OFF-ROAD DIESEL LOW-EMISSION DEMO FOR NITROGEN OXIDES (NO_X), PARTICULATE MATTER (PM), AND TOXICS

OFF-ROAD LOW NO_X DEMONSTRATION PROGRAM
STAGE 1 – BASELINE AND MODELING
CARB CONTRACT NO. 18RD006

FINAL REPORT

SwRI® Project Number 03.24576

Prepared for:

California Air Resources Board

Prepared by:

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April 20, 2021

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TABLE OF CONTENTS

LIST OF FIGURES

Figure **Page**

LIST OF TABLES

Table **Page**

LIST OF ACRONYMS

ANR	Ammonia to NO_X Ratio
ASC	Ammonia Slip Catalyst
BMEP	Brake Mean Effective Pressure
DAAAC	Diesel Aftertreatment Accelerated Aging Cycles
DEF	Diesel Exhaust Fluid (32% urea by weight)
DOC	Diesel Oxidation Catalyst
DPF	Diesel Particule Filter
ECM	Electronic Control Module
EGR	Exhaust Gas Recirculation
EO	Engine Out
EU	European Union
FTP	U.S. Heavy Duty Transient Federal Test Procedure
FUL	Full Useful Life
GHG	Greenhouse Gas
HDIUT	Heavy Duty In Use Testing
LLC	Low Load Cycle
LLAC	Low Load Application Cycle
LO-SCR	Light Off SCR Catalyst
MY	Model Year
NIST	National Institute of Standards and Technology
NRTC	Nonroad Transient Cycle
NTE	Not-to-Exceed
PAG	Program Advisory Group
PMP	EU Particle Measurement Programme
RMC	Ramped Modal Cycle
SCR	Selective Catalytic Reduction (ammonia-based)
SCRF	SCR on Filter (SCR coated on DPF)
TM	Thermal Management
TP	Tailpipe

ABSTRACT

Given the ongoing air quality challenges in California, there has been significant interest extending the efforts of recent on-highway Low NO_X technology demonstration efforts into the Off-road sector. Off-road engines account for 11 percent of statewide NO_X emissions and 29 percent of statewide diesel PM emissions. This study, and subsequent demonstrations of Low NO_X technology focusing on the Off-road sector, is intended to provide important technical support for the promulgation of more stringent standards to reduce NO_X and PM emissions from these engines with relatively little impact on CO_2 emissions, or potentially to leverage additional engine technology to pursue both NO_X and CO_2 reduction, albeit at higher system cost and complexity levels. The program efforts detailed in this report include gathering off-road market information, detailed baseline testing of Tier 4 engines, and modeling efforts to examine potential approaches to reaching NO_X levels up to 90 percent below the current Tier 4 standards, and PM levels 75 percent below the current Tier 4 standards. These efforts include examination of engines under lower load conditions than are currently regulated under the Tier 4 standards. It is anticipated that at least one of the engines used in this program could be carried forward into a future planned Off-road Low NO_X technology demonstration.

EXECUTIVE SUMMARY

This report describes a program conducted by Southwest Research Institute (SwRI) on behalf of the Research Division of the California Air Resources Board (CARB), under contract 18RD006. The objective of this program was to perform several initial investigations to lay the foundation for the expansion of on-going Low NO_X demonstration efforts into the Off-Road Diesel application space. This demonstration is being conducted with the goal of providing technical support for the eventual development of more stringent Off-Road Diesel emission standards. This program was concerned primarily with several initial data gathering exercises, and was divided into four primary task elements:

- An off-road Market Review examining the off-road market in California from both a technology perspective and an application perspective
- Baseline Emissions Testing of two Off-Road Diesel engines, one Diesel Particulate Filter (DPF)-equipped engine and one non-DPF engine
- Detailed Chemical Characterization of toxic and unregulated emissions species from both engines, including gas-phase, semi-volatile phase, and particle phase pollutants
- Modeling of Potential Low NO_X Technology Pathways including engine and aftertreatment technology options

Off-road Market Review

The first program task involved a review of the Off-road market from both an application perspective and a Tier 4 technology perspective. For the market review, SwRI contracted with Yengst and Associates to provide a comprehensive overview of California Off-Road market from an application point of view. It was found that Agricultural tractors make up a little over half the overall Off-Road machine population in California, with the majority being tractors under 100hp. The rest of the machine population is distributed over a wide variety of construction and industrial applications. In terms of technology, it was found that 14% of engines over 56kw did not use EGR, while 60% of engines over 56kw did not use a DPF for PM control. All of these engines use SCR-based aftertreatment for NO_X control.

Tier 4 Engine Baseline Testing

Two different Tier 4 engines were procured, and baseline tested under this program. One engine was a DPF-equipped engine, and the other was a non-DPF engine. The DPF engine was a John Deere 6068HFC09 6.8L 6-cylinder diesel engine having a nominal maximum power rating of 187 kw, and used DOC+DPF+SCR aftertreatment architecture. The non-DPF engine was a John Deere 4045HFC04 4.5L 4-cylinder diesel engine having a nominal maximum power rating of 104kw, and used a DOC+SCR aftertreatment architecture. Baseline testing was carried out using the standard Off-road regulatory cycles for compression ignition engines, including the Off-road Transient Cycle, the steady-state RMC C1 8-mode cycle for variable speed engines, and the steady-state RMC D2 5-mode cycle for constant speed engines. SwRI also worked with John Deere to develop a Low Load Application Cycle to examine emissions under representative low load conditions. Both engines were tested in triplicate on all cycles.

Tailpipe NO_X levels for both engines were well below the Tier 4 standard level of 0.4 g/kw-hr, with significant margin available for catalyst durability and production variability. However, on the lower load LLAC cycle, NO_X emissions were much higher than on any other cycle, well in excess of 1 g/kw-hr. It should be noted that the LLAC is well below the currently regulated load levels for Off-road Diesel engines, and these results indicate an emission performance gap at lower loads and temperatures. For the DPF engine, PM was an order of magnitude below the Tier 4 PM standard of 0.02 g/kw-hr, while for the non-DPF engine, PM on the de-greened engine and aftertreatment was about half the Tier 4 standard. PN levels for the DPF equipped engine were below the EU Stage V off-road standard of 1×10^{12} #/kw-hr. PN emissions for the non-DPF engine were roughly two orders of magnitude higher than the tailpipe PN for the DPF-equipped engine.

TABLE 1. BASELINE OFF-ROAD TAILPIPE EMISSIONS SUMMARY

Test Cycle	6.8L DPF Engine			4.5L Non-DPF Engine		
	NO_X g/kw-hr	PM g/kw-hr	PN #/kw-hr	NO_X g/kw-hr	PM g/kw-hr	PN #/kw-hr
Cold NRTC	0.39	0.001	3.7×10^{12}	0.66	0.011	6.2×10^{13}
Hot NRTC	0.08	0.0005	4.9×10^{10}	0.12	0.009	5.5×10^{13}
Composite NRTC	0.10	0.0004	4.1×10^{11}	0.16	0.009	5.6×10^{13}
RMC C1	0.08	0.0003	2.9×10^{10}	0.05	0.009	5.0×10^{13}
RMC D2	0.02	0.0004	1.1×10^{11}	0.02	0.005	4.9×10^{13}
LLAC	1.8	0.0003	6.3×10^{10}	1.3	0.009	2.9×10^{13}

Detailed Chemical Characterization of Exhaust from Both Engines

A full detailing of the exhaust characterization results is too extensive for this Executive Summary. The detailed chemistry analyses generally indicated good control of unregulated HC emission species from both engines. The DPF equipped engine did demonstrate much better control of heavier particle phase PAH compounds, and somewhat better control of light VOCs as well. N_2O emissions were substantially higher for the non-DPF engine, primarily as a result of the higher engine-out NO_X calibration in combination with the aftertreatment. That higher NO_X calibration is likely needed to help control engine-out PM levels, given that a DPF is not available to clean up engine-out PM, thus limiting the use of EGR as an in-cylinder NO_X control measure. Wear metals, trace elements, inorganic ions, and WSOCs did not show significant levels for either engine. SVOC and IVOC analysis did indicate some trends between HC emissions for the two engines, but generally HC emissions were very low for both engines.

Modeling of Potential Low NO_X Pathways

Simulation studies of potential approaches to reaching future demonstration target NO_X levels on Off-road engines were performed using a combined set of models for the engine and aftertreatment system. SwRI utilized a modified version of an engine model for the 6.8L engine that was obtained from John Deere, and an aftertreatment model consisting of a GT-Suite thermal model and a SwRI-proprietary catalyst kinetic model. Different system architectures and engine calibrations were simulated to examine the potential to reach a target of 90% NO_X reduction from current Off-road standards. The modeling results indicated that it was likely the target NO_X emission levels could be reached using an updated conventional DOC+DPF+SCR aftertreatment architecture, even when considering the lower load LLAC cycle, with only relatively modest calibration changes on the baseline engine. This indicates the potential to pursue Low NO_X levels at relatively little impact on CO_2 emissions, or the possibility to leverage more engine technology to pursue both NO_X and CO_2 reductions, albeit at higher system cost and complexity levels.

Next Steps

It should be noted that the 6.8L John Deere engine has been retained at SwRI for use in subsequent efforts to demonstrate Low NO_X technologies for Off-road applications. The baseline data from this program will serve as the comparison point for both NO_X and CO_2 performance. In addition, the results of the model tasks will be used to provide data to aftertreatment suppliers to enable aftertreatment system design for the upcoming technology demonstration effort. In this way, the results of the program summarized in this report provide a good foundation for future Low NO_X efforts in the Off-road segment.

1.0 INTRODUCTION AND BACKROUND

In recent years, numerous advances have been made in the development of new engines, emissions control technologies, low carbon fuels, and renewable fuel technologies, aiming to reduce the negative air quality and climate impacts of off-road mobile sources. Current Off-road diesel engines with output over 56 kW (75 horsepower [hp]) need to meet Tier 4 final engine standards that are significantly more stringent for nitrogen oxides (NOx) and particulate matter (PM) emissions than Tier 1-3 standards. Today, off-road diesel engines in California contribute 29 percent of statewide diesel PM emissions and 11 percent of statewide NOx emissions. Because of the quick market growth for off-road diesel engines, and the continuous improvement of emission control for on-road engines and vehicles, off-road diesel engines will become increasingly important sources of engine emission-related air pollution.

Off-road and on-road diesel engines share many similarities in engine design and emission control technologies. When used in both engine categories, a diesel particulate filter (DPF) physically traps PM and then combusts accumulated PM through regeneration, and a selective catalytic reduction (SCR) system chemically reduces, in the presence of the catalyst and urea within a specific temperature range, NOx into nitrogen and water vapor. A combined DPF and SCR system technology is used for 2010 and later on-road heavy-duty diesel engines, and some Tier 4 off-road diesel engines, to meet emission standards. However, a growing majority of off-road equipment with power ratings in the range of 56 to 560 kW (75 to 750 hp) employ exclusively SCR for the compliance with the Tier 4 final standards of 0.40 g/kW-hr for NOx and 0.02 g/kW-hr for PM emissions.

SwRI has been engaged in a series of programs for CARB between 2014 and the present to demonstrate the feasibility of technologies to achieve a 90 percent reduction in tailpipe emissions from current standards on on-highway engines. CARB has indicated a desire to pursue reductions of a similar nature in the Off-road sector. In order to prepare for such an effort, CARB contracted with SwRI to perform several test and development efforts to lay the groundwork for a Low NO_X demonstration effort.

To meet these objectives, the program described in this report was designed to include the following high-level tasks:

- Provide a detailed assessment of both current Tier 4 Off-road technology and of the Off-road market and its applications
- Perform baseline emission testing on two representative Tier 4 Off-road engines, covering both regulated pollutants and a detailed chemical characterization of exhaust emission. The two engines included one DPF-equipped engine (DPF+SCR) and one engine without a DPF (SCR-only).
- Perform modeling on potential aftertreatment and engine pathways to achieve up to a 90% reduction in tailpipe emissions from the current Tier 4 standards

It is understood that this effort represents a first phase of work in an effort that may eventually culminate in demonstration of Low NO_X technologies on one or more engines in laboratory. As of the writing of this report, SwRI has already begun work under separate contract (CARB Contract 19RD002) to demonstrate such technologies, and the work performed in this program has provided a valuable foundation for that effort.

2.0 TASK 1 – CURRENT TECHNOLOGY AND EMISSIONS IMPACT ASSESSMENT

The objective of this task as to provide CARB with an examination of the Off-road engine market in California from both population perspective and a technology perspective. Given those objectives, SwRI undertook two efforts as part of this task:

- A review of all available 2019 and 2020 Off-road certifications to understand the application rate of various emissions control technologies.
- An Off-road engine market survey providing a breakdown of the Off-road engine population by application.

2.1 Review of Data from 2019 and 2020 Off-Highway Diesel Engine Certifications

Data was collected from CARB's engine certification database in June 2019. There were only 11 Model Year 2020 certifications available at that time, but there were 260 Model Year 2019 certifications. The data was limited to engines in the power range of 19 to 560 kW, and only engines certified to Tier 4 Final standards were included. A few engines certified to higher levels are not included. This data is being provided to CARB in an Excel spreadsheet "CARB Emissions Certs.xlsx" that is being provided along with this report.

The spreadsheet includes the following information:

- Column A lists the manufacturer's name
- Column B lists the engine family name
- Column C lists the engine displacement
- Column D lists the engine's power category, which determines the emissions standard that must be met
- Column E lists the actual range of power ratings that were certified
- Column F lists the emissions control features on each engine
- Column G lists the applications for which the engine was certified
- Columns H through L list the certified emissions levels in g/kW-hr
- Column M lists emissions control features that were NOT used on the engine, but which might normally be expected in an engine that complies with the standard

A high percentage of engines do not use one or more of the emissions control features that might be expected for a given NOx or PM requirement. Calling a feature "expected" does not imply that it is required to achieve a given emissions level. It only means that many manufacturers use that feature to achieve the emissions target, so in this context, "expected" means "widely used". "Expected" emissions control features include a DOC, DPF and EGR for engines from 19 to 56 kW. The EGR system helps reduce engine-out NOx. The NOx target for this power range can be achieved without EGR, but deleting EGR normally comes with a fuel consumption penalty.

Therefore, leaving out EGR is probably not a concern from a criteria emissions point of view, but it may be a concern from a greenhouse gas point of view. Omission of the DPF is of more interest from a criteria emissions point of view. In this case, there are two questions. The first question is one of how well the engine can maintain low PM throughout its life. The second question is how much additional PM and PN emissions result from compliance without a DPF. There is only one engine in the under 56 kW power category does not use a DOC, and this engine is discussed below.

For the power range from 56 to 560 kW, the "expected" features include EGR, a DOC, a DPF, SCR-U, and an ammonia slip catalyst. As with the lower power category engines, EGR is used to reduce engine-out NOx, which makes the job of the SCR system easier. Deletion of EGR should be acceptable, provided that the SCR system retains its performance over the life of the engine. A non-EGR engine will typically place a higher conversion efficiency demand on the SCR system, and have higher urea consumption, compared to an EGR engine. The DOC helps reduce hydrocarbon emissions and makes a modest contribution towards reducing PM. The DOC can also be used to provide heat for regeneration of the DPF. The ammonia slip catalyst provides assurance that in the event of excessive urea dosing, ammonia slip will be limited. If the ammonia slip catalyst is omitted, ammonia emissions are likely to be higher, and control of ammonia level is very dependent on good control of urea dosing to achieve a balance between the NOx reduction requirement and avoiding ammonia slip. Finally, omission of the DPF is perhaps the most interesting from criteria emissions point of view. As with the lower power category engines, there are two questions: how well the engine can maintain low PM throughout its life, and how much PM/PN impact the DPF's deletion has on overall emissions. Note that no manufacturer of engines in the power category of 56 to 560 kW has tried to meet the NOx requirement without using an SCR system.

Table 1 below provides some statistics on the use of emissions control features. In this table, 2019 and 2020 Model Year engines have been combined to create a single data set. There are almost an equal number of engine families certified above and below 56 kW.

TABLE 2. NUMBER OF ENGINE FAMILIES CERTIFIED, AND PERCENTAGE OF EXECUTIVE ORDERS WITHOUT A TYPICALLY USED EMISSION CONTROL DEVICE

Power Category	# of Engine Families	% Without EGR	% Without DPF	% Without Ammonia Slip Cat	% Without DOC
< 56 kW	133	5%	50%	N/A	1%
56 – 560 kW	138	14%	60%	20%	4%

Half of all Executive Orders for engines below 56 kW do not use a DPF, and the percentage increases to 60% for engines above 56 kW. Percentage of Executive Orders is not a reliable indicator of market sales volume, but it is clear that a substantial number of Tier 4 Final engines are being sold without a DPF.

Only one engine family is certified below 56 kW without using a DOC, the JCB 4.4-liter engine at 55 kW. When this engine was launched on the market, JCB published information describing the extensive development process that allowed them to comply with Tier 4 Final using no aftertreatment of any kind. Above 56 kW, only the 5 engines from AB Volvo Penta are listed as not using a DOC. Since a DOC typically goes in front of an SCR system and can form an integral part of the SCR system, we checked the EPA certification documentation for these engines. All 5 of these Volvo Penta engines are listed as having an ammonia slip catalyst in the EPA documentation, but not in the CARB Executive Orders. It is possible that a DOC is integrated into the SCR catalyst as well, but this information is not publicly available. These Penta engines are the only ones to avoid three normally used emissions devices, according to their CARB Executive Orders: the DOC, the DPF, and an ammonia slip catalyst. The information on the ammonia slip catalyst does not match the EPA certificate documentation.

2.1.1 Certified Emissions Levels

Most engine families below 56 kW are certified to NMHC + NOx levels well below the required 4.7 g/kW-hr. NMHC + NOx certification levels of 3.0 to 4.6 g/kW-hr are common, and a few engines have certification levels below 3 grams. It is not clear why manufacturers have chosen to certify their <56 kW engines at NOx levels significantly below the requirement, since this often involves a fuel consumption penalty. We checked the emissions certificates for all engines in the <56 kW category that were certified below 3.5 grams NOx + HC and found none with a declared FEL lower than the 4.7-gram target.

For engines above 56 kW, certified NOx levels ranged from 0.04 g/kW-hr, which represents only 10% of the required level, up to 0.45 g/kW-hr, which would require the use of credits. There is only one engine certified above the 0.4 g/kW-hr NOx limit for Tier 4 Final engines above 56 kW. This is one of four certified versions of the Cummins 3.8-liter engine. Most engines in the spreadsheet are certified at NOx levels between 0.15 and 0.35 g/kW-hr. There are two engines above 56 kW that were certified at PM levels above the requirement of 0.02 g/kW-hr. One is a 10.8-liter AB Volvo Penta, and the other is an 11.1-liter FPT engine. Both of these engines are certified at 0.03 g/kW-hr PM.

Most engine families certified to Tier 4 Final without the use of a DPF are certified right at the maximum amount of PM allowed. A few engines without a DPF are certified at PM levels as low as 50% of the limit (0.01 g/kW-hr of PM, compared to the limit of 0.02 grams for engines >56 kW), and two engines use credits to comply. Engines using a DPF are often certified at PM levels far below what the regulation requires. A few engines using a DPF are certified at the limit, but most engines are certified at levels between 0.001 and 0.01 g/kW-hr, or one half to one twentieth of the required PM level. A few engines with DPFs are certified to as low as 0.0001 g/kW-hr, which is only 0.5% of the allowed level. On average, the certified PM levels of engines using a DPF are about 10 times lower than the levels of engines without a DPF.

2.1.2 "Missing" Emissions Control Features

Table 3 lists engines that had more than one "missing" emissions control feature. In the case of AB Volvo Penta and FPT Industrial, the pattern of "missing" features was consistent across their entire engine portfolio. As noted above, the Volvo Penta engines are listed in EPA documentation has having a slip catalyst, and it is possible that a DOC is also integrated into the SCR system. For Doosan, the avoidance of an ammonia slip catalyst was common to all their SCR engines, which are engines above 56 kW. Doosan also avoids DPFs across their entire product line from 19 kW on up. For the other manufacturers, engines with two "missing" features were individual exceptions within a broader portfolio of engines. However, at the BAUMA construction equipment show in Munich, which was held in April 2019, it was clear that some manufacturers are planning to remove EGR from their future Tier 4 Final offerings. Cummins and MAN both showed engines demonstrating that approach. There is also a trend towards deleting the DPF, as manufacturers learn how to comply with the PM limit using only in-cylinder control and the DOC. Note that in Europe, the current Stage 5 off-highway standards effectively require a DPF, because they introduce a PN limit in addition to the PM mass limit.

TABLE 3. ENGINE WITH MORE THAN ONE "MISSING" EMISSION CONTROL FEATURE

Manufacturer	Power Category	Displacement (Liters)	"Missing" Emissions Control Features			
			DOC	DPF	EGR	Slip Cat
AB Volvo Penta	$75 \leq kW < 560$	5.1	X	X		X
AB Volvo Penta	$130 \leq kW < 560$	7.7	X	X		X
AB Volvo Penta	$130 \leq kW < 560$	10.8	X	X		X
AB Volvo Penta	$130 \leq kW < 560$	12.8	X	X		X
AB Volvo Penta	$130 \leq kW < 560$	16.1	X	X		X
Agco	$56 \leq kW < 130$	3.3, 4.4, 4.9, 6.6		X	X	
Agco	$75 \leq kW < 560$	4.9, 6.6, 7.4		X	X	
Cummins	$130 \leq kW < 560$	6.7			X	X
Deutz	$56 \leq kW < 130$	3.6		X		X
Deutz	$130 \leq kW < 560$	15.9		X		X
Doosan	$75 \leq kW < 130$	3.4		X		X
Doosan	$75 \leq kW < 560$	5.9		X		X
Doosan	$130 \leq kW < 560$	7.6		X		X
FPT Industrial	$75 \leq kW < 130$	4.5		X	X	
FPT Industrial	$75 \leq kW < 560$	4.5, 6.7		X	X	
FPT Industrial	$75 \leq kW < 560$	4.5, 6.7		X	X	
FPT Industrial	$130 \leq kW < 560$	6.7		X	X	
FPT Industrial	$130 \leq kW < 560$	8.7		X	X	
FPT Industrial	$130 \leq kW < 560$	8.7		X	X	
FPT Industrial	$130 \leq kW < 560$	8.7		X	X	
FPT Industrial	$130 \leq kW < 560$	11.1		X	X	
FPT Industrial	$130 \leq kW < 560$	12.9		X	X	
FPT Industrial	$130 \leq kW < 560$	12.9		X	X	
FPT Industrial	$130 \leq kW < 560$	15.9		X	X	
JCB	$37 \leq kW < 56$	4.4	X	X		
John Deere	$75 \leq kW < 130$	4.5		X	X	
Komatsu	$75 \leq kW < 130$	4.5		X		X

2.2 Review of Data from Machine Population Worksheet

Data on 41 categories of diesel-powered off-road equipment was collected by Yengst Associates for SwRI. Yengst has been in the off-highway market research business for many years and has recognized expertise in this field. Their report, titled "Mobile Off-Highway Machinery Profile for California", is provided separately as a .PDF file. For a few machine types described in the Yengst report, only a few manufacturers dominate the market for that machine type. In those cases, it would be possible to review which emissions technology is employed by each manufacturer, and back out, for example, the rough percentage of machines of Type X with and without a DPF.

The spreadsheet "Population Worksheet" includes the market survey results from Yengst, along with sample emissions inventory calculations by SwRI. The data provided is for machines in the power range of $19 \leq kW < 56$, and $56 \leq kW < 560$. Machines below 19 kW and above 560 kW are not covered by this report or in the population worksheet.

The spreadsheet includes the following information:

- Column B lists the type of equipment
- Column C lists the 2019 North American machine population
- Column D lists the 2019 California estimated machine population as a percentage of the North American total
- Column E lists the 2019 California estimated machine population (number of units)
- Column F lists the 2029 California estimated machine population (number of units)
- Column G lists the forecast population change for each machine category in percent
- Columns H lists the average annual operating hours for each machine category
- Column I shows the average engine power in hp for each machine category
- Column J lists the average load factor range for each machine category
- Column K lists a single value for the average load factor for each machine category
- Column L lists the percentage of machines in each category which have a power below 56 kW (75 hp)
- Columns M and N provide SwRI's estimate of the hybridization potential for each type of machine. Column M provides the estimated fuel consumption / GHG savings, and Column N lists the feasibility for applying a hybrid system to each type of machine.
- Column O provides an average life in hours or years for each machine category
- Columns P through U provide an emissions inventory for the 2019 population, using an assumption that all machines are Tier 4 Final certified. Two different PM levels are given. One assumes certification at the current Tier 4 Final PM limit, typical of non-DPF engines. The second assumes certification at 10% of the current Tier 4 Final PM limit, typical of engines with a DPF.

