO_2	CO	NO_x	THC
1/59	99	97	100	N/A*
3/57	96	92	100	N/A*
5/55	80	87	98	N/A*
10/50	83	80	89	N/A*
15/45	74	86	80	N/A*
20/40	65	77	71	N/A*
20(cold)/40	37	73	33	N/A*

* N/A: Not available due to malfunctioning of instruments.

Table 13. Idling Emissions Reductions Results for Different Idling/Soak Time Scenarios for the Truck #10 Cold Tests.

Idling/Soak Time Scenario	Idling Emissions Reduction (%) compared to One-Hour Continuous (Stabilized) Idling Emissions			
	CO_2	CO	NO_x	THC
1/59	99	99	100	N/A*
3/57	91	98	81	N/A*
5/55	85	97	68	N/A*
10/50	78	95	68	N/A*
15/45	64	92	41	N/A*
20/40	N/A*	N/A*	N/A*	N/A*
20(cold)/40	43	91	-4**	N/A*

* N/A: Not available due to malfunctioning of instruments.
** Negative ("-") reductions mean emission increases.

Table 14. Idling Emissions Reductions Results for Different Idling/Soak Time Scenarios for the Truck #11 Hot Tests.

Idling/Soak Time Scenario	Idling Emissions Reduction (%) compared to One-Hour Continuous (Stabilized) Idling Emissions			
	CO_2	CO	NO_x	THC
1/59	98	98	99	N/A*
3/57	94	95	99	N/A*
5/55	91	92	95	N/A*
10/50	81	83	87	N/A*
15/45	73	74	78	N/A*
20/40	65	73	69	N/A*
20(cold)/40	57	68	63	N/A*

Table 15. Idling Emissions Reductions Results for Different Idling/Soak Time Scenarios for the Truck #11 Cold Tests.

Idling/Soak Time Scenario	Idling Emissions Reduction (%) compared to One-Hour Continuous (Stabilized) Idling Emissions			
	CO_2	CO	NO_x	THC
1/59	N/A*	N/A*	N/A*	N/A*
3/57	N/A*	N/A*	N/A*	N/A*
5/55	N/A*	N/A*	N/A*	N/A*
10/50	78	86	85	N/A*
15/45	66	77	77	N/A*
20/40	N/A*	N/A*	N/A*	N/A*
20(cold)/40	38	73	45	N/A*

Table 16. Idling Emissions Reductions Results for Different Idling/Soak Time Scenarios for the Truck #12 Hot Tests.

Idling/Soak Time Scenario	Idling Emissions Reduction (%) compared to One-Hour Continuous (Stabilized) Idling Emissions			
	CO_2	CO	NO_x	THC
1/59	99	98	100	N/A*
3/57	94	96	95	N/A*
5/55	91	95	93	N/A*
10/50	86	86	97	N/A*
15/45	78	80	92	N/A*
20/40	72	73	90	N/A*
20(cold)/40	52	38	23	N/A*

* N/A: Not available due to malfunctioning of instruments.

Table 17. Idling Emissions Reductions Results for Different Idling/Soak Time Scenarios for the Truck #12 Cold Tests.

Idling/Soak Time Scenario	Idling Emissions Reduction (%) compared to One-Hour Continuous (Stabilized) Idling Emissions			
	CO_2	CO	NO_x	THC
1/59	99	98	100	N/A*
3/57	95	94	99	N/A*
5/55	93	90	98	N/A*
10/50	84	81	80	N/A*
15/45	70	73	80	N/A*
20/40	71	62	93	N/A*
20(cold)/40	51	70	75	N/A*

* N/A: Not available due to malfunctioning of instruments.

APPENDIX D

PM Cold Start Idling Emissions Results

Truck #	Idling time for hot tests (min)						Idling time for cold tests (min)					
	1	**3**	**5**	**10**	**15**	**20**	**1**	**3**	**5**	**10**	**15**	**20**
1	0.15	Ng*	Ng*	Ng*	Ng*	Ng*	0.33	0.42	Ng*	Ng*	Ng*	Ng*
2	N/A**	N/A**	N/A**	N/A**	N/A**	N/A**	0.13	Ng*	Ng*	Ng*	Ng*	Ng*
3	N/A**	N/A**	N/A**	N/A**	N/A**	N/A**	0.17	0.39	0.55	Ng*	Ng*	Ng*
4	Ng*	Ng*	Ng*	Ng*	Ng*	Ng*	Ng*	Ng*	Ng*	Ng*	Ng*	Ng*
5	Ng*	Ng*	Ng*	Ng*	Ng*	Ng*	Ng*	Ng*	Ng*	Ng*	Ng*	Ng*
6	Ng*	Ng*	Ng*	Ng*	Ng*	Ng*	Ng*	Ng*	Ng*	Ng*	Ng*	Ng*
7	0.21	Ng*	Ng*	Ng*	Ng*	Ng*	N/A**	N/A**	N/A**	N/A**	N/A**	N/A**
8	Ng*	Ng*	Ng*	Ng*	Ng*	Ng*	Ng*	Ng*	Ng*	Ng*	Ng*	Ng*
9	Ng*	Ng*	Ng*	Ng*	Ng*	Ng*	Ng*	Ng*	Ng*	Ng*	Ng*	Ng*
10	Ng*	Ng*	Ng*	Ng*	Ng*	Ng*	Ng*	Ng*	Ng*	Ng*	Ng*	Ng*
11	Ng*	Ng*	Ng*	Ng*	Ng*	Ng*	Ng*	Ng*	Ng*	Ng*	Ng*	Ng*
12	Ng*	Ng*	Ng*	Ng*	Ng*	Ng*	Ng*	Ng*	Ng*	Ng*	Ng*	Ng*

* Ng: Negligible because the measured PM emissions were under detection limits.
** N/A: Not available due to malfunctioning of the instrument.