- Columns V through AA provide an emissions inventory for the 2029 population, using an assumption that all machines are Tier 4 Final certified. Two different PM levels are given. One assumes certification at the current Tier 4 Final PM limit, typical of non-DPF engines. The second assumes certification at 10% of the current Tier 4 Final PM limit, typical of engines with a DPF.
- Columns AB through AD provide average power assumptions for those machine categories that have engines both above and below 56 kW. The estimates for each power category (Columns AB and AC) are checked in Column AD to make sure they match the average power provided in Column I.
- Columns AE through AJ provide user-selectable assumptions for 2019 population certified emissions levels. SwRI has provided a preliminary assumption based on an eyeball average of 2019/2020 emissions certification values for engines with and without a DPF, but users may plug in any desired assumptions to play "what if" scenarios.
- Columns AK through AP provide user-selectable assumptions for 2029 population certified emissions levels. SwRI has provided a preliminary assumption based on 2019/2020 emissions certification values for engines with and without a DPF, but users may plug in any desired assumptions to play "what if" scenarios.

Yengst and Associates provided the data in Columns B through J, as well as Columns L and O. Columns K, AB, and AC were the result of a joint effort between SwRI and Yengst and Associates. SwRI is responsible for the information in Columns M and N and P through AA and column AD. SwRI has provided preliminary assumptions for Columns AE through AP. CARB is invited to explore the impact of changes to any of the assumptions made in Columns AE through AP. A subset of the population data provided by Yengst is show in Table 4.

The emissions inventory calculations in the final spreadsheet are based on several assumptions. For the example values provided by SwRI, the first assumption is that all machines in the population are certified to Tier 4 Final emissions. This assumption is obviously not correct for the 2019 population, which includes many Tier 1, 2, and 3 machines, and perhaps even a few that predate emissions requirements completely. Since data is not available to break the population down by emissions certification, the assumption of Tier 4 Final was used. This assumption is going to be much closer to validity for the 2029 emissions inventory. By 2029, most (but not all) pre-Tier 4 Final machines should be retired or operating at very limited hours per year. The assumption of Tier 4 Final emissions for the entire inventory allows the impact of population changes projected for 2029 to be evaluated directly.

The second assumption regards certification values for NO_X. For engines < 56 kW, we assumed that HC emissions are approximately 0.1 g/kW-hr, so NO_X values are reduced from the quoted NO_X + HC levels on the certificate by that amount. The third assumption in our values is that we selected NO_X levels that approximately represent the eyeball average for 2019/2020 emissions certifications, rather than the required certification level. If desired, the required certification levels (or any other value) can be entered in Columns AE through AP.

The fourth assumption made in Columns AE through AP is that we should represent the results for PM levels matching the standard (which would represent the performance of engines certified without a DPF), and at 10% of the standard (representing typical values for DPF engines). This allow the effect of the DPF / no DPF decision to be made. From the certification data spreadsheet, about half of all certificates have a DPF, but that does not necessarily mean that half of all engines sold in the market have a DPF. To determine the market share of DPF engines, the sales volume of individual engines would have to be made available.

TABLE 4. SUBSET OF NONROAD AND OFF-ROAD POPULATION DATA

Type of Equipment	North America 2019 Populaton (Units)	Est. California % of Total	Est. 2019 California Population	Est. 2029 California Population	Forecast Change In Population %	Average Hours per Year	Average Engine Power (hp)	Average Load Factor %	Average Load Factor Single Value%	% Of Machines < 56 kW	Life of Machine
Earthmoving Machinery											
Articulated Dump Trucks	44,000	6	2,650	3,600	36%	900	375	50-60%	55%	0%	12000 - 15,000 hrs
Rigid Haulers	12,585	3	350	450	29%	1,000	575	50-60%	55%	0%	15,000 - 20,000 hrs
Backhoe Loaders	410,000	6	24,600	26,000	6%	800	65	25-30%	28%	80%	6,000-10,500 hr
Crawler Dozers	227,500	6	13,650	16,600	22%	900	125	30%	30%	20%	15-20 yrs
Crawler Loaders	21,500	5	1,100	1,150	5%	600	190	25-30%	28%	0%	15 - 25 yrs
Crawler Excavators	338,000	7	23,660	33,300	41%	1,000	200	30%	30%	0%	15-20 yrs
Wheeled Excavators	12,450	6	750	850	13%	900	200	25-30%	28%	0%	15-20 yrs
Mini Excavators	370,000	6	22,200	32,800	48%	1,000	40	30%	30%	100%	10 - 15 yrs
Motor Graders	81,000	7	5,670	6,800	20%	1,000	200	30%	30%	0%	20 - 25 yrs
Scrapers	6,700	4	250	250	0%	700	450	50%	50%	0%	20 years or more
Skid Steer Loaders	740,000	6	44,400	51,000	15%	800	60	25-30%	28%	90%	5,000-9,000 hr life
Compact Track Loaders	415,000	6	24,900	36,800	48%	800	75	25-30%	28%	50%	5,000-9,000 hr life
Wheel Loaders (All Sizes)	447,000	6	26,800	36,000	34%	900	125	30%	30%	20%	6000-9000 hr -compacts
Agricultural Machinery											15-20 yrs for larger WLs.
Ag Tractors											
<100 hp	3,125,000	10	313,000	363,000	16%	500	50	40-50%	45%	80%	15-20 yrs
>100hp	1,000,000	6	60,000	66,000	10%	500	200	60-70%	65%	0%	25-30 yrs
Harvesting Combines	250,000	3	7,500	8,000	7%	300	375	75%	75%	0%	25-30 yrs
Materials Handling Machines											
Scissor Lifts (IC only)	136,600*	7	9,500	11,000	16%	800	40	10-20%	15%	80%	15-20 years
Boom Lifts (IC only)	197,000*	7	13,800	18,000	30%	800	75	10-20%	15%	50%	15-20 years
Lattice Boom Cranes	12,200	7	850	950	12%	500	550	30%	30%	0%	20-30 yrs
Rough-Terrain Cranes	43,800	6	2,600	3,000	15%	600	275	30%	30%	0%	15-20 years
All-Terain Cranes	4,620	7	300	375	25%	600	425	30%	30%	0%	15-20 years
Telescopic Crawler Cranes	1,000	6	60	100	67%	600	275	25-30%	28%	0%	15-20 years
Industrial Cranes	12,700	8	1,000	1,200	20%	800	125	30%	30%	25%	15-20 years
RTLTs - Masted	40,750	6	2,450	2,800	14%	800	100	25-30%	28%	30%	15-20 yrs
RTLTs - Telescopic	265,000	6	15,900	19,400	22%	800	100	25-30%	28%	10%	15-20 yrs
Industrial Lift Trucks Cl 4 IC	419,000	10	2,900	3,300	14%	1,200	40	25-30%	28%	95%	10-15 yrs
Industrial Lift Trucks Cl 5 IC	566,800	10	8,500	9,600	13%	1,200	125	25-30%	28%	30%	10-15 yrs.
Forestry Machinery											
Wheeled Feller Bunchers	10,500	4	425	475	12%	600	225	30-40%	35%	0%	10-15 yrs
Log Skidders	27,000	5	1,400	1,500	7%	600	260	30-40%	35%	0%	10-15 yrs
Wh Tree Harvesters	1,000	4	50	60	20%	600	175	30-40%	35%	0%	10-15 yrs
Wh Forwarders	2,500	3	75	90	20%	600	175	30-40%	35%	0%	10-15 yrs
Forestry Excavators	3,600	3	110	125	14%	600	175	30-40%	35%	0%	10-15 yrs
Miscellaneous Equipment											
Asphalt Pavers - Highway	7,850	7	550	625	14%	1,000	200	60-70%	65%	0%	10-15 yrs
Asphalt Pavers - Commercial	12,140	7	850	1,000	18%	1,000	75	60-70%	65%	60%	10-15 yrs
SD Vibratory Compactors	80,000	7	5,600	6,400	14%	1,000	125	25-30%	28%	25%	15-20 yrs
DD Vibratory Compactors	64,000	7	4,500	5,150	14%	1,000	200	25-30%	28%	0%	15-20 yrs
Pneumatic Compactors	6,400	6	400	450	13%	800	150	25-30%	28%	0%	15-20 yrs
Static Compactors	8,000	6	500	550	10%	700	90	25-30%	28%	30%	15-20 yrs
Combination Compactors	1,600	6	100	115	15%	700	125	25-30%	28%	20%	15-20 yrs
Milling Machines/Cold Planers	5,000	6	300	350	17%	1,000	325	60-70%	65%	0%	15 yrs
Portable Air Compressors	270,000	6	16,200	15,000	-7%	1,000	75	30-40%	35%	60%	10-15 yrs

These data are illustrated in a qualitative sense in Figure 1 for the 2019 data, and in Figure 2 for the 2029 projections. It can be observed from these figures that the Ag Tractor category below 300hp represents nearly half the population of non-road machines by number in California. The next three largest categories by population are Ag Tractors above 300hp, Skid Steer loaders, Backhoe loaders, and Compact Track loaders. These five categories combined account for 76%

of all off-road machines in California. However, there are several other categories of construction equipment which 3% range as well. There is some movement among the construction equipment populations projected by 2029, but overall the important categories remain in similar proportions.

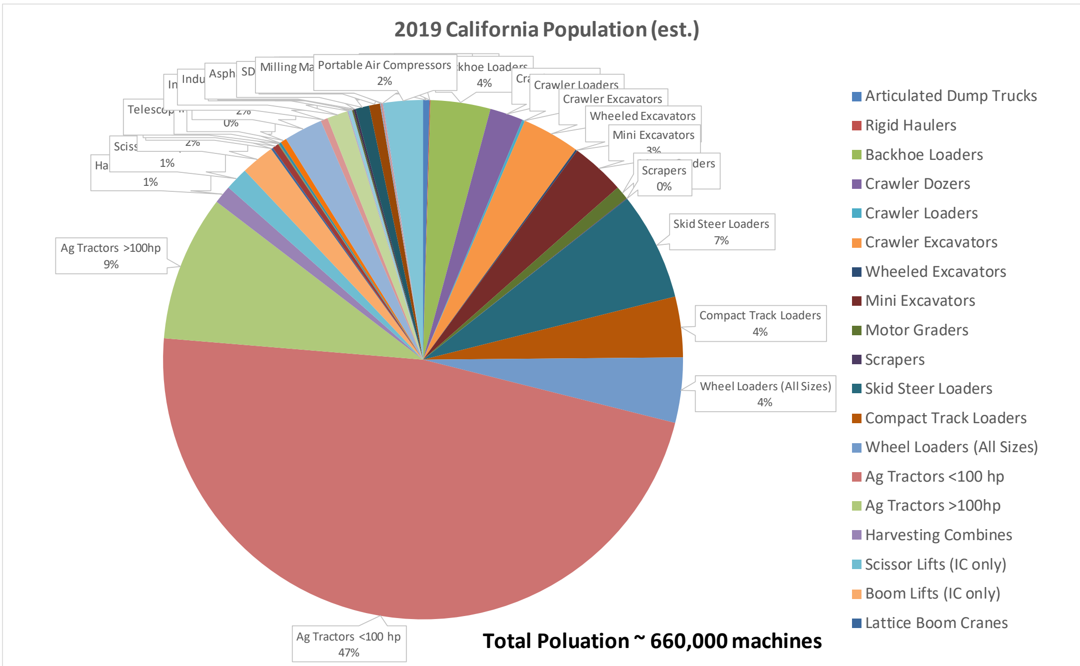


FIGURE 1. 2019 CALIFORNIA OFF-ROAD MACHINE POPULATION BY APPLICATION CATEGORY

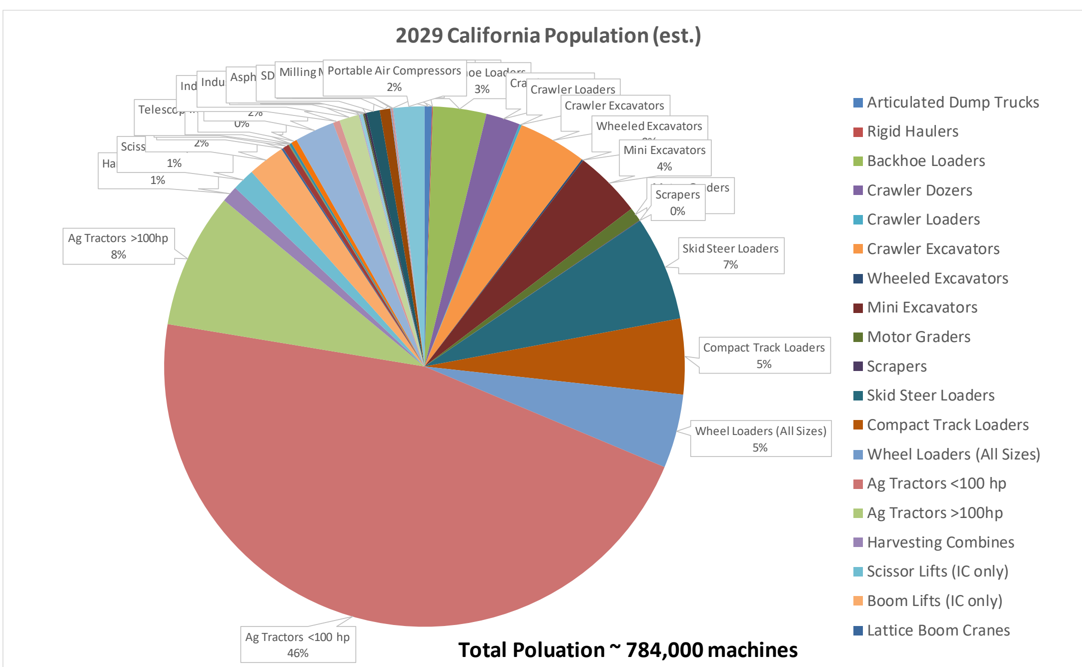


FIGURE 2. PROJECTED 2029 CALIFORNIA OFF-ROAD MACHINE POPULATION BY APPLICATION CATEGORY

A few conclusions can be made from the data in the population spreadsheet, using the preliminary assumptions provided by SwRI. It should be noted that these are comparative estimates rather than being a detailed emission inventory. For example, the calculations do not account for the inventory of pre-Tier 4 engines within the population, therefore these conclusions should be taken only as qualitative comparisons.

1. Engines under 56 kW represent 81% of total NO_X emissions from off-road machines, but only 35% of PM emissions.
2. The projected growth to 2029 has almost no effect on the distribution of emissions between low power (<56 kW) and higher power (≥ 56 kW) engines.
3. The machine categories with the largest contribution to off-road machine engine NO_X emissions are:
    a. Ag tractors under 100 HP: 6,721 tons (44% of the total)
    b. Skid steer loaders: 1,483 tons (10% of the total)
    c. Ag tractors over 100 HP: 960 tons (6% of the total)
    d. These three machine categories account for 60% of all off-road machine engine NO_X emissions
4. The machine categories with the largest contribution to PM emissions are:
    a. Ag tractors under 100 HP: 69.6 tons at the Tier 4 PM limit (26% of the total)
    b. Ag tractors over 100 HP: 58.2 tons at the Tier 4 PM limit (22% of the total)
    c. Crawler excavators: 21.2 tons at the Tier 4 PM limit (8% of the total)
    d. These three machine categories account for 56% of all off-road machine engine PM emissions
5. Note that although emissions are predicted to increase from 2019 to 2029, this prediction does not include the effect of retirement of older machines that do not comply with Tier 4 Final emissions regulations. Retirements of pre-Tier 4 Final machines should contribute to a decline in overall NO_X and PM emissions during the 2019 – 2029 time-frame.

3.0 TASK 2 - ENGINE AND TEST CYCLE SELECTION

The engines and test cycles used for the baseline emission characterization tasks were chosen in partnership with CARB, and with the assistance and recommendations of the program OEM partner, John Deere. The overall objective of the selections was to characterize a pair of representative off-road engines which met the current Tier 4 Off-road diesel standards in the range from 56kw to 560kw over representative test cycles, including both regulatory cycles and a cycle characteristic of lower load field operations.

3.1 Engine Selection

A key objective for the selection of the two test engines was that one of them was requested to be equipped with the DPF for PM control, while the second engine was intended to be a non-DPF equipped engine. This would enable comparison of detailed exhaust chemistry in both configurations. It was desired that the two engines be similar in terms of architecture and engine technology, to enable a meaningful comparison between the two engines. Furthermore, CARB had indicated that it was desirable for the engines to fall in the range from 100 to 200 kw if possible. Furthermore, it was hoped that the selected engines would be normally installed in a wide variety of applications.

Given these desired characteristics, SwRI worked with John Deere to select engines that would achieve the program objectives. These selections were vetted in discussions with CARB and ultimately approved for use on the program. The engines and aftertreatment systems were supplied by John Deere at no cost to the program, and both engines were de-greened prior to shipment to SwRI. However, it should be noted that the aftertreatment system were supplied to SwRI in a new state, and they were degreened at SwRI by running over 50 hours on the engines, as discussed later.

The two selected engines were a John Deere 6068HFC09, which was the DPF engine, and a John Deere 4045HFC04 engine, which was the non-DPF engine. A comparison of basic engine characteristics is given in Table 5. The two engines have the same basic architecture and combustion system, and feature the same bore and stroke, with the 6068 have 6 cylinders and the 4045 having four cylinders. Both engines utilize cooled EGR for engine-out NO_X control. The most broadly used 6068 engine utilized a series two-stage turbocharger, while the most widely used version of the 4045 engine features a single wastegated turbocharger. Both engines use the same urea-SCR technology, but the 6068 aftertreatment system has a DOC+DPF+SCR architecture, while the 4045 has a DOC+SCR architecture.

TABLE 5. COMPARISON OF SELECTED ENGINES

	John Deere 4045HFC04 4.5L Industrial Diesel Engine		John Deere 6068HFC09 6.8L Industrial Diesel Engine
EMISSIONS CERTIFICATIONS	CARB, EPA Tier 4	**EMISSIONS CERTIFICATIONS**	CARB, EPA Tier 4, EU Stage IV
GENERAL ENGINE DATA		**GENERAL ENGINE DATA**	
Model	4045HFC04	**Model**	6068HFC09
PowerTech Type	PWL	**PowerTech Type**	PSS
Number of Cylinders	4	**Number of Cylinders**	6
Cylinder Head Valves	4	**Cylinder Head Valves**	4
Displacement-- L (cu in)	4.5 (275)	**Displacement-- L (cu in)**	6.8 (415)
Bore and Stroke-- mm (in)	106 x 127 (4.17 x 5.00)	**Bore and Stroke-- mm (in)**	106 x 127 (4.17 x 5.00)
Compression Ratio	17.0 : 1	**Compression Ratio**	16.7 : 1
Engine Type	In-line, 4-cycle	**Engine Type**	In-line, 4-cycle
Aspiration	Turbocharged and air-to-air aftercooled	**Aspiration**	Turbocharged and air-to-air aftercooled
Turbocharging	Wastegate	**Turbocharging**	Series
Power Ratings	63-104 kW	**Power Ratings**	168-224 kW
Aftertreatment Configuration	DOC/SCR	**Aftertreatment Configuration**	DOC/DPF/SCR
EGR	Cooled exhaust gas recirculation	**EGR**	Cooled exhaust gas recirculation

The 6068 DPF-equipped engine is shown installed in the transient cell at SwRI in Figure 3, and the characteristics of the particular engine and rating selected are given in Table 6. Prior to emission testing, the aftertreatment system was degreened according to instructions provided by John Deere. A total of 50 hours of high-power operation were run, with 3 active DPF regenerations performed over the course of that 50-hour run.

FIGURE 3. DEERE 6068HFC09 ENGINE

TABLE 6. DPF ENGINE (6068) CHARACTERISTICS

Engine Description	6068HFC09, 6.8L I-6 (dual series turbo)
Nominal Maximum Power	187 kw @ 2200 rpm
Nominal Peak Torque	1026 Nm @ 1600 rpm
Maximum Test Speed	2200 rpm
Idle Speed	800 rpm
Aftertreatment	DOC+DPF+SCR

The 4045 non-DPF engine is shown installed in the transient cell at SwRI in Figure 4, and the characteristics of the particular engine and rating selected are given in Table 7. Prior to emission testing, the aftertreatment system was degreened according to instructions provided by John Deere. A total of 50 hours of high-power operation were run, with 3 higher temperature desulfation (deSO$_X$) events performed over the course of that 50-hour run.

FIGURE 4. DEERE 4045HFC04 ENGINE

TABLE 7. NON-DPF ENGINE (4045) CHARACTERISTICS

Engine Description	4045HFC04, 4.5L I-4 (waste-gated turbo)
Nominal Maximum Power	104 kw @ 2200 rpm
Nominal Peak Torque	540 Nm @ 1600 rpm
Maximum Test Speed	2200 rpm
Idle Speed	800 rpm
Aftertreatment	DOC+SCR

3.2 Test Cycle Selection

3.2.1 Regulatory Cycles

The regulatory test cycles used for baseline testing were the standard cycles used for Tier 4 emission certification, as detailed in 40 CFR Part 1039. These included the Off-road Transient Cycle (NRTC) and both of the steady-state ramped modal cycles normally used for these engines depending on application. Both the RMC C1 8-mode cycle for variable speed applications and the RMC D2 5-mode cycle for constant speed engines were run. All cycles were run in triplicate, and the test matrix is detailed later under Section 4 of this report.

3.2.2 Low Load Application Cycle (LLAC)

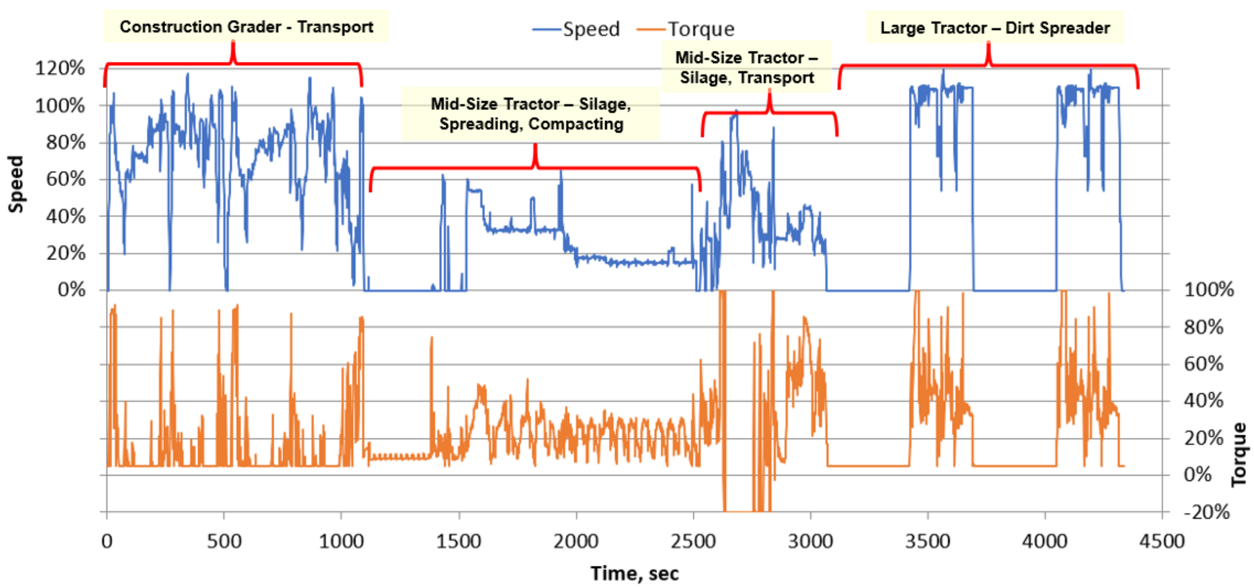
In addition to the regulatory cycles described above, CARB also requested the evaluation of baseline emissions over a vocational cycle that represented "typical low average load operations that the selected engines might experience during job performance." No such cycle was available at the start of the program therefore it was necessary to develop a low load vocational cycle for use in this program.

Given the limited scope and time available in the program, it was not possible to engage in an exhaustive cycle development effort. As a result, SwRI worked with John Deere to leverage activity cycle information that they already had available to develop a representative lower load cycle. This cycle was designated as the "Low Load Application Cycle" (LLAC). The LLAC was developed from a series of application specific duty cycles that were provided by John Deere to SwRI for this specific use.

John Deere provided SwRI with a total of 24 different application duty cycles that they had developed to represent a wide variety of both agricultural and construction applications. These cycles were developed based on actual field recorded data. It should be noted that these were proprietary duty cycles developed by John Deere for internal use, and therefore the specific details of each of the source application cycles cannot be given here. However, it is understood that these cycles were developed to provide a series of field representative challenges to the engine and aftertreatment system to aid in product development. As such, they can be considered representative of field operations.

SwRI evaluated all of the cycles provided by John Deere, and ultimately chose a subset of them that featured significant lower load operation segments that could be useful in the development of a final low load application cycle. These low load operating segments were extracted from their individual application cycles, and later combined into several candidate cycles which were vetted by both John Deere and CARB. From these candidates, a final cycle was chosen to be used as the LLAC, and that cycle is shown in Figure 5. The figure shows the final normalized cycle which is denormalized using the same approach use for the NRTC that is outlined in 40 CFR Part 1065. The cycle is also annotated to show the applications that each segment of the cycle was derived from.

FIGURE 5. OFF-ROAD LOW LOAD APPLICATION CYCLE



The LLAC has an average load of 15% of maximum power. This is considerably lower than the NRTC which has an average load of 35% of maximum power, or the two RMC cycles which have an average load of 54% and 45% for the C1 and D2 cycles, respectively. The LLAC also falls almost entirely below the NTE control zone that is currently specified for in-use compliance. Figure 6 illustrates an example of NTE analysis of the LLAC using data from one of the runs on the 6.8L engine. As can be seen in the chart, the engine is only above the NTE control zone limits for short periods of time (indicated by a 1 on the left side of the chart), and in only three short cases is it above that limit for more than 30 seconds. All three of these short potential NTE events would be eliminated by the current aftertreatment temperature threshold for the example engine in question. These analyses indicate that the LLAC is well below the load range covered by current regulatory cycles and NTE requirements, indicating that it should be well within the low load space. At the same time, these duty cycles are all based on actual field data, so they should be representative of real-world light load operations.

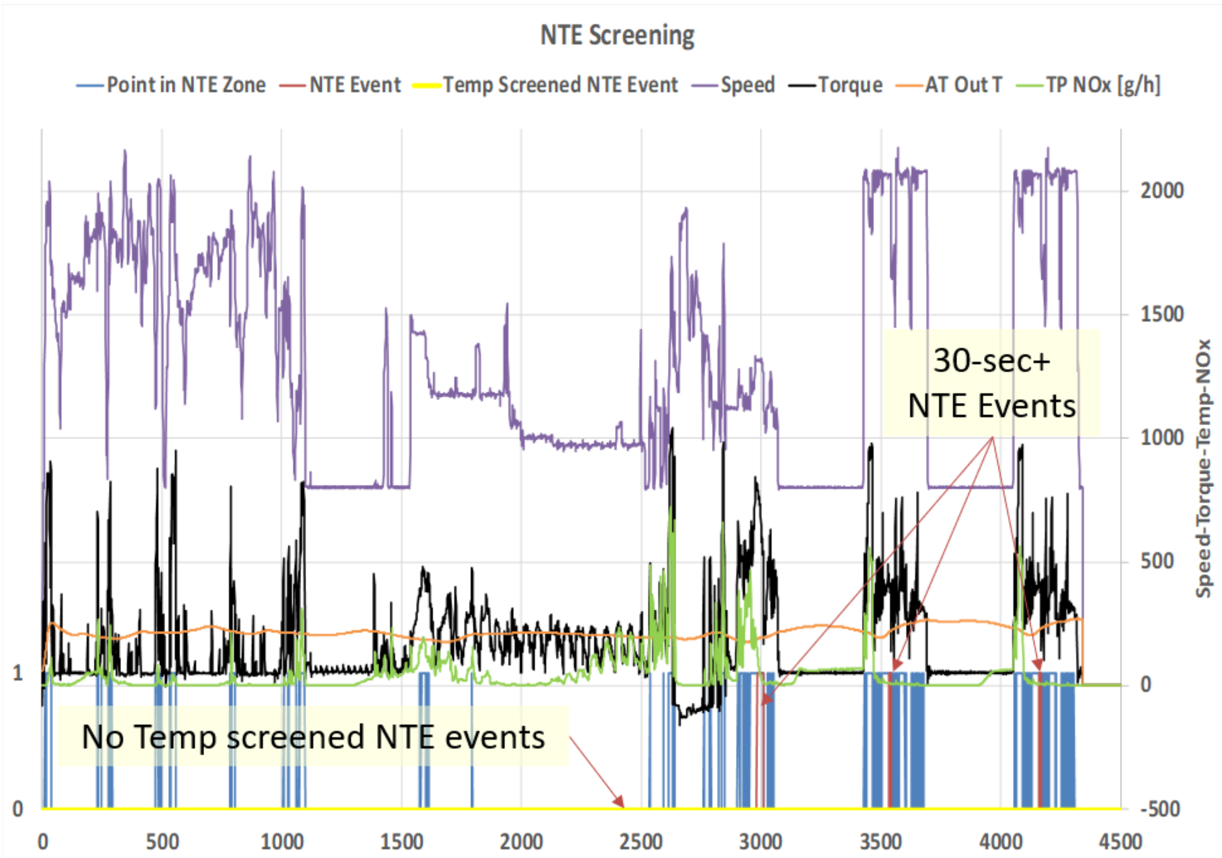


FIGURE 6. EXAMPLE OF LLAC NTE ANALYSIS ON DEERE 6.8L ENGINE

4.0 TASK 3 - LABORATORY SETUP, QA/QC PROCESSES, AND PRECONDITIONING

All baseline test was conducted using procedures and facilities that were compliant with 40 CFR Parts 1039 and 1065.

4.1 Emissions Sampling Instrumentation

The engines and associated hardware were installed in a 40 CFR Part 1065 compliant test cell. The test cell was equipped with a full-flow CVS tunnel system utilized to collect dilute emissions from the tailpipe sampling location. A schematic of the over emission sampling arrangement is given in Figure 7 below. The instrumentation in the tunnel included dilute gaseous emissions measurements, PM filter sample collection, and particle number (PN) emissions measurements. The PM measurements were sampled via double-dilution sampling as given in 40 CFR Part 1065 and PN measurements were sampled based on the Particle Measurement Program method. In addition to the mentioned instrumentation, the CVS tunnel also provided the dilute sample required for the detailed emissions characterization (i.e. HC speciation, trace elements, inorganic ions, and water-soluble organic carbon). The tailpipe emissions measurements also included the use of an FTIR, which sampled raw tailpipe gaseous emissions. Because of the extensive instrumentation at the tailpipe location the emissions characterization included THC, CO, CO_2, NO_X, CH_4, NO, NO_2, NH_3, N_2O, PM and PN.

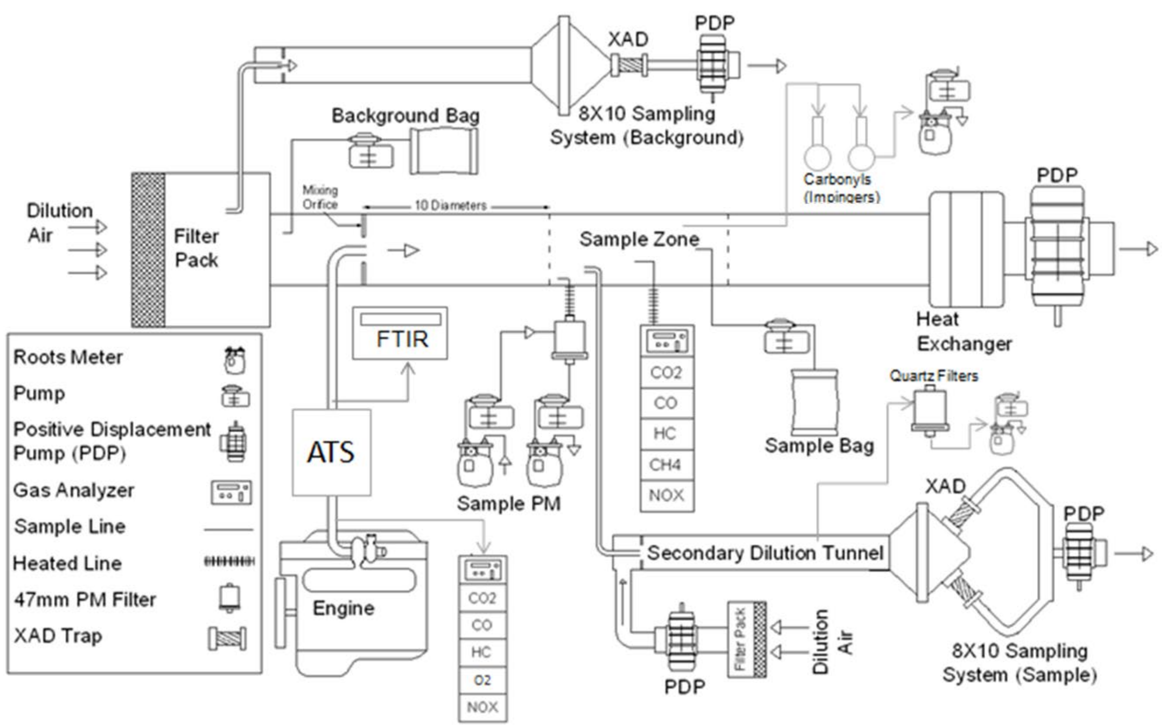


FIGURE 7. OVERALL EMISSION SAMPLING SYSTEM SCHEMATIC

SwRI's Solid Particle Number System (SPNS, shown in Figure 8) was utilized to sample solid particles in accordance with the EU Particulate Measurement Program (PMP) protocol. The system utilizes a TSI model 3790 condensation particle counter (CPC) with a 50% detection efficiency of 23 nm particles. The SPNS is equipped with a catalytic stripper to remove volatile particles. The system is designed to remove volatiles with a very high efficiency while still maintaining a high penetration of solid particles. The catalytic stripper used in the SPNS prevents re-nucleation / condensation by oxidizing the volatile material.

FIGURE 8. SWRI'S SOLID PARTICLE NUMBER SYSTEM (SPNS)

The Sierra BG-3 (shown in Figure 9) is a partial flow sampling system that can be used to perform proportional exhaust sampling during transient test cycles. The system includes a radial inflow porous, stainless steel dilution tunnel that helps dilute exhaust sample with minimal losses. Dry dilution air from the BG-3 controller was passed through a high efficiency particulate air (HEPA) filter before being delivered to the dilution tunnel. This removes background contaminants that could otherwise contribute to filter PM. Tailpipe exhaust flowrate signal was provided to the BG-3 to enable proportional exhaust sampling. In this program, the BG-3 was used to conduct engine-out measurements upstream of the aftertreatment system. The BG-3 was typically operated at a total flowrate of 30 slpm and proportional flow sampling was conducted such that minimum dilution ratio was ~ 6 to 1.

FIGURE 9. SIERRA BG-3 PARTIAL FLOW SAMPLING SYSTEM

Engine out emissions were also characterized through the use of a raw emissions sampling analyzer and PM filter sample collection through a partial flow dilution system. Emissions characterized for the engine out location included THC, CO, CO_2, NO_X, O_2, and PM.

On each engine, following initial installation and debug, a transient torque map was executed, followed by preparatory tests to verify cycle statistics, set up sampling, and validate QA parameters as needed. The chemistry sampling and hardware required to support the emissions characterization was also validated and checked during preparatory tests. Under Task 4A, the engines were installed and characterized for emissions performance at the engine out and tailpipe location. Engines installations were completed in sequence with the 6.8L engine being the first to be evaluated. Prior certification cycle testing, the engine was debugged, the DPF was regenerated to start with a clean filter, a transient torque map was generated, cycle statistics were verified, sampling instruments were configured, and QA parameters were validated.

The full test sequence for emission testing is as follows:

- Two preconditioning NRTC cycles (separated by 20-minute soak)
- Overnight cold soak.
- One cold-start NRTC test, followed by a 20-minute soak.
- Three successive hot-start NRTC tests, with a 20-minute soak between tests.
- 20-minute soak followed by one LLAC (see Task 2)
- One 8-mode C1 test, run as a ramped-modal cycle (RMC)
- One 5-mode D2 test, run as a ramped-modal cycle (RMC)

During each of the cycles evaluated, tailpipe emissions of THC, NMHC, CO, CO_2, NO_X, NO, NO_2, PM, and CH_4 were measured in accordance with procedures outlined in 40 CFR Part 1065. Tailpipe measurements were made utilizing dilute sampling techniques via a full flow CVS dilution system. PM measurements were made via double-dilution sampling as given in 40 CFR Part 1065. In addition, engine out emissions of THC, CO, CO_2, NO_X, and O_2 were characterized via raw sampling. Raw exhaust flow rates were measured utilizing a dire3ct intake flow measurement (via a laminar flow element) and the chemical balance equations in 40 CFR Part 1065.655.

4.2 Preconditioning Details

For all regulatory cycles, preconditioning adhered to the guidance given in 40 CFR Part 1065. For the NRTC testing, two preconditioning hot-start NRTC cycles were run prior to the start of the overnight cold soak. In the case of the RMC testing, each RMC test for record was preceded directly by a preconditioning run of the same RMC cycle. The preconditioning RMC and test RMC were run head-to-tail with no dwell between cycles. Sampling systems were not started in these cases until the start of the test for record, and integration of results was only carried out during the test interval of the test for record.

In the case of the LLAC, it was determined that the hot NRTC would be used as the preconditioning for the LLAC, in a fashion similar to how the hot FTP is used as preconditioning for the on-highway Low Load Cycle (LLC). In practice, the LLAC was always run after the final hot-start NRTC of a given test day, following a 20-minute engine-off soak.

4.3 Experimental Test Matrix

The final sampling matrix used for each engine is illustrated below in Figure 10, where a 1 indicates both sampling and analysis were performed. It should be noted that regulated pollutants both engine-out and tailpipe locations were also sampled on all tests. The matrix below shows the sampling plan to generate all required data and samples for the detailed chemical characterization of emissions described in detail in Section 6 of this report.

Test	PN	FTIR	C1 to C12 speciation		aldehydes/ketones		PAH/NPAH		GCxGC		Trace ICP	EC-OC	Inorganic Ions	WSOC
	continuous	continuous	bags		impingers		XAD-2 + zefluor		XAD-2 + zefluor		teflon filter	quartz filter	teflon filter	quartz filter
	sample	sample	sample	BG	sample	BG	sample	BG	sample	BG	sample	sample	sample	sample
Day 1														
Cold	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Hot	1	1	1	1	1		1				1	1	1	1
Hot	1	1	(sample only)	(sample only)	(sample only)	sample only								
Hot	1	1	(sample only)	(sample only)	(sample only)									
RMC C1 8Mode	1	1	1	1	1	1	1		1		1	1	1	1
RMC D2 5Mode	1	1	1	1	1	1	1		1		1	1	1	1
Low Load Cycle	1	1	1	1	1	1	1		1		1	1	1	1
Day 2														
Cold	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Hot	1	1	1	1	1		1				1	1	1	1
Hot	1	1	(sample only)	(sample only)	(sample only)	sample only								
Hot	1	1	(sample only)	(sample only)	(sample only)									
RMC C1 8Mode	1	1	1	1	1	1	1		1		1	1	1	1
RMC D2 5Mode	1	1	1	1	1	1	1				1	1	1	1
Low Load Cycle	1	1	1	1	1	1	1		1		1	1	1	1
Day 3														
Cold	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Hot	1	1	1	1	1		1		1		1	1	1	1
Hot	1	1	(sample only)	(sample only)	(sample only)	sample only								
Hot	1	1	(sample only)	(sample only)	(sample only)									
RMC C1 8Mode	1	1	1	1	1	1	1		1		1	1	1	1
RMC D2 5Mode	1	1	1	1	1	1								
Low Load Cycle	1	1	1	1	1	1	1				1	1	1	1

FIGURE 10. SAMPLING TEST MATRIX FOR EMISSION CHARACTERIZATION

5.0 TASK 4A – ENGINE TESTING AND REGULATED EMISSIONS

This section of the report details the baseline emission test results for both engines, focusing primarily on the regulated pollutants. Certain other pollutants that may be regulated in other markets or engine applications, such as N_2O, NH_3, and PN, are also covered in this section of the report. The remainder of results for unregulated pollutants under the detailed chemical characterization of exhaust emissions are covered under Section 6 of the report.

5.1 John Deere 6.8L DPF-Equipped Engine

With a nominal power rating of 187 kW, the 6.8L John Deere 6068 engine complied with Tier 4 Final emission standards for the following power rating specification category: 130 ≤ kW ≤ 560. Emission standard information is shown in Table 8 and includes the additional EPA's recommendation for NH_3 emissions (not regulated).

TABLE 8. TIER 4 FINAL CRITERIA EMISSION STANDARDS: 130 ≤ KW ≤ 560

	Tier 4 Final Emission Standards [g/kW-hr]				
	NO_X	PM	NMHC	CO	NH_3
Standard	0.40	0.02	0.19	3.5	< 10 ppm average

Baseline engine out and tailpipe emission results are shown in Table 9 and Table 10. The values reflect the averages based on three (3) replicates completed for each cycle. NRTC composite results were calculated based on cold start cycle weighting of 5% and a hot start cycle weighting of 95%, as given in 40 CRR 1039.510(b). In addition to CO_2 and the criteria emissions, brake specific PN results were also reported for the tailpipe measurements only.

Figure 11 shows reported brake specific CO_2 results from the tailpipe location. The NRTC cold and hot start cycle composite resulted in an average of 748 g/kW-hr, while the RMC cycles were lower by ~ 6.7%. The LLAC was reported with a relatively high CO_2 value at 835.8 g/kW-hr, which also indicated higher brake specific fuel consumption. Overall, results were consistent between replicates, with the highest COV at 0.5%.

TABLE 9. JOHN DEERE 6.8 L BASELINE ENGINE-OUT EMISSIONS RESULTS

			NRTC						LLAC	RMC-C1	RMC-D2
			Cold	Hot 1	Hot 2	Hot 3	Composite	Hot-Avg	LLAC	RMC-C1	RMC-D2
Average	THC	g/kw-hr	0.11	0.08	0.10	0.10	**0.08**	0.09	0.19	0.07	0.06
	NMHC	g/kw-hr	0.11	0.10	0.07	0.10	**0.10**	0.09	0.19	0.06	0.06
	CO	g/kw-hr	1.2	1.0	1.0	1.0	**1.0**	1.0	1.3	0.4	0.5
	NOx	g/kw-hr	3.1	3.0	3.0	3.0	**3.0**	3.0	5.3	3.1	2.5
	PM	g/kw-hr	0.11	0.11	0.10	0.10	**0.11**	0.10	0.10	0.02	0.03
	CO2	g/kw-hr	760.3	745.5	745.0	744.5	**746.2**	745.0	830.3	698.1	701.8
	Work	kw-hr	23.88	23.79	23.77	23.76	**23.8**	23.77	34.60	51.69	28.7
Stdev	THC	g/kw-hr	0.0021	0.0019	0.0029	0.0019	**0.0017**	0.0022	0.0049	0.0006	0.0039
	NMHC	g/kw-hr	0.0021	0.0024	0.0021	0.0018	**0.0022**	0.0021	0.0048	0.0006	0.0038
	CO	g/kw-hr	0.0078	0.0138	0.0139	0.0095	**0.0134**	0.0119	0.0109	0.0015	0.0021
	NOx	g/kw-hr	0.0096	0.0034	0.0076	0.0058	**0.0035**	0.0036	0.0188	0.0097	0.0097
	PM	g/kw-hr	0.0045	0.0101	0.0101	0.0196	**0.0093**	0.0125	0.0051	0.0287	0.0013
	CO2	g/kw-hr	1.10	0.66	1.18	1.33	**0.68**	1.04	1.56	0.52	0.8086
	Work	kw-hr	0.003	0.008	0.004	0.009	**0.008**	0.007	0.029	0.01	0.04
COV	THC	%	1.9%	2.4%	2.8%	1.8%	2.1%	2.3%	2.6%	0.9%	6.1%
	NMHC	%	1.9%	2.4%	2.8%	1.8%	2.2%	2.3%	2.6%	0.9%	6.1%
	CO	%	0.6%	1.4%	1.4%	1.0%	1.3%	1.2%	0.8%	0.4%	0.4%
	NOx	%	0.3%	0.1%	0.3%	0.2%	0.1%	0.1%	0.4%	0.3%	0.4%
	PM	%	4.1%	9.5%	9.7%	19.5%	8.8%	12.1%	5.3%	141.4%	4.1%
	CO2	%	0.1%	0.1%	0.2%	0.2%	0.1%	0.1%	0.2%	0.1%	0.1%
	Work	%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.1%

TABLE 10. JOHN DEERE 6.8 L BASELINE TAILPIPE EMISSION RESULTS

			NRTC						LLAC	RMC-C1	RMC-D2
			Cold	Hot 1	Hot 2	Hot 3	Composite	Hot-Avg	LLAC	RMC-C1	RMC-D2
Average	THC	g/kw-hr	0.005	0.004	0.005	0.005	0.004	0.004	0.005	0.005	0.003
	NMHC	g/kw-hr	0.005	0.004	0.004	0.005	0.004	0.004	0.005	0.005	0.003
	CO	g/kw-hr	0.245	0.061	0.060	0.062	0.070	0.061	0.000	0.013	0.024
	NOx	g/kw-hr	0.387	0.083	0.076	0.076	0.098	0.078	1.826	0.079	0.018
	PM	g/kw-hr	0.0014	0.0003	0.0005	0.0005	0.0004	0.0005	0.0003	0.0003	0.0004
	CO2	g/kw-hr	760.9	747.4	746.8	746.7	748.0	747.0	835.8	696.8	698.8
	Work	kw-hr	23.88	23.79	23.77	23.76	23.8	23.77	34.60	51.69	28.72
	PN	#/kw-hr	3.7E+12	5.0E+10	4.9E+10	4.8E+10	4.1E+11	4.9E+10	2.9E+10	1.1E+11	6.3E+10
Stdev	THC	g/kw-hr	0.0009	0.0007	0.0007	0.0007	0.0007	0.0007	0.0022	0.0011	0.0020
	NMHC	g/kw-hr	0.0008	0.0007	0.0007	0.0007	0.0006	0.0007	0.0022	0.0011	0.0020
	CO	g/kw-hr	0.0124	0.0078	0.0171	0.0155	0.0069	0.0133	0.0000	0.0039	0.0063
	NOx	g/kw-hr	0.0082	0.0020	0.0022	0.0025	0.0017	0.0014	0.0895	0.0129	0.0008
	PM	g/kw-hr	0.0009	0.0002	0.0003	0.0003	0.0002	0.0003	0.0003	0.0002	0.0001
	CO2	g/kw-hr	2.98	3.26	3.74	3.43	3.25	3.47	2.22	0.56	3.1870
	Work	kw-hr	0.003	0.008	0.004	0.009	0.008	0.007	0.029	0.01	0.04
	PN	#/kw-hr	8.9E+11	1.3E+09	2.1E+09	4.4E+09	9.0E+10	2.4E+09	9.0E+08	4.8E+10	1.2E+09
CVar	THC	%	17%	20%	16%	15%	17%	16%	47%	24%	58%
	NMHC	%	17%	20%	16%	15%	17%	16%	47%	24%	58%
	CO	%	5%	13%	29%	25%	10%	22%	0%	30%	26%
	NOx	%	2.1%	2.4%	2.9%	3.3%	1.8%	1.7%	4.9%	16.2%	4.6%
	PM	%	68.0%	62.4%	69.3%	47.2%	58.1%	55.4%	85.4%	86.6%	20.2%
	CO2	%	0.4%	0.4%	0.5%	0.5%	0.4%	0.5%	0.3%	0.1%	0.5%
	Work	%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.1%
	PN	%	24.0%	2.7%	4.2%	9.1%	21.7%	4.9%	3.1%	45.3%	1.9%

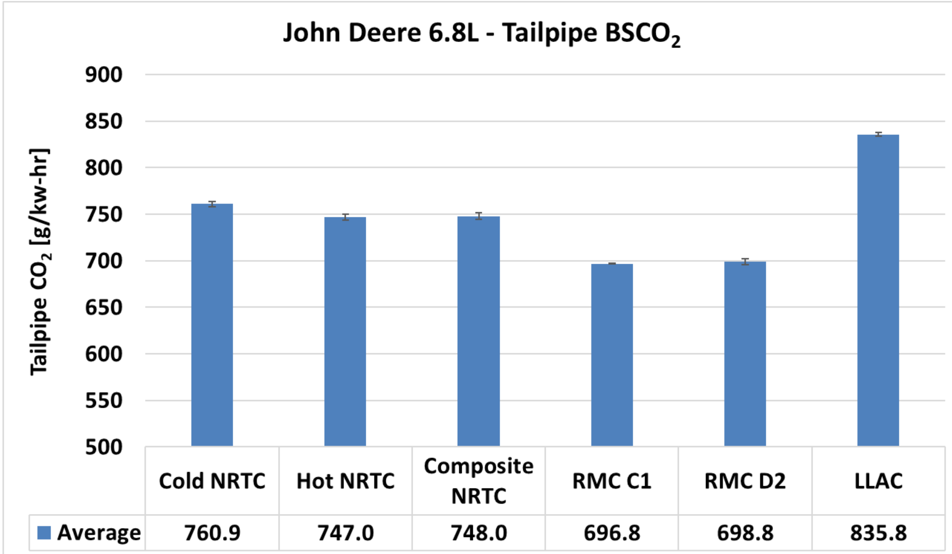
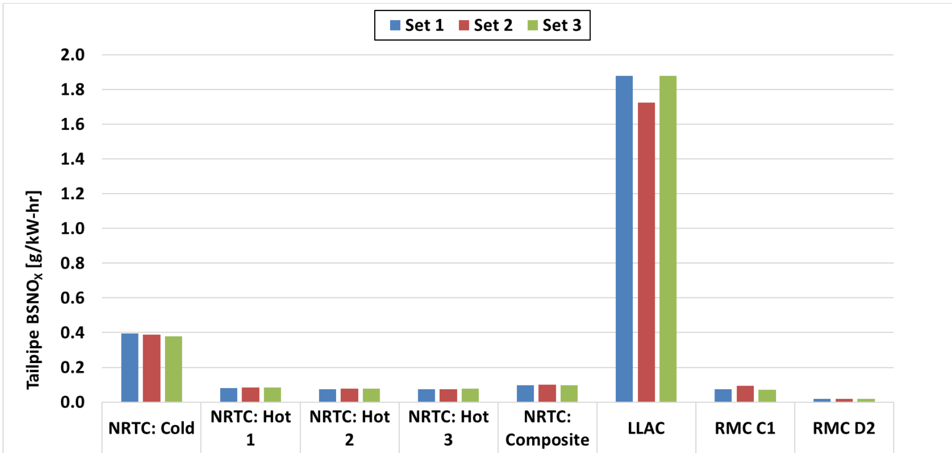


FIGURE 11. JOHN DEERE 6.8 L TAILPIPE CO_2 EMISSIONS

Figure 12 shows the brake specific tailpipe NO_X results from the individual replicates and cycles. The NRTC composite results revealed that the degreened engine and aftertreatment system produced NO_X emissions well below the Tier 4 final NO_X standard of 0.4 g/kW-hr. The RMC-C1 and RMC-D2 also exhibited low NO_X emissions with averages of 0.076 g/kW-hr and 0.02 g/kW-hr, respectively. The LLAC results, however, resulted in tailpipe NO_X that was 4.5X higher than the Tier 4 final NO_X standard. This was expected given that the application's aftertreatment controller calibration was likely configured to comply with the certification cycle testing. In previous work funded by CARB, on-road applications that met the 2010 federal emissions requirements were tested utilizing the LLC. The results revealed aftertreatment system and thermal management issues, which needed to be addressed to meet lower tailpipe NO_X standard targets. This includes sustained low load operation which decreases exhaust temperatures, and maintaining system readiness at low loads to control emissions when the engine resumes higher load operations. Similarly, the LLAC has highlighted areas that will require improvement to meet future regulatory standards the include lower load operations. Additional details will be discussed in subsequent paragraphs.



	NRTC: Cold	NRTC: Hot 1	NRTC: Hot 2	NRTC: Hot 3	NRTC: Composite	LLAC	RMC C1	RMC D2
Set 1	0.393	0.081	0.073	0.075	0.096	1.88	0.07	0.02
Set 2	0.389	0.085	0.078	0.073	0.100	1.72	0.09	0.02
Set 3	0.378	0.083	0.076	0.078	0.098	1.88	0.07	0.02

FIGURE 12. JOHN DEERE 6.8 L BASELINE TAILPIPE NO_X EMISSIONS

Figure 13 considers the continuous data for a cold start NRTC cycle. Prior to testing this cycle, two (2) hot start preparatory NRTC cycles were executed and followed by an overnight soak period. Since the testing procedures complied with 40 CFR Part 1065, the aftertreatment system temperatures remained within 20°C to 30°C. The data highlights low NO_X conversion performance occurring for the first 180 seconds, and this is fairly typical for a modern off-road engine on the cold NRTC. This performance is caused by the low exhaust and catalyst temperatures, which haven't reached the necessary conditions for catalyst light-off. Following 180 seconds, the NO_X conversion performance began to improve significantly with tailpipe NO_X emissions suddenly decreasing. As the aftertreatment system temperatures increased, the tailpipe NO_X emissions became very low and eventually achieved NO_X conversion performance of 98% or greater. This performance was observed after 400 seconds into the cold start NRTC. Overall, the NRTC NO_X conversion was reported at 88% in the replicate example shown below.

The next test was a hot start NRTC, which was followed by a 20-minute soak period after the conclusion of the cold start cycle. Figure 14 reflects the continuous data from the hot start NRTC cycle. The aftertreatment temperatures are shown to be low at that start of the cycle and contribute to the tailpipe NO_X emissions in the first 150 seconds. Additionally, the tailpipe NO_X mass rate peak was caused by a momentary aftertreatment temperature decrease, which reduced NO_X conversion. Other than the start, NO_X reduction performance remained at full conversion for the rest of the cycle.

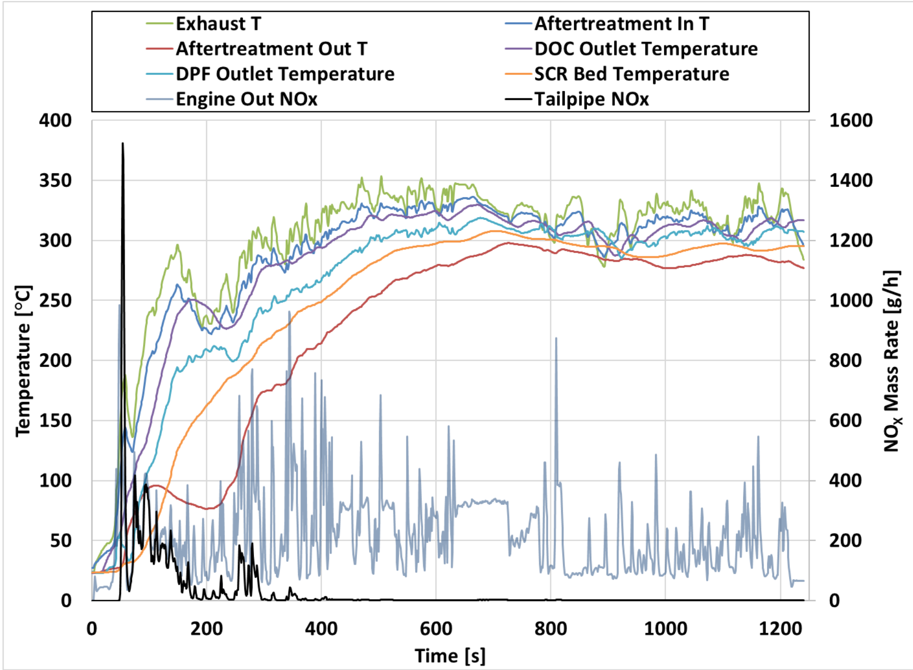


FIGURE 13. JOHN DEERE 6.8 L COLD START NRTC TEMPERATURE AND NO_X PROFILES

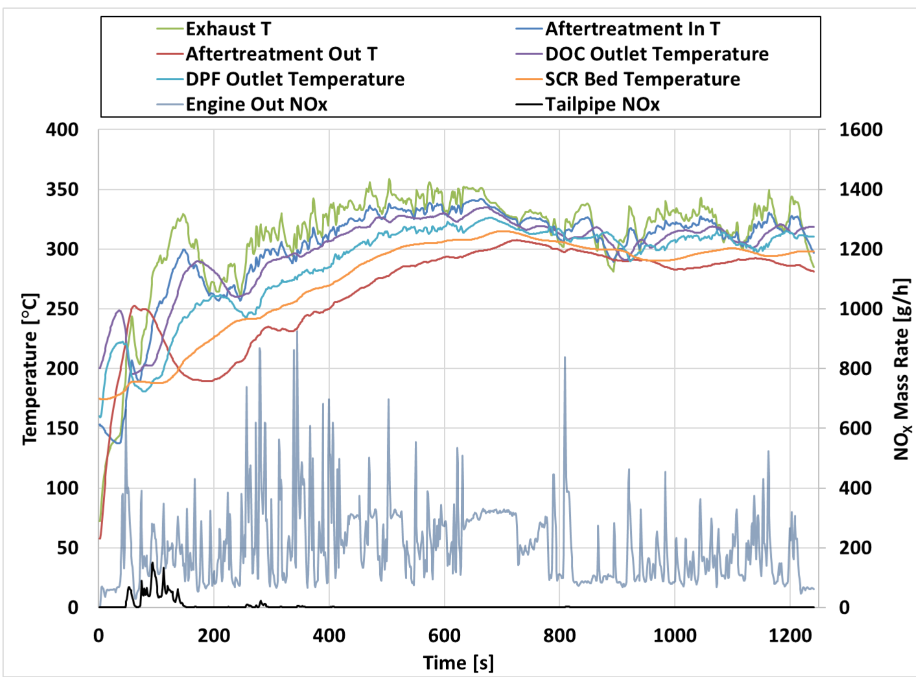


FIGURE 14. JOHN DEERE 6.8 L HOT START NRTC TEMPERATURE AND NO_X PROFILES

After the third hot start NRTC, the LLAC was evaluated with an accessory load. The minimum accessory load for this cycle was configured for 5% with the exception of the motoring segments. Similar to the conventional NRTC cycle execution procedures, the LLAC followed a

20-minute soak period before the test was initiated. With an average duty cycle of 15% the cycle was expected to provide challenges to the baseline hardware and calibration strategies.

Figure 15 considers the continuous NO_X mass rate and temperature data from the LLAC cycle. The temperatures are observed to be operating near the SCR's low temperature limit, or light-off temperature. This temperature behavior was observed at various points within the cycle. Regions where high tailpipe NO_X is observed coincide with an SCR bed temperature at or below 225 °C. When the SCR bed state approached this critical temperature, NO_X control was gradually lost until the aftertreatment system returned to an "in-service" state. For example, the cycle featured long idle segments after 3000 seconds and temperatures were observed to decrease over these idle periods. As the temperatures decrease, the SCR catalyst is observed to completely lose its ability to reduce NO_X since the inlet and outlet NO_X mass rates were the same. The engine then entered a momentary load condition where the aftertreatment temperatures increased and the SCR catalyst achieved light off. The low exhaust temperatures resulted in the cycle NO_X conversion of 67%.

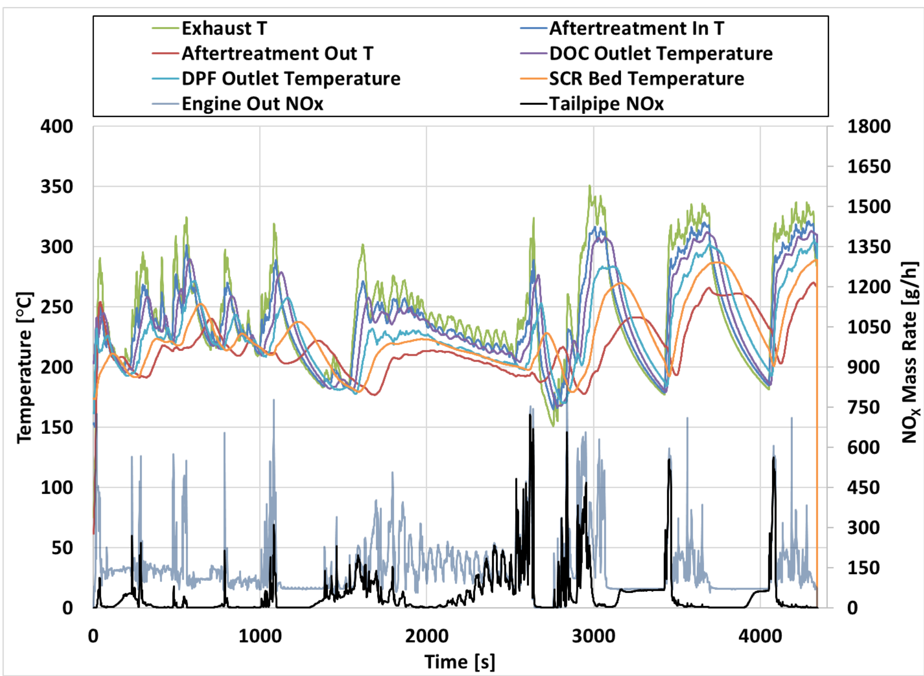


FIGURE 15. JOHN DEERE 6.8 L LLAC TEMPERATURE AND NO_X PROFILES

The last two cycles, which are shown in Figure 16 and Figure 17 are the RMC-C1 and RMC-D2 cycles. The RMC-C1 cycle was observed to have high NO_X conversion performance throughout the cycle with the exception of the first 250 seconds. Specifically, the transition from idle to the first mode is challenging due to the sudden increase in engine out NO_X and because it takes time for temperature to propagate throughout the aftertreatment system. Beyond that, the system is shown to have high NO_X reduction for an overall result of 97.6% NO_X conversion.

The RMC-D2 is considered a favorable cycle for the aftertreatment system due to the exhaust conditions generated from the engine. The aftertreatment temperatures are shown to remain above 300 °C for the entirety of the cycle and there are no segments that contribute to low aftertreatment temperatures (i.e. extended idle periods). Coupled with lower engine out NO_X and the high temperatures, the RMC-D2 cycle was characterized with an overall NO_X conversion of 99.3%.

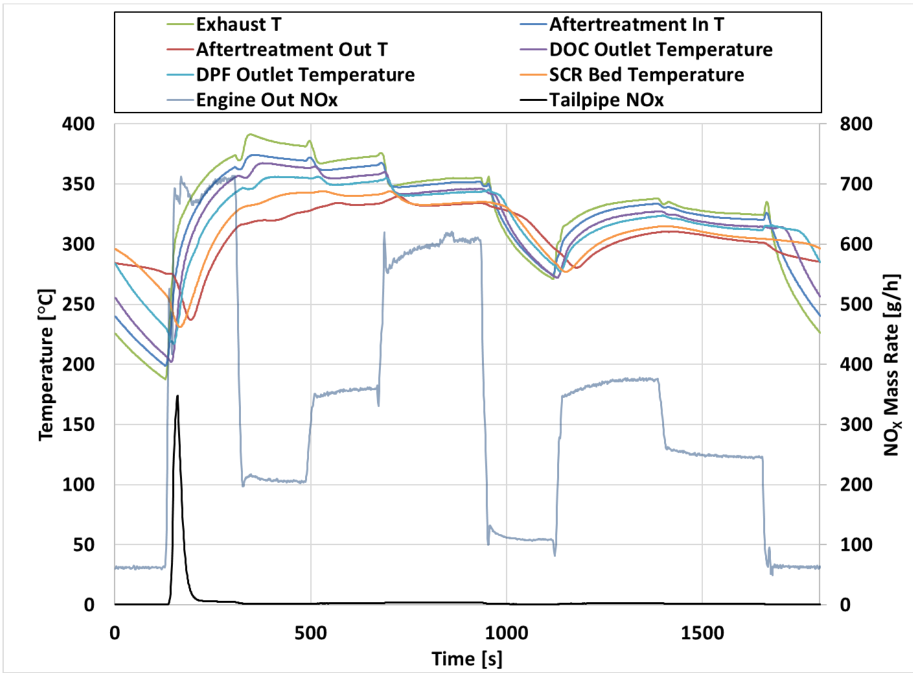


FIGURE 16. JOHN DEERE 6.8 L RMC-C1 TEMPERATURE AND NO_X PROFILES

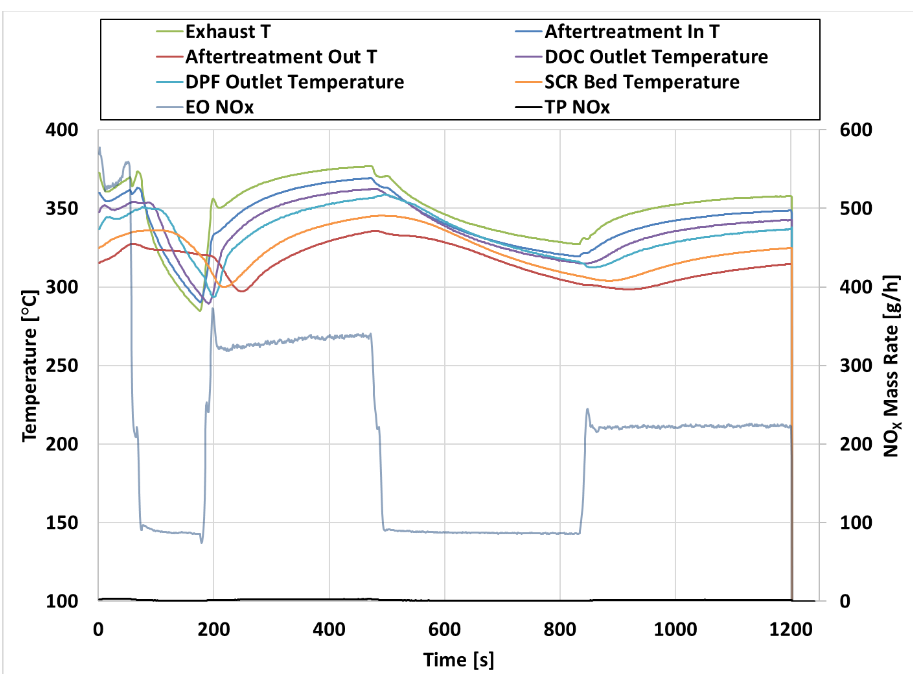


FIGURE 17. JOHN DEERE 6.8 L RMC-D2 TEMPERATURE AND NO_X PROFILES

PM tailpipe emissions, summarized below in Figure 18, also revealed that the engine and aftertreatment system were capable of meeting the Tier 4 final emissions standard of 0.02 g/kW-hr. As expected, the highest amount of PM emissions occurred during the cold start cycle where results were up to 4 times higher compared to the other evaluated cycles. Still, the inclusion of a DPF in the aftertreatment system enabled the cold start NRTC result to be lower than the standard. Average results for the remainder of the cycles remained below 0.5 mg/kW-hr.

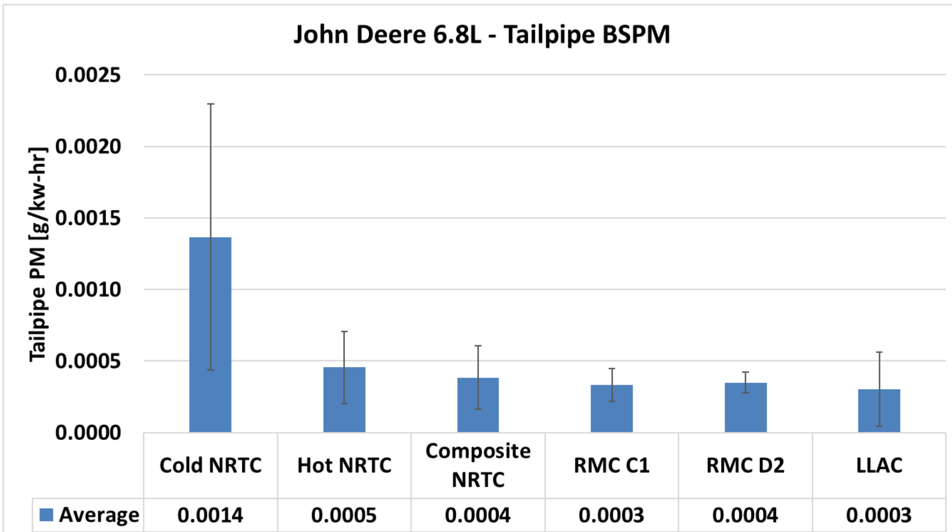


FIGURE 18. JOHN DEERE 6.8 L AVERAGE BSPM TAILPIPE RESULTS

5.2 John Deere 4.5L Non-DPF Engine

The nominal power rating for the John Deere 4045 engine is 104 kW at 2200 rpm, which needs to comply with the emission standards for engine power ratings between 56kw and 130kw, shown in Table 11. Other than the CO standard, the other emissions remain the same as those for the previous engine platform.

TABLE 11. TIER 4 FINAL CRITERIA EMISSIONS STANDARDS: 56 ≤ KW < 130

	Tier 4 Final Emission Standards [g/kW-hr]				
	NO_X	PM	NMHC	CO	NH_3
Standard	0.40	0.02	0.19	5.0	< 10 ppm average

Baseline engine out and tailpipe criteria emission results are found in Table 12 and Table 13. The tables include information for the individual cycle averages, standard deviation, and COV. As with the last engine platform, the sample composite calculations are applied for the NRTC cycles (i.e. 5% weighting on the cold start NRTC and 95% weighting on the hot start NRTC). Also, three (3) replicate test cycles were considered as part of the statistical analysis.

TABLE 12. JOHN DEERE 4.5 L BASELINE ENGINE-OUT EMISSIONS RESULTS

			NRTC								
			Cold	Hot 1	Hot 2	Hot 3	Composite	Hot-Avg	LLAC	RMC-C1	RMC-D2
Average	THC	g/kw-hr	0.27	0.21	0.29	0.29	0.22	0.26	0.54	0.19	0.22
	NMHC	g/kw-hr	0.27	0.28	0.21	0.28	0.28	0.26	0.53	0.18	0.21
	CO	g/kw-hr	1.06	0.85	0.84	0.84	0.86	0.84	2.03	0.42	0.84
	NOx	g/kw-hr	5.44	5.34	5.38	5.37	5.35	5.36	7.20	4.95	4.81
	PM	g/kw-hr	0.020	0.016	0.016	0.017	0.016	0.016	0.016	0.013	0.008
	CO2	g/kw-hr	808.4	784.9	784.6	783.5	786.1	784.3	901.1	739.4	728.8
	Work	kw-hr	13.26	13.21	13.21	13.20	13.2	13.21	18.72	28.41	15.738
Stdev	THC	g/kw-hr	0.0055	0.0048	0.0058	0.0055	0.0048	0.0054	0.0089	0.0032	0.0026
	NMHC	g/kw-hr	0.0054	0.0063	0.0043	0.0054	0.0063	0.0053	0.0087	0.0032	0.0026
	CO	g/kw-hr	0.0138	0.0161	0.0141	0.0158	0.0159	0.0151	0.0141	0.0053	0.0129
	NOx	g/kw-hr	0.0535	0.0557	0.0461	0.0445	0.0555	0.0481	0.0586	0.0182	0.0110
	PM	g/kw-hr	0.0024	0.0026	0.0008	0.0015	0.0026	0.0015	0.0012	0.0004	0.0025
	CO2	g/kw-hr	1.60	0.87	1.07	1.36	0.90	1.08	3.24	2.36	2.4570
	Work	kw-hr	0.006	0.003	0.006	0.001	0.003	0.002	0.003	0.04	0.00
CVar	THC	%	2%	2%	2%	2%	2%	2%	2%	2%	1%
	NMHC	%	2%	2%	2%	2%	2%	2%	2%	2%	1%
	CO	%	1%	2%	2%	2%	2%	2%	1%	1%	2%
	NOx	%	1.0%	1.0%	0.9%	0.8%	1.0%	0.9%	0.8%	0.4%	0.2%
	PM	%	11.8%	16.3%	5.1%	9.0%	16.0%	9.5%	7.9%	3.0%	30.0%
	CO2	%	0.2%	0.1%	0.1%	0.2%	0.1%	0.1%	0.4%	0.3%	0.3%
	Work	%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%

TABLE 13. JOHN DEERE 4.5 L BASELINE TAILPIPE EMISSIONS RESULTS

			NRTC								
			Cold	Hot 1	Hot 2	Hot 3	Composite	Hot-Avg	LLAC	RMC-C1	RMC-D2
Average	THC	g/kw-hr	0.013	0.011	0.011	0.011	0.011	0.011	0.020	0.008	0.006
	NMHC	g/kw-hr	0.013	0.010	0.011	0.011	0.010	0.011	0.020	0.007	0.006
	CO	g/kw-hr	0.103	0.000	0.003	0.010	0.005	0.004	0.008	0.011	0.010
	NOx	g/kw-hr	0.661	0.130	0.126	0.113	0.157	0.123	1.331	0.047	0.018
	PM	g/kw-hr	0.011	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.005
	CO2	g/kw-hr	805.4	785.1	789.1	787.7	786.1	787.3	889.4	736.5	727.0
	Work	kw-hr	13.3	13.2	13.2	13.2	13.2	13.2	18.7	28.4	15.7
	PN	#/kw-hr	6.2E+13	5.5E+13	5.5E+13	5.6E+13	5.6E+13	5.5E+13	5.0E+13	4.9E+13	2.9E+13
Stdev	THC	g/kw-hr	0.0014	0.0032	0.0032	0.0031	0.0031	0.0032	0.0038	0.0028	0.0028
	NMHC	g/kw-hr	0.0013	0.0031	0.0032	0.0031	0.0030	0.0031	0.0038	0.0028	0.0027
	CO	g/kw-hr	0.0042	0.0000	0.0039	0.0066	0.0002	0.0035	0.0074	0.0005	0.0060
	NOx	g/kw-hr	0.0219	0.0142	0.0163	0.0059	0.0146	0.0121	0.1161	0.0052	0.0027
	PM	g/kw-hr	0.0002	0.0002	0.0001	0.0003	0.0002	0.0001	0.0002	0.0002	0.0004
	CO2	g/kw-hr	2.43	0.14	4.97	5.24	0.16	3.29	2.53	2.02	3.9571
	Work	kw-hr	0.006	0.003	0.006	0.001	0.003	0.002	0.003	0.04	0.00
	PN	#/kw-hr	6.1E+11	4.3E+11	6.0E+11	3.6E+11	4.2E+11	4.3E+11	1.5E+11	2.0E+12	3.5E+11
CVar	*THC*	*%*	*10%*	*30%*	*29%*	*28%*	*29%*	*29%*	*19%*	*37%*	*44%*
	NMHC	*%*	*10%*	*30%*	*29%*	*28%*	*29%*	*29%*	*19%*	*37%*	*44%*
	CO	%	4%	#DIV/0!	141%	68%	4%	84%	93%	5%	61%
	NOx	%	3.3%	10.9%	12.9%	5.2%	9.3%	9.9%	8.7%	11.1%	14.6%
	PM	%	1.8%	1.9%	0.6%	2.7%	1.7%	0.6%	2.0%	2.3%	6.9%
	CO2	%	0.3%	0.0%	0.6%	0.7%	0.0%	0.4%	0.3%	0.3%	0.5%
	Work	%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%

The average tailpipe brake specific CO_2 results are shown in Figure 19. The cold and hot start NRTC results were observed to have higher CO_2 emissions compared to the (2) RMC cycle results. The LLAC cycle is shown to have the highest CO_2 emissions amongst the cycles with

13% higher CO_2 compared to the NRTC. Overall CO_2 values were consistent for all of replicates with 0.7% as the highest COV value.

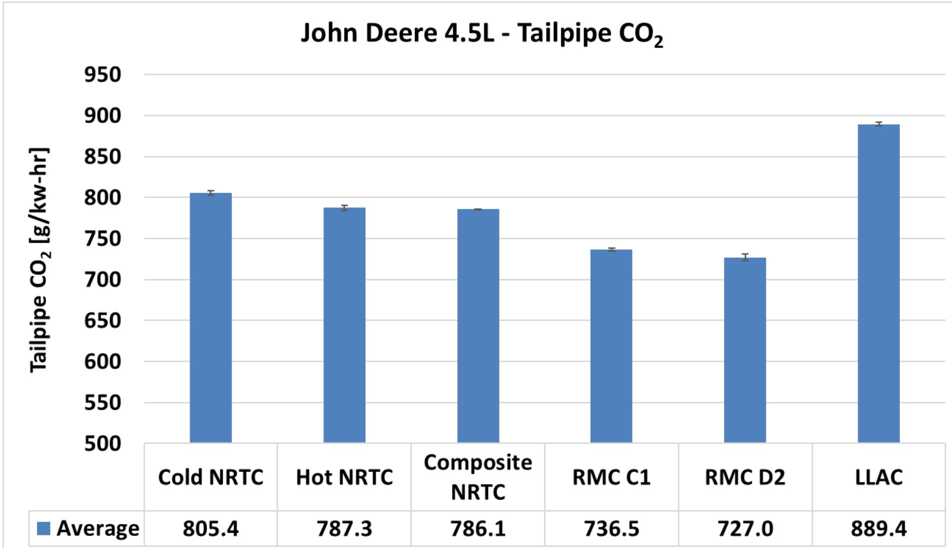


FIGURE 19. JOHN DEERE 4.5 L BASELINE TAILPIPE CO_2 EMISSIONS RESULTS

Brake specific NO_X tailpipe emissions, which are illustrated in Figure 20, are shown to be within the Tier 4 final limits. As expected, the cold start cycle yielded the highest emissions amongst the NRTC cycles due to the low catalyst temperature conditions. The RMC cycles yielded the lowest NO_X emissions because of ideal exhaust conditions for the aftertreatment system. This includes higher temperature and low idle time. The continuous performance will be discussed in a subsequent paragraph, which will highlight the temperature and NO_X conditions. As was observed in the previous engine platform, the LLAC provided the most challenge since low temperature exhaust temperatures conditions occur at a higher frequency.

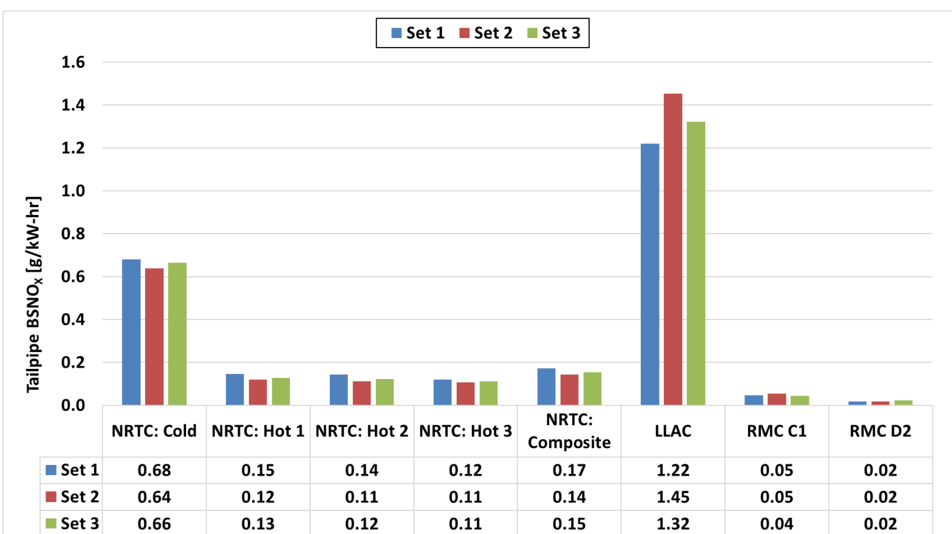


FIGURE 20. JOHN DEERE 4.5 L BASELINE TAILPIPE NO_X EMISSIONS RESULTS

As mentioned previously, the two (2) engine platforms evaluated for this study were subjected to the same test matrix that included the NRTC, LLAC, and RMC cycles. Pre-test equipment checks and temperature conditions were monitored to ensure the test met the 40 CFR Part 1065 criteria. Additionally, the testing sequence was initiated following two (2) NRTC preparatory cycles and an overnight soak. The cold start NRTC was then tested the following day.

Figure 21 shows that cold-start NRTC temperature and NO_X profiles. The cold-start cycle started with aftertreatment catalyst temperatures between 20 °C to 30 °C. Following the engine start, the aftertreatment systems takes ~ 165 seconds to reach the SCR light off temperature. During this time, tailpipe NO_X emissions are shown to decrease as the aftertreatment temperatures increase. Full NO_X conversion (i.e. NO_X conversion in excess of 98%) occurs after 300 seconds. After reaching the catalyst light state, tailpipe NO_X emissions are relatively low and the aftertreatment system temperatures are maintained above 250 °C. Overall, the engine and aftertreatment systems achieved an 88% conversion efficiency.

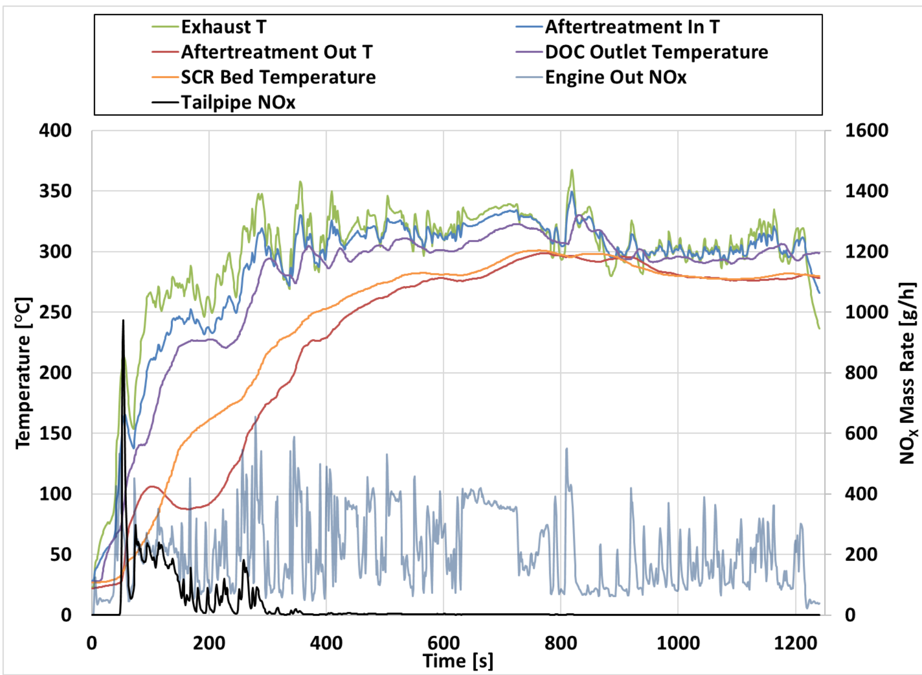


FIGURE 21. JOHN DEERE 4.5 L COLD START NRTC TEMPERATURE AND NO_X PROFILES

The subsequent hot start, which is shown in Figure 22, has the most NO_X emissions at the start of the cycle. Aftertreatment temperatures up to 150 seconds are low and continue to decrease, which is not ideal for the SCR catalyst. This results in tailpipe NO_X emissions that peak at ~ 100 seconds. After 200 seconds, the aftertreatment temperatures stabilize and the SCR catalyst reaches full conversion. The SCR catalyst is able to reduce most NO_X emissions for an overall conversion of 97.7%.

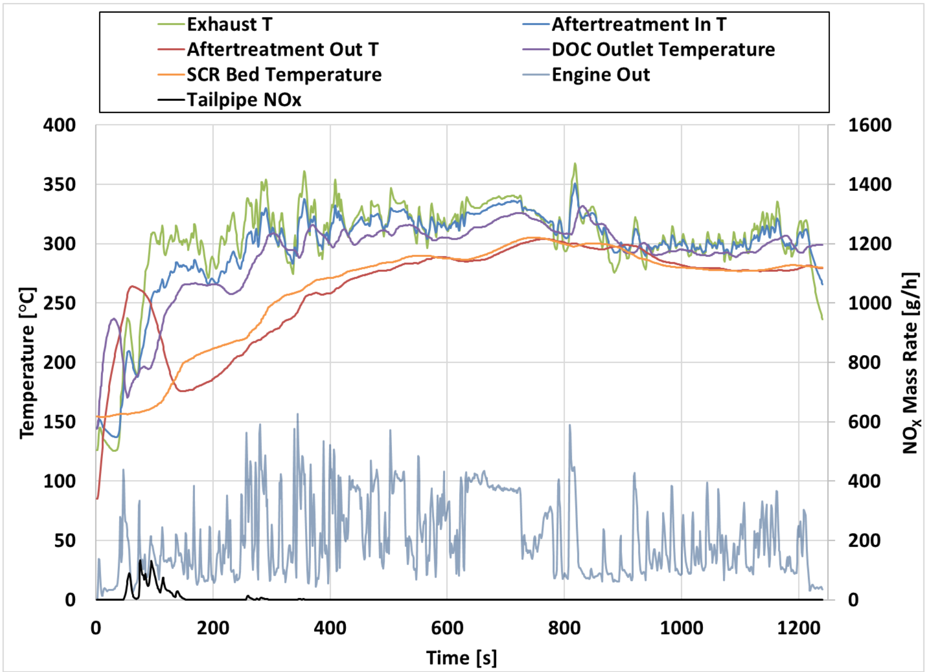


FIGURE 22. JOHN DEERE 4.5 L HOT START NRTC TEMPERATURE AND NO_X PROFILES

Following the three (3) NRTC replicates, the LLAC was evaluated with the minimum accessory load of 5%. Figure 23 shows the temperature and NO_X profiles for the LLAC cycle. During the early portions of the cycle, the engine and aftertreatment system are able to reduce a considerable amount of NO_X. Compared to the 6.8 L engine platform in Figure 15, the 4.5 L engine and aftertreatment system have superior control of NO_X emissions during the first 2000 seconds. This is due to the higher exhaust temperatures in this segment of the cycle. For the 4.5 L engine, the aftertreatment temperatures are near 250 °C, whereas the temperatures observed for the 6.8 L stayed between 200°C and 225°C. In general, the SCR temperatures were about 25°C -30°C higher on the 4.5L engine on the LLAC at lower loads. This helped the SCR catalyst performance better than was observed for the 6.8L engine, with a cycle NO_X conversion efficiency at 82%. However, given the higher engine-out NO_X levels on the 4.5L engine, the tailpipe NOX on the LLAC was still quite high at 1.3 g/kw-hr.

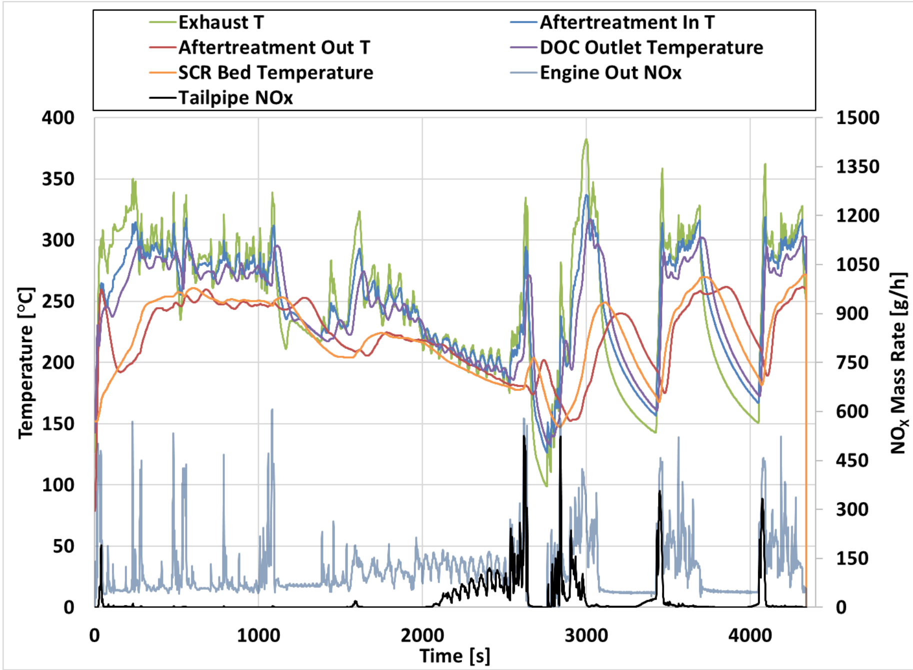


FIGURE 23. JOHN DEERE 4.5 L LLAC TEMPERATURE AND NO_X PROFILES

Figure 24 and Figure 25 show the instantaneous results for the RMC-C1 and RMC-D2 cycles. Figure 24, or the RMC-C1 cycle shows the tailpipe NO_X increase during the first mode transition from idle. Since there is a sudden increase in engine out NO_X emissions and temperatures weren't ideal, NO_X breakthrough occurred. Once the aftertreatment temperatures stabilized, full NO_X conversion was observed. There was also a slight increase in tailpipe NO_X at the end of the rated power mode, or 900 seconds. At this point, it is likely that the high catalyst temperature led to NH_3 oxidation, which caused NO_X to breakthrough. Aside from that, the low NO_X emissions led to a 99.1% NO_X conversion efficiency for the entire cycle.

Figure 25, or the RMC-D2 cycles shows low NO_X emissions for the entirety of the cycle. Because aftertreatment temperatures remained within an ideal operating temperature range, the NO_X conversion performance was high. Additionally, there was very little in the form of sudden temperature ramps like observed in Figure 24. Overall NO_X conversion efficiency was 99.6% for the entire cycle.

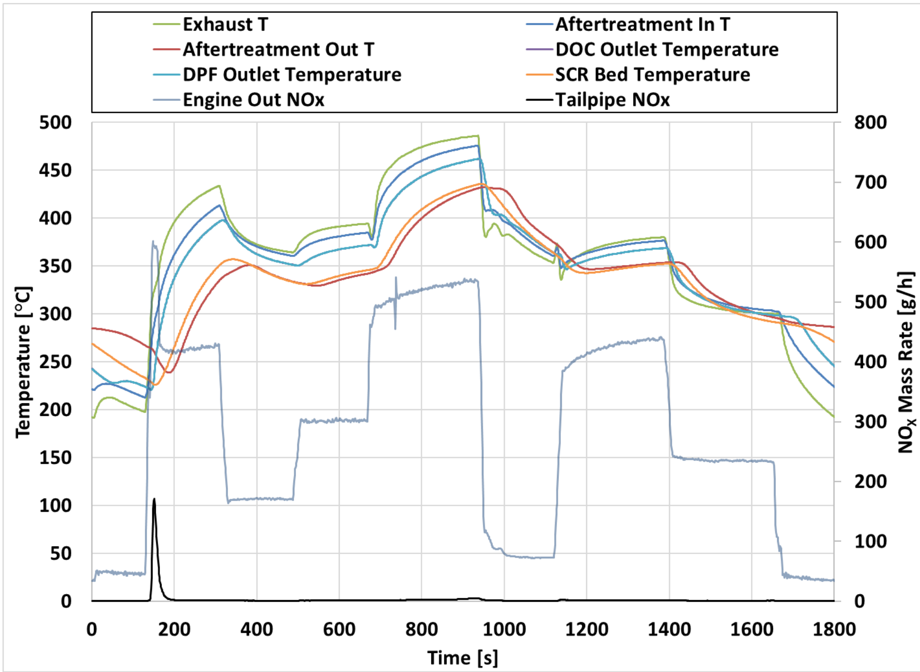


FIGURE 24. JOHN DEERE 4.5 L RMC-C1 TEMPERATURE AND NO_X PROFILES

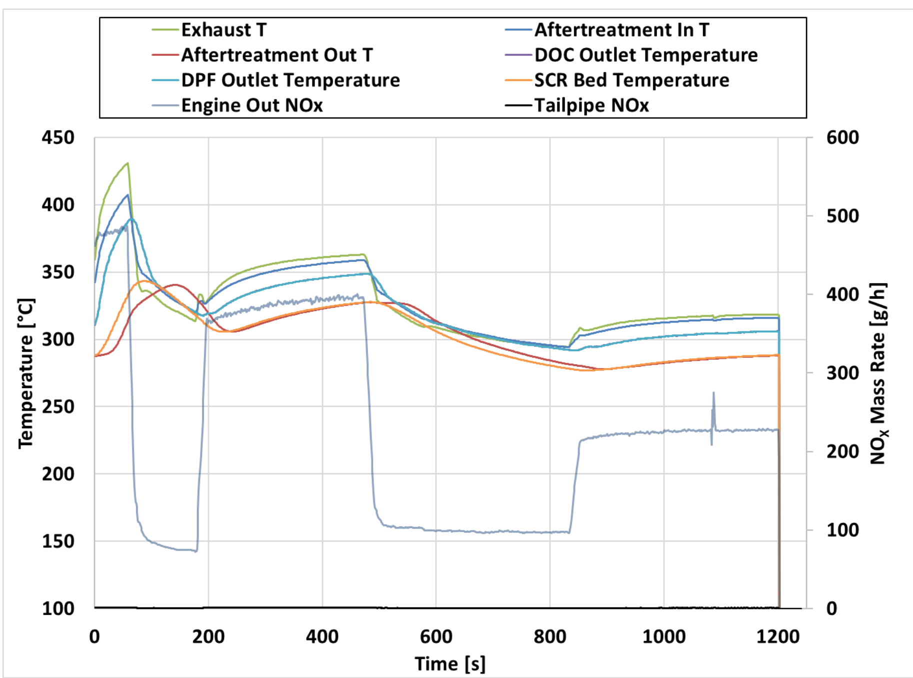


FIGURE 25. JOHN DEERE 4.5 L RMC-D2 TEMPERATURE AND NO_X PROFILES

The John Deere 4045 aftertreatment system was not equipped with a DPF, which resulted in higher PM emissions, compared to the 6068 engine platform. Figure 26 compares the engine out and tailpipe PM emissions for the 4.5 L engine. The data highlights a 40% to 50% PM reduction across the DOC, which is primarily attributed to the oxidation of soluble organic fraction, or SOF. In comparison to the DPF equipped 6.8 L engine, these PM results are one to two orders of magnitude higher. Compared to the Tier 4 final standard, the tailpipe PM emissions are 55% to 75% lower.

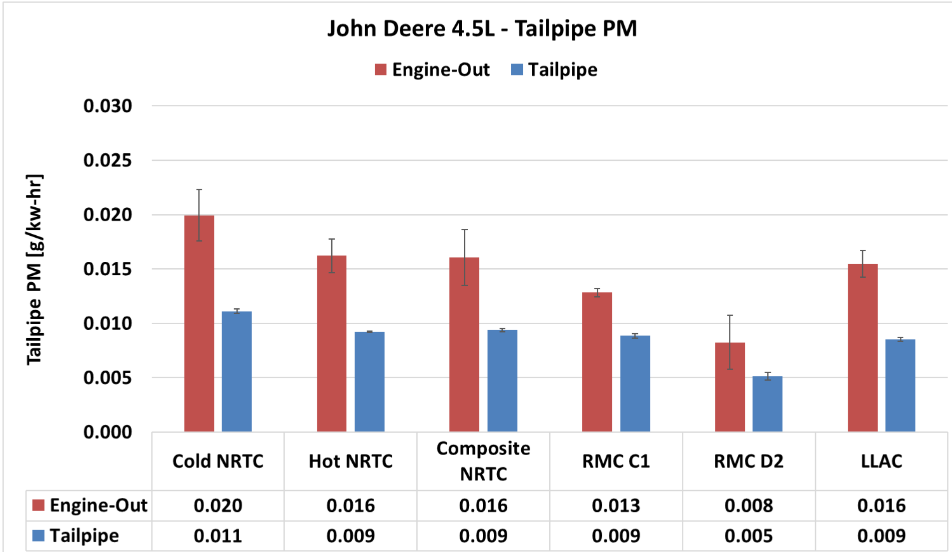


FIGURE 26. JOHN DEERE 4.5 L AVERAGE ENGINE OUT AND TAILPIPE PM EMISSIONS

5.3 Particle Number (PN) Results

A summary of PN emissions for both engines is given in Figure 27 below. As expected, the DPF-equipped 6.8L engine produces PN levels that are roughly 2 orders of magnitude lower than those produced by the non-DPF 4.5L engine. In addition, the DPF engine produced PN levels on all cycles that would be compliant with the EU Nonroad standard of 1 X 10^{12} #/kw-hr. It should be noted that for calculation of the composite NRTC PN values, the EU cold-hot weight factors of 10% cold and 90% hot were used, to enable meaningful comparison with the EU standard in this case.

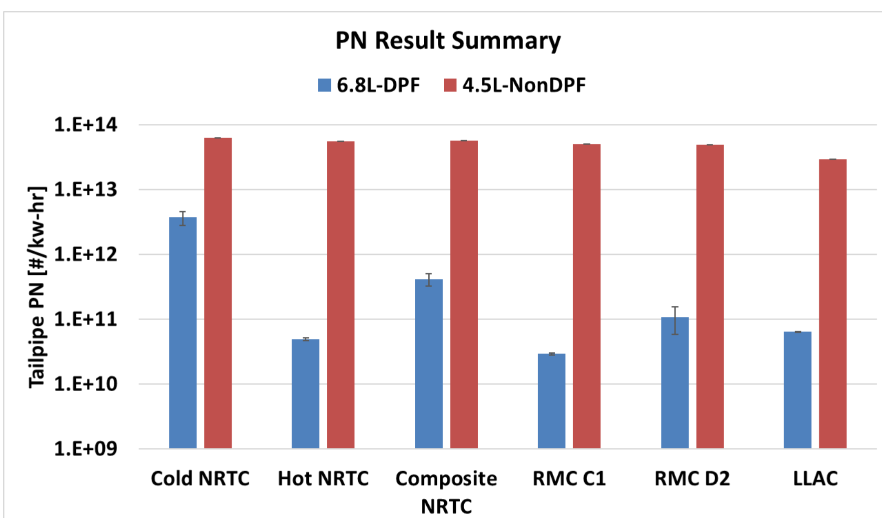


FIGURE 27. JOHN DEERE 6.8 L AND 4.5 L TAILPIPE PN EMISSIONS COMPARISON

5.4 Nitrous Oxide (N_2O) Results

Figure 28 shows a comparison of N_2O emissions at the tailpipe for both the 6068 and 4045 engines. There was a substantial difference in N_2O rates between the two engines. The 6.8L engine generally had N_2O levels comparable to some of the best current on-highway engines, based on data available to SwRI. The 4.5L engine had N_2O rates that were twice as high as the 6.8L engine, and also were at levels that would be above the on-highway standard of 0.10 g/hp-hr (0.13 g/kw-hr). This increase is likely due in part to the higher engine-out NO_X level for the 4.5L engine, which runs at roughly 5 g/kw-hr, as compared to the 3 g/kw-hr engine-out level of the 6.9L engine.

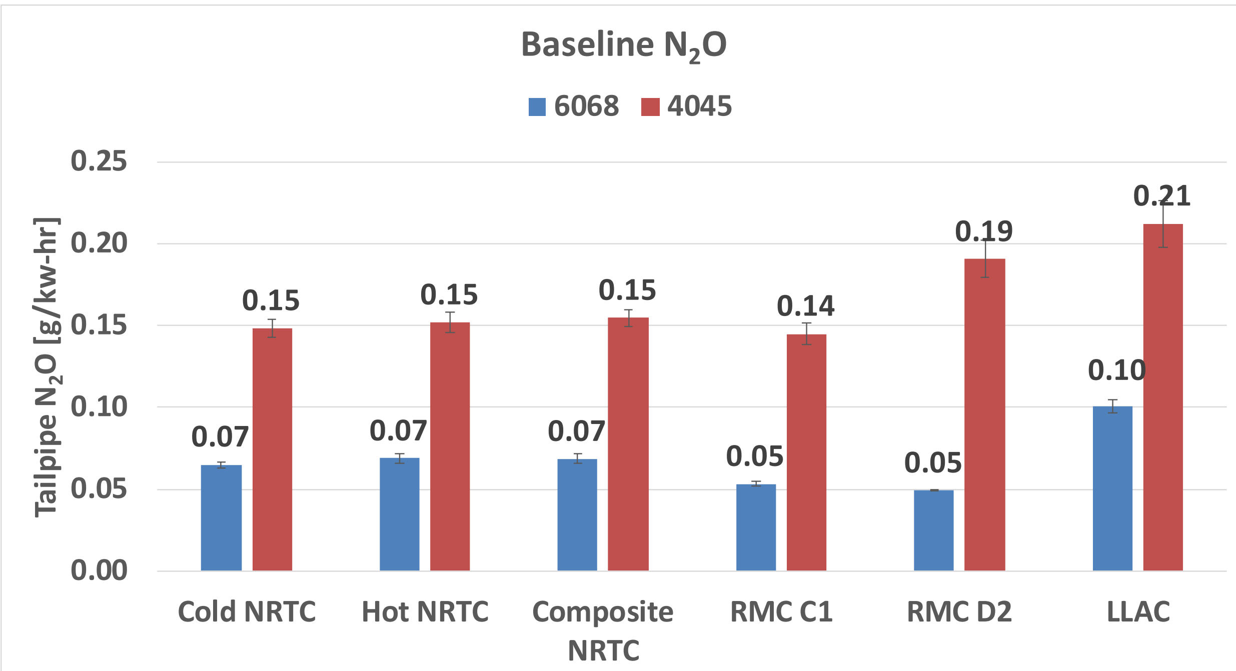


FIGURE 28. JOHN DEERE 6.8L AND 4.5L N_2O COMPARISON

6.0 TASK 4B – DETAILED CHEMICAL EMISSION CHARACTERIZATION

An extensive list of measurements was designed to provide a detailed characterization of various components of the exhaust, including both regulated and unregulated pollutants, as well as a variety of air toxics and other compounds. A list of these planned measurements is given in Table 14 below. Descriptions of analytical methods for each component are presented first below. Following the section on methodology, a summary of the results for each component is given.

TABLE 14. CHEMICAL EMISSION CHARACTERIZATION

Analysis Component	Collection Media	Notes
VOC	Bag	Auto Oil/CARB Speciation
Carbonyls	Impingers	Part 1065, Subpart I DNPH-HPLC
PAH/NPAH	8X10 Zefluor + XAD traps	Part 1065, Subpart L and Method 429 GC/MS
Trace Metals	Teflon 47 mm filter	EPA SW-846 Method 6020B using ICP-MS
Inorganic Ions	Teflon 47 mm filter	Extraction and IC
WSOC	Quartz 447 mm filter	Water extraction and EPA Method 8270D
EC/OC	Quartz 447 mm filter	Sunset Laboratory Inc. TOR and TOT
IVOC/SVOC	XAD traps	GCXGC/TOFMS

6.1 Sampling and Analytical Methodology

6.1.1 Volatile Organic Compounds (VOC)

Volatile organic compounds (VOC) were determined using analytical procedures for measuring the hydrocarbon speciation (C_1 to C_{12} hydrocarbons) which were similar to the Coordinating Research Council (CRC) Auto/Oil Phase II method and the California Air Resources Board (CARB) Standard Operating Procedures (SOP) No. MLD102/103 which was derived from CARB Methods 1002 and 1003. With these methods, exhaust emissions samples were analyzed for the presence of more than 200 different VOC exhaust species. Three gas chromatography (GC) procedures were used to identify and quantify specific compounds. One GC was employed for the measurement of the C_2-C_4 species, and a second was used for the C_5-C_{12} species including some of the higher molecular weight alcohols and ethers. A third GC was used to measure 1-methylcyclopentene, benzene, toluene, 2,3-dimethylhexane, cyclohexane, and 2,3,3-trimethylpentane, which co-elute and cannot be accurately quantified by other methods. Analysis of all emission "sample" bags were begun within 30 minutes of sampling and before the "background" bags, so that reactive exhaust compounds could be analyzed as quickly as possible. Data were reported as background corrected. A brief description of these procedures is given in the following sections.

6.1.1.1 C_2-C_4 Species

With the aid of a DB-WAX pre-column and a 10-port switching valve, this procedure allowed the separation and determination of exhaust concentrations of C_2-C_4 individual hydrocarbon species, including: ethane; ethylene; acetylene; propane; propylene; trans-2-butene; butane; 1-butene; 2-methylpropene (isobutylene); 2,2-dimethypropane (neopentane); propyne; 1,3-butadiene; 2-methylpropane; 1-butyne; and cis-2-butene. Bag samples were analyzed with a GC system which utilized an Agilent Model 7890 Series A GC with an FID, two pneumatically operated and electrically controlled valves, and two analytical columns. The first column separated the C_2-C_4 hydrocarbons from the higher molecular weight hydrocarbons and the polar compounds. These higher molecular weight hydrocarbons (and water and alcohols) were retained on the pre-column while the C_2-C_4 hydrocarbons were passed through to the analytical column (50 m Alumina PLOT/KCl with 10 µm film thickness and 0.53 mm i.d.). At the same time, the C_2-C_4 hydrocarbons were separated on the analytical column, the pre-column was back-flushed with helium to prepare for the next analysis. The carrier gas for this analysis was helium. The GC was calibrated daily using a CRC Auto/Oil 23-component calibration mixture. Analysis for the C_2-C_4 hydrocarbons was typically begun within 30 minutes after sample collection was completed. Detection limits for the procedure were on the order of 0.05 mg/kw-hr in dilute exhaust for all compounds.

6.1.1.2 C_5-C_{12} Species

Bag samples were analyzed using a gas chromatograph equipped with an FID. The GC system utilized an Agilent Model 7890 Series A GC with an FID, a pneumatically operated and electrically controlled valve, and a 60 m DB-1 fused silica open tubular (FSOT) column with a 1.0 µm film thickness and a 0.32 mm i.d. The carrier gas was helium. Gaseous samples were pumped from the bag through a sample loop and then introduced into a liquid nitrogen cooled column. The column oven was then programmed to a maximum temperature of 200°C. The analog signal from the FID was sent to a networked computer system via a buffered analog to digital converter. The GC was calibrated daily using a CRC Auto/Oil 23-component calibration mixture. Detection limits for the procedure were on the order of 0.05 mg/kw-hr in dilute exhaust for all compounds.

6.1.1.3 Benzene and Toluene

This procedure used a separate system configured similarly to the C_5-C_{12} GC method (with a 30 m DB-5 analytical column in place of the DB-1 FSOT column) to resolve individual concentrations of benzene and toluene according to the CRC Auto/Oil Phase II Protocols. Separation of benzene and toluene from co-eluting peaks was carried out by fine-tuning the column head pressure to give benzene a retention time of 22 to 23 minutes. The GC was calibrated daily using a CRC 7-component calibration mixture. Detection limits for the procedure were 0.05 mg/kw-hr in dilute exhaust for all compounds.

6.1.2 Carbonyls (Aldehydes and Ketones)

Aldehydes and ketones samples were collected with a sampling system that consisted of impingers containing a DNPH absorbing solution using a method similar to CARB Method 1004. Samples were analyzed immediately or stored in ground glass stopped vials at 0°C for no more than one week prior to analysis. For analysis, a portion of the acetonitrile solution was injected into a liquid chromatograph equipped with an ultra-violet (UV) detector. External standards of the aldehyde and ketone DNPH derivatives were used to quantify the results. The aldehydes and ketones included: formaldehyde, acetaldehyde, acrolein, acetone, propionaldehyde, crotonaldehyde, n-butyraldehyde, isobutyraldehyde, methylethylketone, benzaldehyde, isovaleraldehyde, valeraldehyde, o-tolualdehyde, m-tolualdehyde/p-tolualdehyde (not resolved from each other during normal operating conditions, and so reported together), hexanaldehyde, and 2,5-dimethylbenzaldehyde. Detection limits for this procedure were on the order of 0.05 mg/kw-hr aldehyde or ketone in dilute exhaust, and the limit of quantification was 0.1 mg/kw-hr.

6.1.3 Polycyclic Aromatic Hydrocarbons (PAH) and nitro-PAH (NPAH)

Sampling for PAH and NPAH compounds was conducted via methods consistent with 40 CFR Part 1065 Subpart L. An 8X10-inch Zefluor filter was used to collect the particulate phase compounds, and four 4-inch diameter XAD traps were used to collect the semi-volatile phase compounds. In addition, an ambient background sample was collected during each test to improve the accuracy of the analytical procedure. The XAD traps contained 100 g of XAD-2 resin and were incorporated to improve the trapping efficiency for the lighter molecular weight PAH and NPAH compounds.

The analytical method was similar to CARB SOP MLD 429 using an isotope dilution technique. The 26 PAH target compounds included: naphthalene, 2-methylnaphthalene, 1-methylnaphthalene, 2,6-dimethylnaphthalene, acenaphthene, acenaphthylene, dibenzofuran, fluorene, phenanthrene, anthracene, 9-methylanthracene, fluoranthene, pyrene, benzo(a)anthracene, chrysene, 1-methylchrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(e)pyrene, benzo(a)pyrene, perylene, indeno(1,2,3-cd)pyrene, dibenz(a,h)anthracene, benzo(ghi)perylene, coronene, and biphenyl; and the five NPAH compounds included: 7-nitrobenzo[a]anthracene, 6-nitrobenzo[a]pyrene, 6-nitrochrysene, 2-nitrofluorene, and 1-nitropyrene.

Volatile-phase PAH and NPAH samples presented a particular problem for sampling because the conventional sampling techniques would not allow for a sufficient sample to be gathered to meet EPA detection requirements. Commercially available sample media and hardware were of insufficient size to allow for the collection of sample volumes necessary to meet these detection limits. Sample media size was also limited by the ability to extract and concentrate samples. Therefore, an approach was devised which involved both custom built sampling hardware and a modified sampling plan. SwRI has used this sampling protocol frequently in the past. The XAD traps were sized to allow a media diameter of 4 inches, rather than the conventional 2.5 inches. This larger diameter allowed for much higher flowrates, while maintaining the face velocity within the recommended levels for the smaller, conventional sample media. The XAD resin was held in place using fine metal retaining screens, coarse wire meshes and rings, as shown in Figure 29. This volume of dilute exhaust sample was sufficient for the analysis to meet a detection threshold of 0.05 ng/kw-hr for PAH and NPAH. Figure 30 shows the PAH and NPAH sampling system.

The filters were extracted with methylene chloride and toluene, and the traps was extracted with methylene chloride and the samples were analyzed separately to determine the semi-volatile and particulate phase compounds. The XAD-2 sample media was cleaned prior to testing. First, the XAD-2 was cleaned by siphoning five times with water using a Soxhlet. The residual water was then removed under vacuum. The XAD-2 was Soxhlet extracted four times: once with methanol for 24 hours, once with acetone for 48 hours, once with hexane for 48 hours, and finally with methylene chloride for 48 hours. The residual methylene chloride was removed by purging with heated nitrogen.

FIGURE 29. XAD TRAP (TOP, SIDE, AND BOTTOM VIEWS)

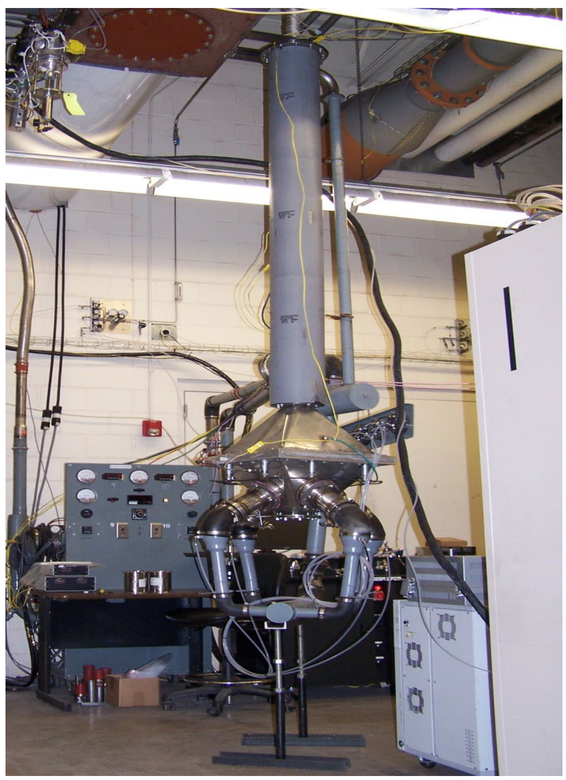


FIGURE 30. PAH AND NPAH SAMPLING SYSTEM

Prior to sampling, the XAD-2 traps were spiked with a deuterated sampling surrogate, D12-benzo(e)pyrene. Filter and XAD trap samples were then generated during each cold-start and six hot-start test sequence. The cold-start and six hot-start test sequence was repeated three times each for the aftertreatment-out and the engine-out emissions with each of the fuels. This system sampled only background air from the CVS after the HEPA filter pack, but before the introduction of the engine exhaust as shown in Figure 31.

Following testing, sample sets were delivered to the analytical laboratory for extraction and analysis. In cases where immediate extraction was not possible, samples were stored in a freezer at less than -4°C. Each filter and the entire XAD sample material were extracted separately.

FIGURE 31. AMBIENT BACKGROUND AIR SAMPLING SYSTEM

Prior to extraction of the filters, each filter was spiked with an internal standard solution containing seven deuterated PAH compounds:

- Benzo[a]anthracene-d12
- Chrysene-d12
- Benzo[b]fluoranthene-d12
- Benzo[k]fluoranthene-d12
- Benzo[a]pyrene-d12
- Indeno[1,2,3-cd]pyrene-d12
- Dibenzo[a,h]anthracene-d14

and four deuterated NPAH compounds:

- 2-nitrofluorene-d9
- 1-nitropyrene-d9
- 6-nitrochrysene-d11
- 6-nitrobenzo[a]pyrene-d11

This spiked internal standard was used to quantify the target PAH and NPAH in the sample. The filters were then Soxhlet extracted with methylene chloride for a minimum of 18 hours and again with toluene for a minimum of 18 hours. For the XAD traps, each was spiked with the same deuterated PAH and NPAH solutions as used for the filters. The trap samples were then Soxhlet extracted for 16 hours with methylene chloride. Following extraction, the methylene chloride extract for the adsorbent traps and the combined toluene/methylene chloride extract for the filters underwent a macro concentration step to 15 mL using Kuderna Danish/Snyder column evaporation technique with a water bath held at 75 to 80^{o}C. The sample is then split into three 5 ml aliquots: one for PAH clean-up, one for NPAH clean-up, and one as a reserve. For sample clean-up for the PAH aliquot, the sample extracts underwent solvent exchange into hexane, followed by base wash with 0.1N NaOH solution and silica gel column cleanup. The extracts were brought up to a final volume ranging from 250 to 500 µL in cyclohexane and submitted for analysis. For sample clean-up for the NPAH aliquot, the sample extract was first solvent-exchanged into about 2 mL of hexane. A silica gel column was prepared by filling a glass column (10 mm i.d. x 300 mm length) with 1.5 inches of activated silica gel. The sample extract was transferred onto the silica gel column, and the NPAH were eluted from the column with 6 mL of methylene chloride/hexanes (75/25 by volume) in 2 mL increments. The final sample extract was blown down to 250 uL in cyclohexane. Separate gas chromatograph/mass spectroscopy (GC/MS) analyses were necessary to acquire both the PAH and NPAH data.

Samples for both the volatile- and the particulate-phase PAH were analyzed by GC/MS using either an Agilent 5973N MSD with a 30 m by 0.25 mm i.d. DB-5 column and a 0.25 µm film thickness or an Agilent 5975 Insert MSD with a ZB-Semi-volatiles analytical column of the same dimensions. For each analysis, a 1-2 µL aliquot of the sample extract was injected into the instrument. A calibration curve consisting of at least five points was obtained prior to sample analysis to ensure linearity, and a mid-point continuing calibration was performed each day after the initial five-point calibration. The concentrations of the curve points ranged from 5000 pg/µL to 1.0 pg/µL. The acceptance criteria used for the initial calibration was 30 percent Relative Standard Deviation (RSD), and continuing calibrations were less than 20 percent drift. Analysis of NPAH compounds was performed using the negative ion/chemical ionization (NI/CI) mode and analysis for PAH compounds was performed using the positive ion/electron ionization (PI/EI) mode. Two or three characteristic ions for each PAH were monitored.

Samples for NPAH were analysis by GC/MS using an Agilent 5973N MSD with a 30 m by 0.25 mm i.d. ZB-XLB column with a 0.25 µm film thickness. For each analysis, a 1 µL aliquot of the sample extract was injected into the instrument. A calibration curve consisting of at least five points was obtained prior to sample analysis to ensure linearity, and a mid-point continuing calibration was performed each day after the initial five-point calibration. The concentrations of the curve points ranged from 300 pg/µL to 1.0pg/µL. Four NPAH internal standards (IS) were used in the initial calibration curve with each NPAH IS at 400 pg/uL. The acceptance criteria used for the initial calibration was 30 percent RSD, and continuing calibrations were 25 percent drift or less. Analysis of NPAH compounds was performed using the negative ion/chemical ionization/selected ion monitoring (NI/CI/SIM) mode. One characteristic ion (usually the molecular ion) for each of the NPAH and the NPAH IS was monitored.

6.1.4 Trace Elements

Trace elements were determined by collecting the exhaust with a Teflon™ filter. Each filter was digested with acid, and the resulting solution was analyzed by inductively coupled plasma-mass spectroscopy (ICP-MS) using EPA SW-846 Method 6020B. Blank filters were analyzed to assess any contribution from the filter media and the extraction/digestion solutions. The elements included:

- Aluminum (Al)
- Antimony (Sb)
- Barium (Ba)
- Boron (B)
- Cadmium (Cd)
- Calcium (Ca)
- Chromium (Cr)
- Copper (Cu)
- Iron (Fe)
- Lead (Pb)
- Magnesium (Mg)
- Manganese (Mn)
- Molybdenum (Mo)
- Nickel (Ni)
- Phosphorus (P)
- Potassium (K)
- Silicon (Si)
- Silver (Ag)
- Sodium (Na)
- Strontium (Sr)
- Tin (Sb)
- Titanium (Ti)
- Vanadium (V)
- Zinc (Zn)

6.1.5 Inorganic Ions

Anion and cation samples were collected on Teflon filters. Half of the filter was extracted with 60 percent isopropanol and 40 percent water solution and analyzed for cations via ion chromatography (IC) with a CG12A 2mm Guard Column and Ionpac CS12A 2mm Analytical Column and a conductivity detector. Cations included lithium ion (Li^+), sodium ion (Na^+), ammonia ion (NH_4^+), potassium ion (K^+), magnesium ion (Mg^+), and calcium ion (Ca^+). The second half of the filter was placed in an ammonization chamber prior to extraction to convert the sulfuric acid to an ammonium sulfate salt, $(NH_4)_2SO_4$. The soluble anions were leached from the filter with a 60 percent isopropanol and 40 percent water solution. An aliquot of this extract was injected into a second ion chromatograph and analyzed with an AG4A-SC 2mm Guard Column and Ionpac AS4A-SC 2mm Analytical Column with a conductivity detector. Anions included sulfate ion (SO_4^{-2}), nitrate ion (NO_3^-), phosphate ion (PO_4^{-3}), chloride ion (Cl^-), and bromide ion (Br^-). for cation analysis.

6.1.6 Water Soluble Organic Carbon (WSOC)

Quartz filters were used to collect WSOC from the exhaust. The sample filters were leached in deionized water, filtered, and analyzed for WSOC with EPA Method 8270D. Table 15 lists the typical analytes for this measurement.

TABLE 15. LIST OF ANALYTES FOR WSOC

CAS Number	Analyte	CAS Number	Analyte
62-75-9	N-nitrosodimethylamine	100-02-7	p-nitrophenol
62-53-3	Aniline	58-90-2	2,3,4,6-tetrachlorophenol
111-44-4	bis(2-chloroethyl)ether	938-95-5	2,3,5,6-tetrachlorophenol
108-95-2	Phenol	86-73-7	Fluorene
95-57-8	2-chlorophenol	7005-72-3	4-chlorophenyl phenyl ether
541-73-1	m-dichlorobenzene	84-66-2	Diethyl phthalate
106-46-7	p-dichlorobenzene	86-30-6/122-39-4	N-nitrosodiphenylamine/Diphenylamine
95-50-1	o-dichlorobenzene	100-01-6	p-nitroaniline
100-51-6	Benzyl alcohol	534-52-1	4,6-Dinitro-o-cresol
108-60-1	2,2-oxybis(1-chloropropane)	101-55-3	4-bromophenyl phenyl ether
67-72-1	Hexachloroethane	118-74-1	Hexachlorobenzene
621-64-7	N-nitrosodipropylamine	87-86-5	Pentachlorophenol
98-95-3	Nitrobenzene	85-01-8	Phenanthrene
78-59-1	Isophorone	120-12-7	Anthracene
88-75-5	o-nitrophenol	84-74-2	di-n-butyl phthalate
105-67-9	2,4-dimethylphenol	206-44-0	Fluoranthene
111-91-1	bis(2-chloroethoxy)methane	129-00-0	Pyrene
120-83-2	2,4-dichlorophenol	85-68-7	Butylbenzylphthalate
120-82-1	1,2,4-trichlorobenzene	56-55-3	Benzo[a]anthracene
91-20-3	Naphthalene	91-94-1	3,3'-dichlorobenzidine
106-47-8	4-chloroaniline	218-01-9	Chrysene
87-68-3	Hexachlorobutadiene	117-81-7	bis(2-ethylhexyl)phthalate
59-50-7	p-chloro-m-cresol	117-84-0	Di-n-octyl phthalate
91-57-6	2-methylnaphthalene	205-99-2	Benzo[b]fluoranthene
77-47-4	Hexachlorocyclopentadiene	207-08-9	Benzo[k]fluoranthene
88-06-2	2,4,6-trichlorophenol	50-32-8	Benzo[a]pyrene
95-95-4	2,4,5-trichlorophenol	193-39-5	Indeno[1,2,3-cd]pyrene
91-58-7	2-chloronaphthalene	53-70-3	Dibenz[a,h]anthracene
88-74-4	o-nitroaniline	191-24-2	Benzo[g,h,i]perylene
208-96-8	Acenaphthylene	110-86-1	Pyridine
131-11-3	Dimethyl phthalate	86-74-8	Carbazole
606-20-2	2,6-dinitrotoluene	95-48-7	o-cresol
99-09-2	m-nitroaniline	108-39-4/106-44-	m & p-cresol
83-32-9	Acenaphthene	91-57-6	1-methylnaphthalene
51-28-5	2,4-dinitrophenol	103-33-3	Azobenzene
132-64-9	Dibenzofuran	65-85-0	Benzoic Acid
121-14-2	2,4-dinitrotoluene		

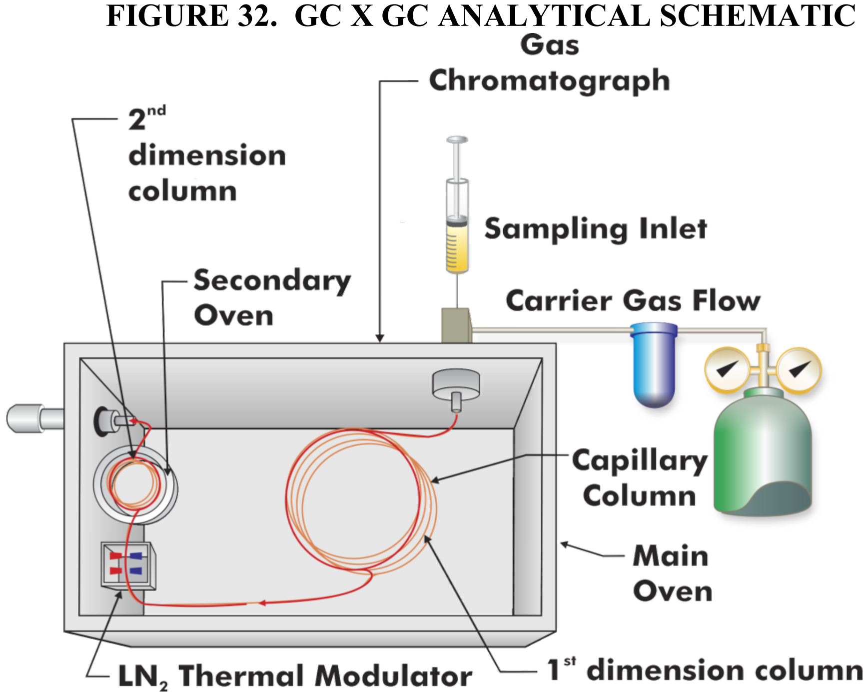
6.1.7 Elemental Carbon/Organic Carbon (EC/OC)

An EC/OC laboratory instrument was used to analyze aerosol particles collected on quartz-fiber filters for both organic carbon and elemental carbon (EC/OC). One sample of ambient air (background) and one sample of dilution air was taken during the entire test. These two filters were used as corrections to the overall OC measurement. Samples were analyzed on a Sunset Laboratory Inc. Thermal/Optical Carbon Aerosol Analyzer using the thermal optical reflectance (TOR) and the thermal optical transmittance (TOT) methods using NIOSH Method 5070 as described in the literature.

6.1.8 Intermediate Volatile Organic Compounds (IVOC) and Semi-volatile Organic Compounds (SVOC)

IVOC and SVOC were collected on the same XAD traps used for PAH and NPAH. One half of the extract was analyzed for PAH and NPAH, and the other half was used to determine the IVOC and SVOC by analysis with two-dimensional gas chromatography time-of-flight mass spectrometry (GCxGC-TOFMS), which is illustrated in Figure 32. The XAD sample extracts for IVOC and SVOC were further diluted by a factor of 4 prior to GCxGC-TOFMS analysis. This dilution resulted in a final effective volume (FEV) of 60mL. An aliquot of the sample extracts was spiked with internal standard such that the concentrations of the deuterated compounds were at 1.0 ppm in the diluted extracts.

FIGURE 32. GC X GC ANALYTICAL SCHEMATIC



The two-dimensional gas chromatography time-of-flight mass spectrometry (GCxGC/TOFMS) analysis was performed using an Agilent 7890 gas chromatograph coupled to a PEGASUS 4D-TOFMS (LECO, St. Joseph, MI). Injection volume was 1.0 µL. The inlet temperature was 280°C, and the inlet mode was splitless with a 1-minute purge. The transfer line temperature was set to 300°C. Separation was achieved using two columns. The primary column (first Dimension) was a RXi-1MS (30 m × 0.25 mm × 0.25 µm; Restek, Bellefonte, PA) and the second column (second Dimension) was a RXi-17SilMS, (1.5 m × 0.18 mm × 0.18 µm; Restek, Bellefonte, PA). The first column was held at 50°C for 3 minutes, ramped to 290°C at a rate of 8°C/min, ramped to 300°C at a rate of 20°C/min and held for 3 minutes. The second column and modulator were offset by 5 and 20 degrees Celsius, respectively. Helium carrier flow was set to constant flow at 1.0 mL/min. The modulation period was 4 seconds (1.0 s hot, 1.0 s cold with

2 cycles per modulation period) through entire run. The mass spectrometer was operated using electron ionization (EI) at 70eV. Spectra were collected from 40–650 m/z with a scan time of 100 spectra/sec. Sensitivity was checked by verifying a signal to noise ratio (S/N) of 10 with 2 pg of hexachlorobenzene on-column.

A multi-component standard was assayed using the Detailed Hydrocarbon Analysis (DHA) ASTM Methods D6729, D6730 and D6733 paraffins, iso-paraffins, aromatics, naphthenes and olefins (PiONA) reference standard (Restek Cat. no 30730, Bellefonte, PA) spiked with pristine, phytane, and additional n-alkanes providing retention definition of carbon numbers up to C_{32}. Data was processed using LECO's Chromatof software to integrate peaks and to quantify them against the reference standard or identify them based on National Institute of Standards and Technology (NIST) library searching (for compounds not in the calibration curve). Chromatof classification regions were used to define areas of the chromatogram where specific classes of compounds tend to elute.

6.2 Detailed Emission Characterization Results

A summary of the results of the Chemical characterizations is given below for each analysis component. Detailed individual results by compound and by test will be supplied to CARB in spreadsheet format, and these detailed results are far too expansive to include in this report. Results are given for both engines, and comparisons between the DPF and on-DPF engine are also given.

6.2.1 VOC and Carbonyl Results (C_1 to C_{12})

The results of the bag VOC and impinger-based carbonyl (aldehyde and ketone) results are typically combined under a single report detailing light-end HC emissions speciation. Detailed summary reports of the results by test and by compounds were supplied in spreadsheet form. A summary of the results for both engines is given in the figures below in several formats. A breakdown of the results by Carbon Number for both engines is given in Figure 33 on a brake-specific mass basis, and in Figure 34 on the basis of relative contribution to the total C_1 to C_{12} mass. Figure 35 shows a breakdown of these results by Hydrocarbon Class on a brake-specific mass basis, while Figure 36 shows a similar breakdown by relative contribution to the total C_1 to C_{12} mass. In these figures, Engine 1 is the 6068 (DPF-equipped) engine, and Engine 2 is the 4045 (non-DPF) engine.

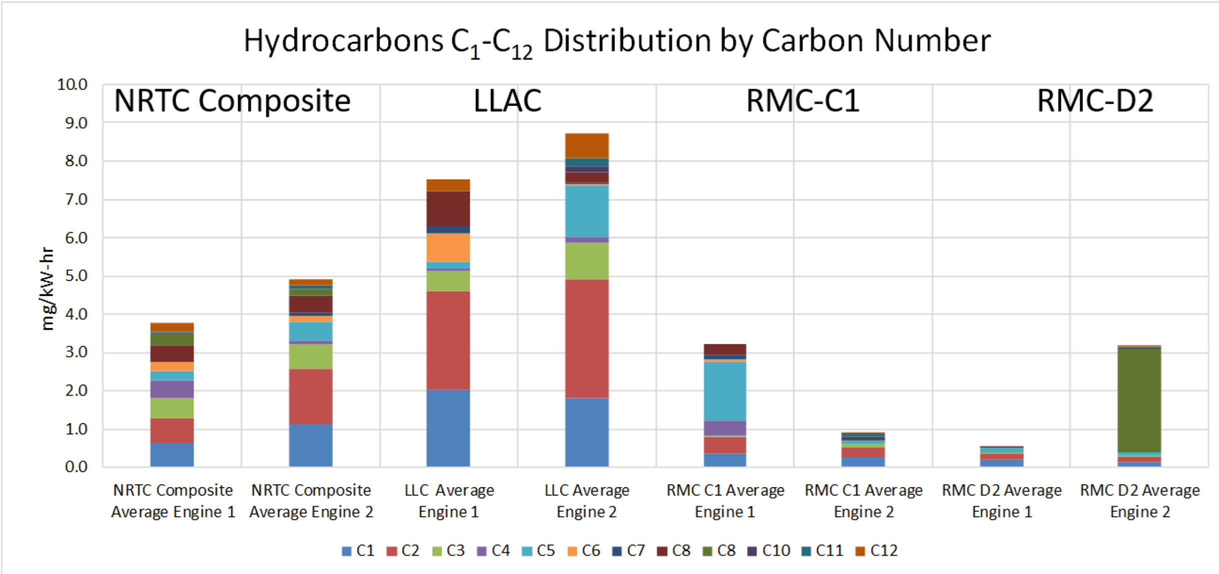


FIGURE 33. VOC AND CARBONYL MASS RESULTS BY TEST CYCLE AND CARBON NUMBER

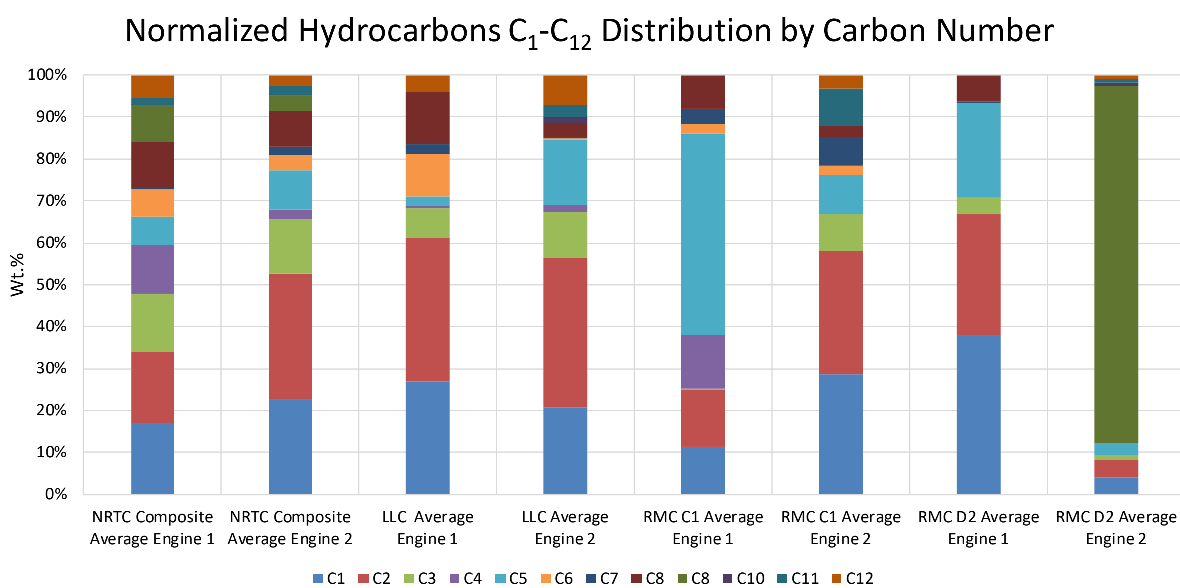


FIGURE 34. VOC AND CARBONYL RELATIVE CONTRIBUTIONS TO TOTAL MASS BY TEST CYCLE AND CARBON NUMBER

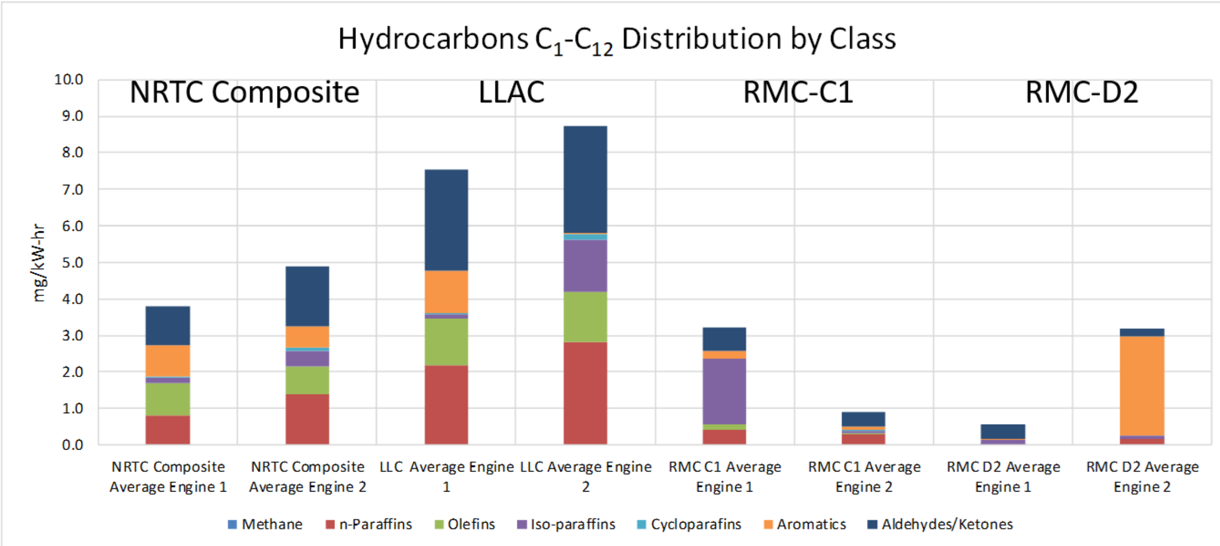


FIGURE 35. VOC AND CARBONYL MASS RESULTS BY TEST CYCLE AND HC CLASS

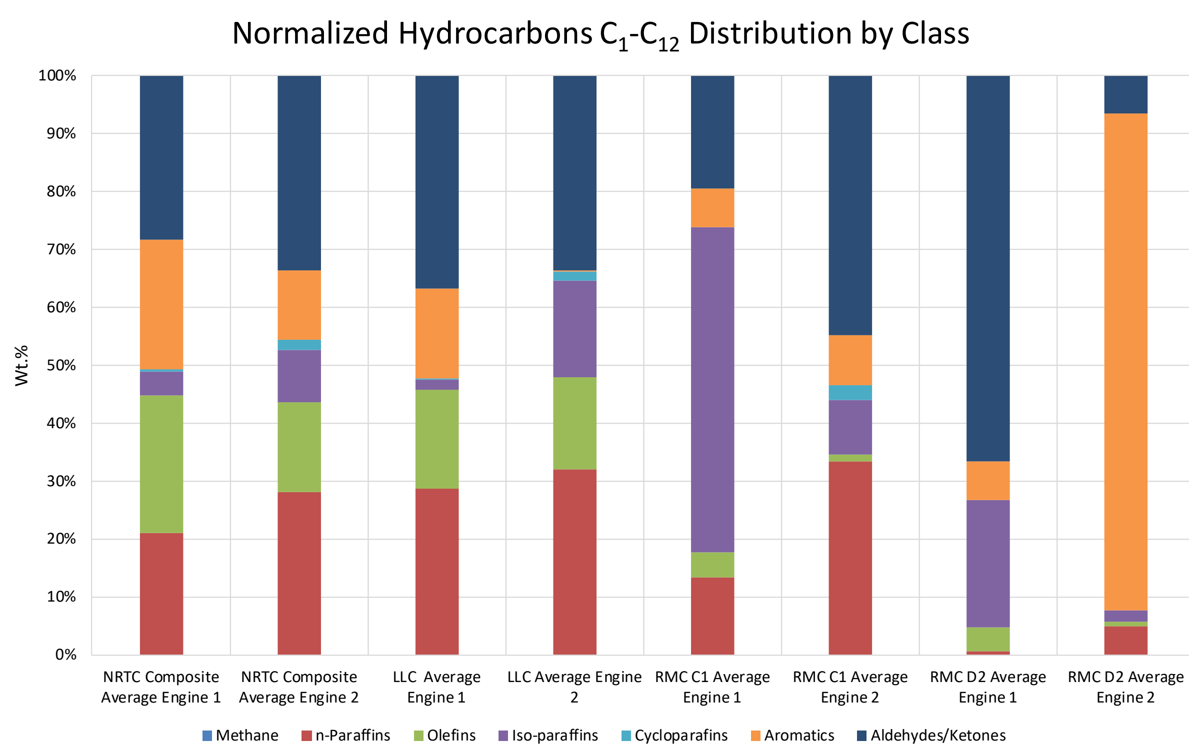


FIGURE 36. VOC AND CARBONYL RELATIVE CONTRIBUTIONS BY TEST CYCLE AND HC CLASS

Looking at the VOC results overall, there are several trends that emerge. First, the summed values for all of these results are less than 0.01 g/kw-hr, with the LLAC having the highest total tailpipe HC emissions. For the both engines the sum of the C_1 to C_{12} speciated hydrocarbons, not including formaldehyde (which does not appear on FID-based HC measurements), represents about half of the measured tailpipe THC. This is a fairly typical result, with the remaining hydrocarbons in a diesel engine generally being too heavy to be capture via unheated bag sampling. Hydrocarbon levels were generally lower on the DPF-equipped engine for the various transient cycles (NRTC and LLAC), although in both cases the aftertreatment system was about 95% efficient in removing engine-out HC emissions. Transient VOC emissions were generally mostly composed of lighter-end HCs, with 50% accounted for by C_1 and C_2 HCs, and 75% accounted for up to about the C_4 to C_5 range. In terms of HC type, the majority the transient VOCs were relatively evenly split between n-paraffins, olefins, and aldehydes, with a smaller portion composed of aromatics, and very little contribution from iso-paraffins and cycloparaffins. VOC emissions were much lower on the steady-state RMC cycles, and showed more variations regarding carbon number and composition trends, likely due to the very low levels.

6.2.2 PAH and Nitro-PAH Results

Detailed reports of the PAH and nitro-PAH emissions by test and compounds were provided in spreadsheet form. The data are summarized below by compound for both engines over a variety of cycles. Generally, these summary charts show results combining PAH emissions for both the semi-volatile phase (collected on XAD-2 traps) and the particulate phase (collected on Zefluor filters), unless noted otherwise for a specific comparison. The results are generally the average of three tests, although certain cycles (such as the D.2-cycle) are only be the average of two samples as noted earlier in the experimental matrix. All of the results shown are background corrected values. The error bars on these charts all show one standard deviation. All of the PAH results are reported in ng/kw-hr unless otherwise noted.

Figure 37 shows brake-specific emission levels for PAH emissions on the both the cold-start and hot-start NRTC cycle for the 6.8L engine. The values are display on a logarithmic scale due to the wide range of values, which span over several orders of magnitude between the lighter semi-volatile PAH compounds, often observed on the order of 10s of μg/kw-hr and the heaviest particle phase PAH compounds, often observed on the order of 10s of ng/kw-hr. A similar summary for the 4.5L engine is given in Figure 38. For both engines cold-start PAH emissions were higher than hot-start PAH emissions, although the separation between cold-start and hot-start PAH levels is smaller for the 6.8L (DPF) engine. There are also noticeable gaps in the particle phase PAH data for the DPF-equipped engine and the compounds that remain often have error bars which overlap zero. For the non-DPF engine, particle phase PAH compounds generally all present, and the error bars do not overlap zero, indicating that these compounds are likely present. This would be consistent with expectations for comparing a DPF-equipped engine to a non-DPF engine. For the lighter PAH compounds, the 4.5L non-DPF engine had somewhat lower levels, likely due to overall higher exhaust temperatures at the DOC inlet for those cycles.

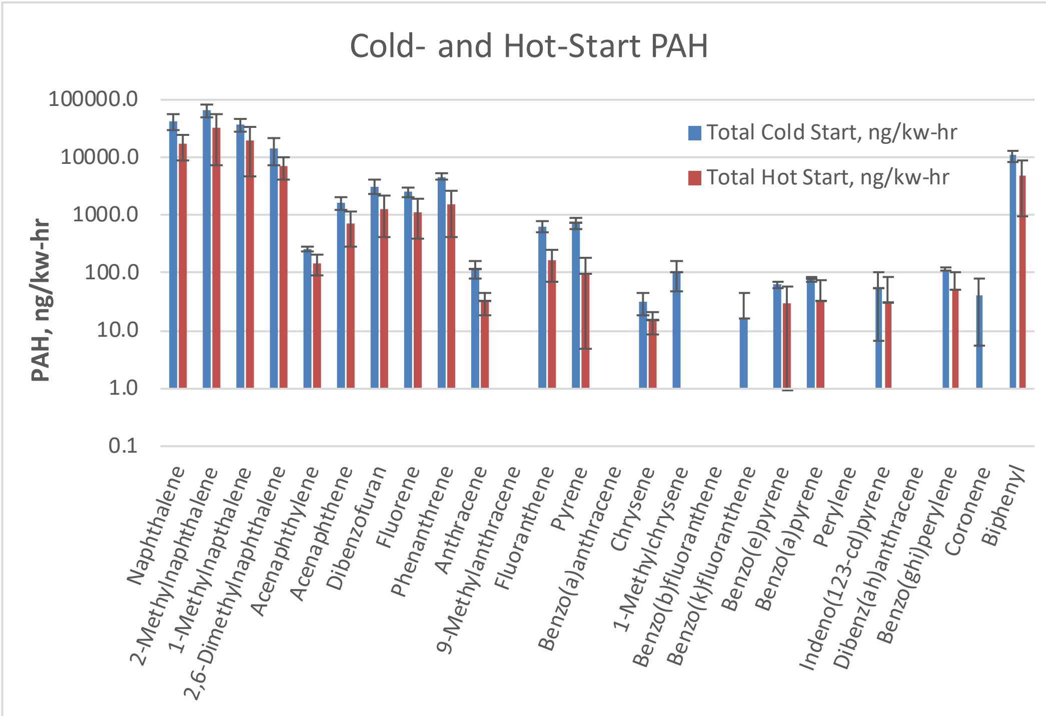


FIGURE 37. PAH BY COMPOUND FOR 6.8L (DPF) ENGINE ON NRTC CYCLE

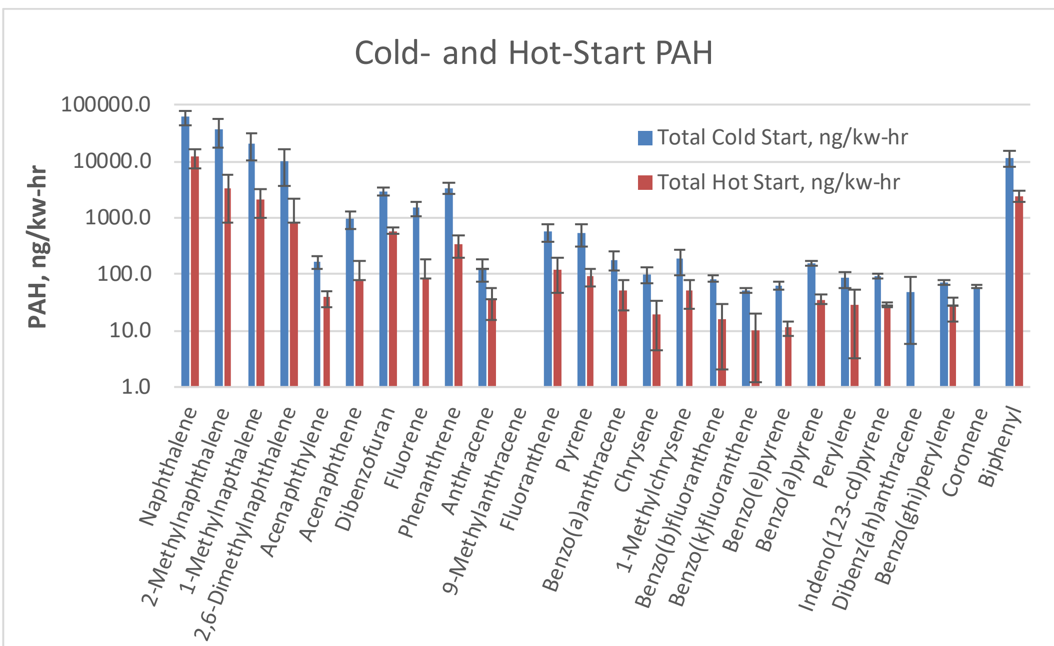


FIGURE 38. PAH BY COMPOUND FOR 4.5L (NON-DPF) ENGINE ON NRTC CYCLE

Nitro-PAH emissions over the NRTC are shown in Figure 39 for the 6.8L engine and Figure 40 for the 4.5L engine. These levels were very small, less than 2.5 ng/kw-hr in all cases, and were the same for both engines. Very little nitro-PAH was detected on any cycle for both engines.

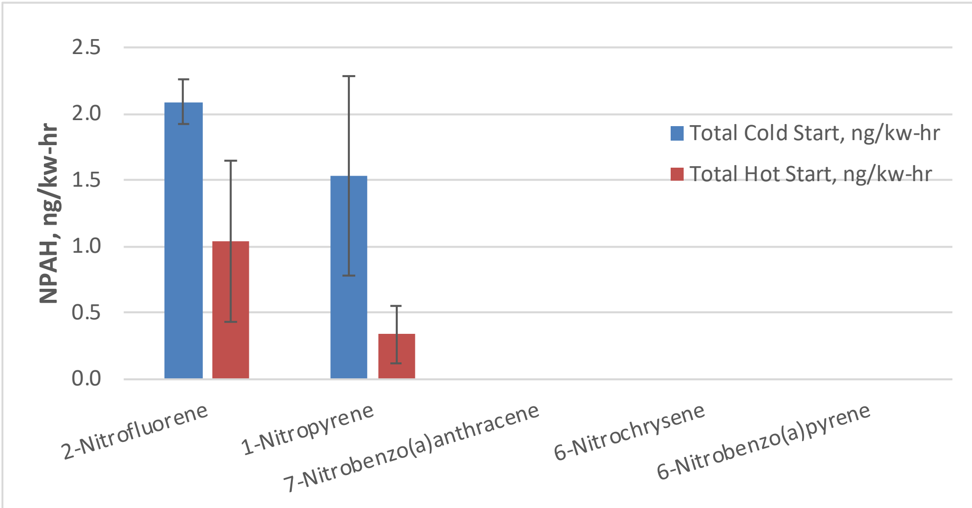


FIGURE 39. NITRO-PAH BY COMOPUND FOR 6.8L (DPF) ENGINE ON NRTC CYCLE

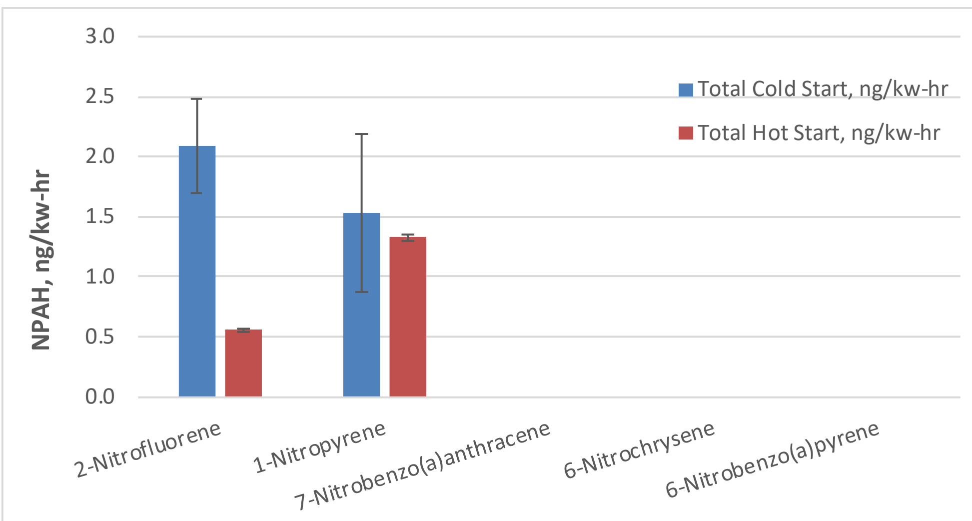


FIGURE 40. NITRO-PAH BY COMOPUND FOR 4.5L (NON-DPF) ENGINE ON NRTC CYCLE

PAH emission summaries for the RMC C1, RMC D2, and LLAC cycles are given in Figure 41 for the 6.8L engine, and in Figure 42 for the 4.5L engine, respectively. For the 6.8L engine, lighter PAHs were similar for all three cycles, while there were essentially no particle phase PAHs detected on any of these cycles. For the 4.5L engine, semi-volatile PAH emissions were generally higher on the LLAC than for the two steady-state cycles, while the particle phase PAHs were generally observed on all cycles. Again, it is noticeable that no particle phase PAHs were detected with the DPF, while the non-DPF shows evidence of particle phase PAHs which are likely transported by the soot particles that are still present in the exhaust of the 4.5L engine.

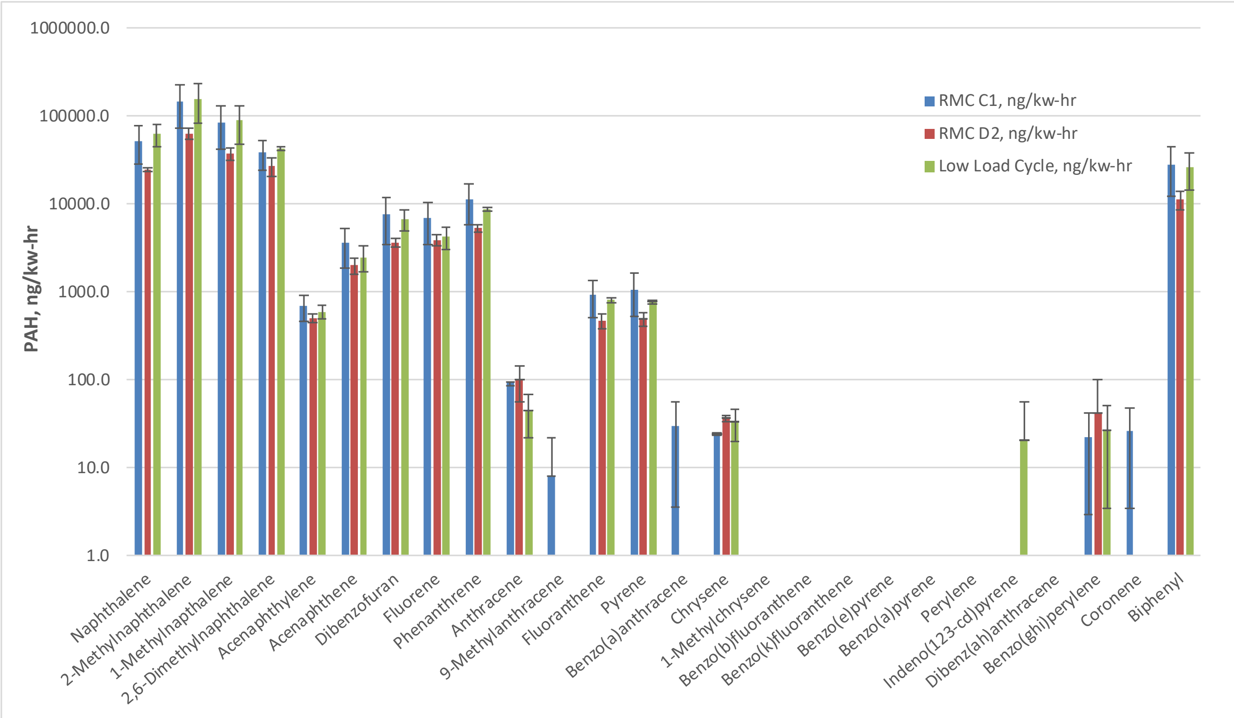


FIGURE 41. PAH BY COMPOUND FOR RMC AND LLAC CYCLES ON 6.8L (DPF) ENGINE

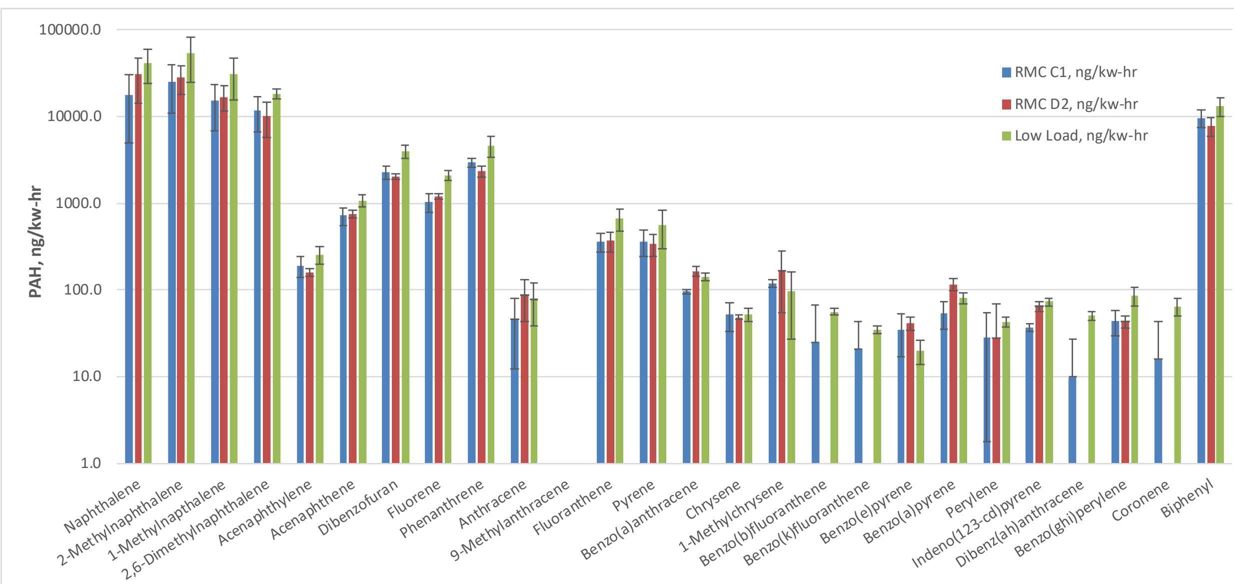


FIGURE 42. PAH BY COMPOUND FOR RMC AND LLAC CYCLES ON 4.5L (NON-DPF) ENGINE

Figure 43 shows a direct comparison of composite NRTC PAH levels between the two engines. Similar comparisons are shown in Figure 44 for the cold-start NRTC, Figure 45 for the hot-start NRTC, Figure 46 for the RMC C1, and Figure 47 for the LLAC, respectively. The RMC-D2 data is not show because that data is very similar to the RMC C1. The data confirm that semi-volatile PAH levels for the NRTC are lower with the 4.5L engine, primarily due to lower hot-start results. They further confirm that some missing gaps and particle phase PAH compounds for the 6.8L engine with the DPF, and the remaining compounds often have error bars that overlap zero, which is not the case for the 4.5L engine.

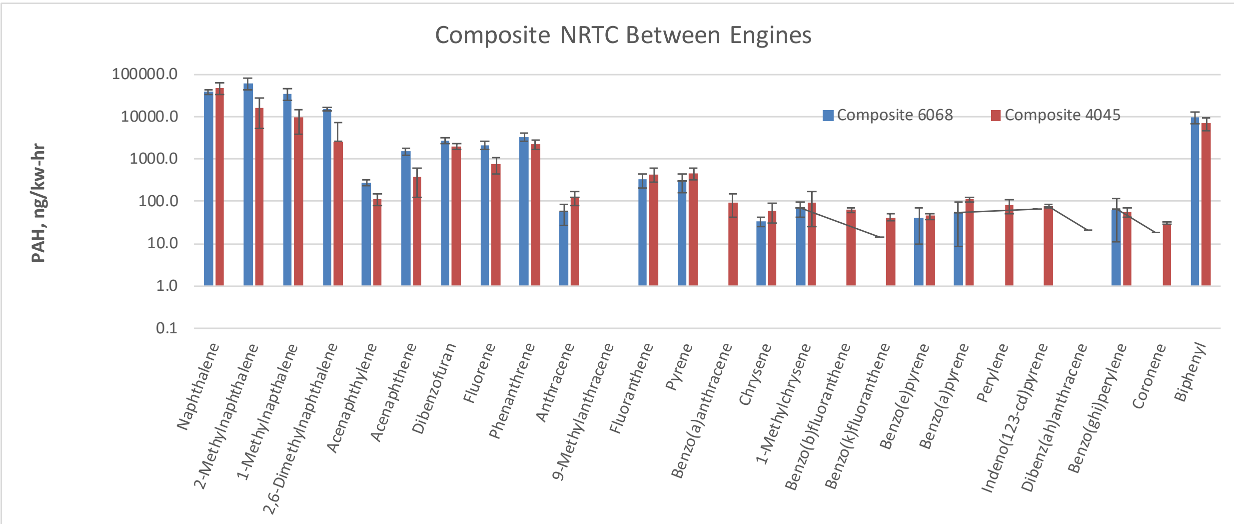


FIGURE 43. COMPOSITE NRTC PAH BY COMOUND – COMPARISON BETWEEN 6.8L (DPF) AND 4.5L (NON-DPF) ENGINE

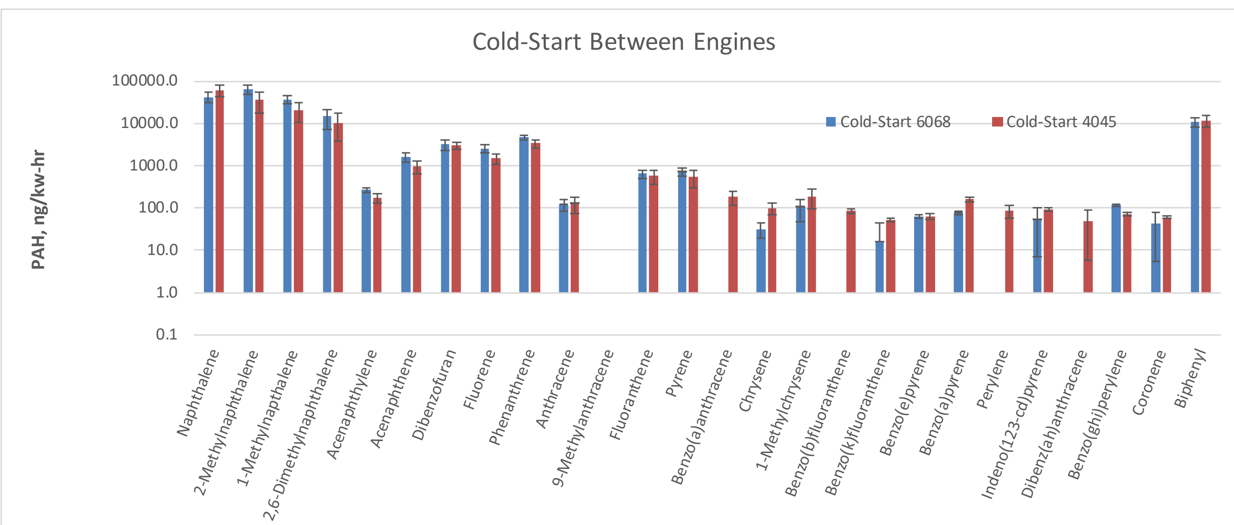


FIGURE 44. COLD NRTC PAH – COMPARISON BETWEEN ENGINES

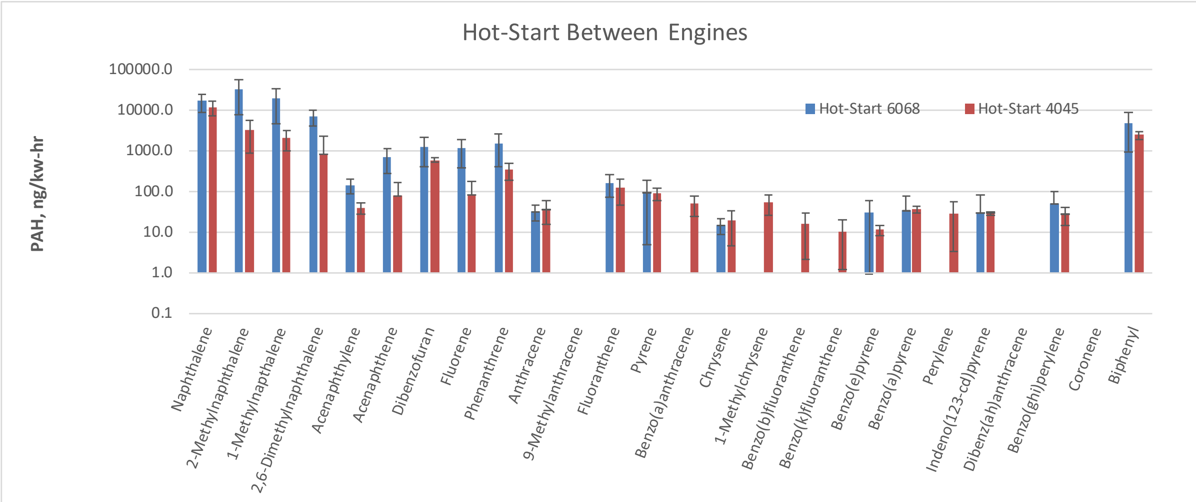


FIGURE 45. HOT NRTC PAH – COMPARISON BETWEEN ENGINES

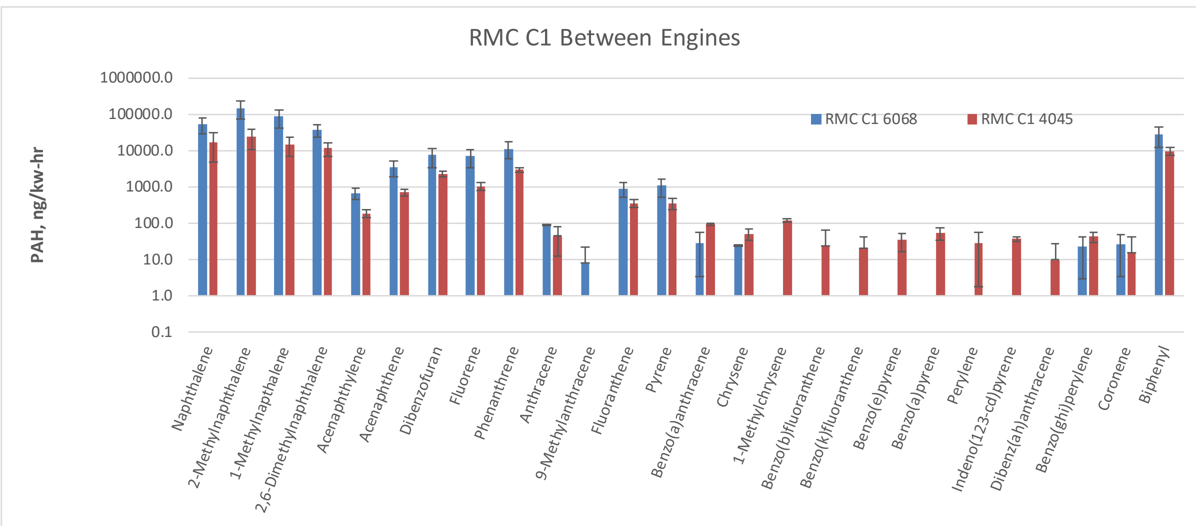


FIGURE 46. RMC C1 CYCLE PAH – COMPARISON BETWEEN ENGINES

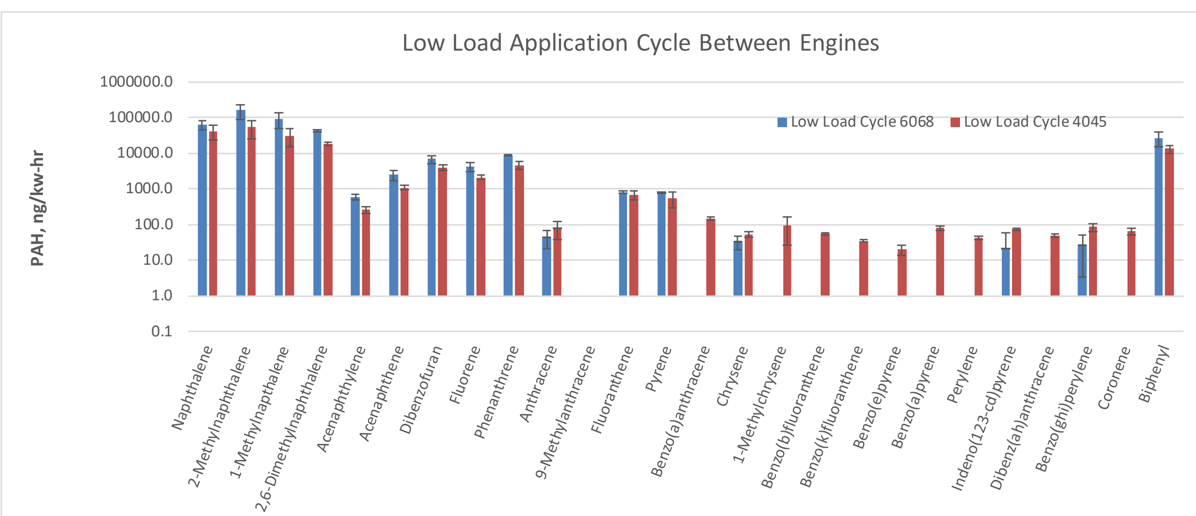


FIGURE 47. LLAC PAH – COMPARISON BETWEEN ENGINES

The remaining comparisons between the engines generally follows the same trends, with the 4.5L engine generally showing lower levels of semi-volatile PAHs, likely due to higher DOC temperatures, while the 6.8L engine shows very little presence of particle phase PAHs due to the presence of the DPF.

Given the discussion of particle phase and semi-volatile phase PAHs, Figure 48 below shows an example of how the PAHs partition by size between the semi-volatile XAD-2 samples and the particle phase Filter samples. The light-end compounds and biphenyl are dominated by the semi-volatile phase, with the partitioning slowly moving until relatively even partitioning is seen in the range of phenanthrene though chrysene (the particular transition point is generally determined by the average temperature observed on the Filter which is located upstream of the XAD-2 cartridges). On the other hand, many of the heavier PAHs are only observed in the particle phase.

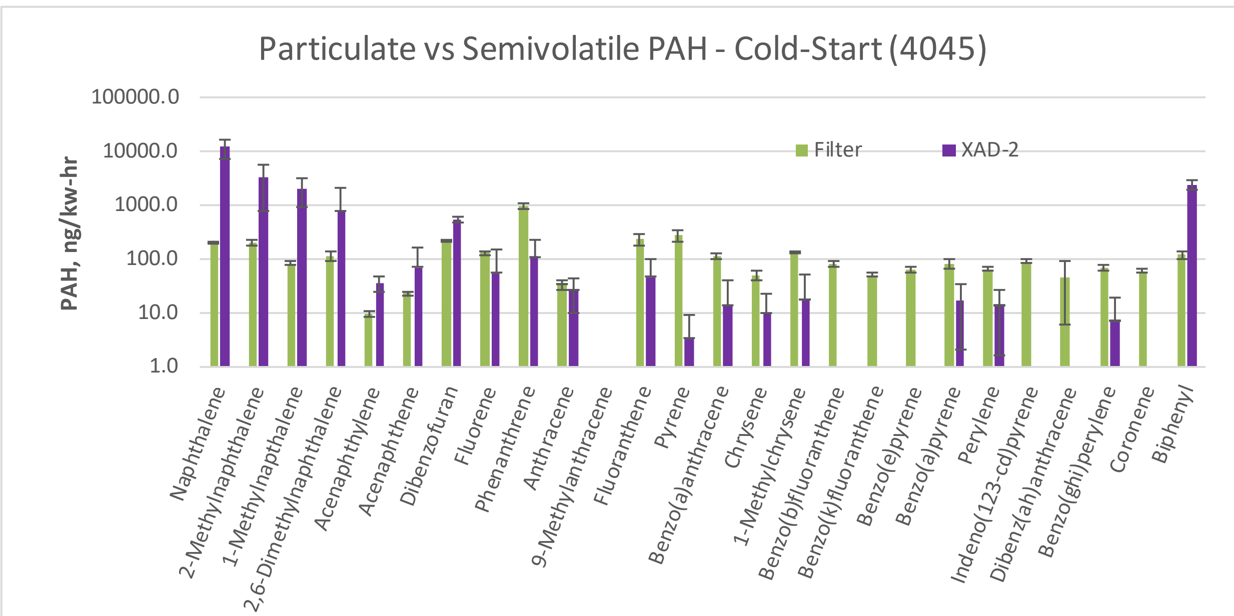


FIGURE 48. EXAMPLE OF PAH PARTITIONING BETWEEN SEMI-VOLATILE (XAD) AND PARTICLE (FILTER) PHASE – 4.5L (NON-DPF) ENGINE COLD NRTC

6.2.4 Trace Metals and Inorganic Ion Results

Most of the trace elements were not detected on either of the two engines. For the 6.8L engine, no trace metals or inorganic ions were detected above the thresholds on any tests.

For the trace metals, it was noted that most of the samples contained trace levels of Nickel (Ni). Aluminum (Al), Silicon (Si), Calcium (Ca), Cerium (Ce), Iron (Fe), Manganese (Mn), and Chromium (Cr) were all detected at trace levels on random single samples for the 4.5L engine, but none were consistently observed across all three test repeats for any given cycle. There was no duty cycle related pattern to these detections. Towards the end of the testing, Iron (Fe) and

Chromium (Cr) (often associated with ring wear) were detected on the Final LLAC test at 0.0005 g/kw-hr for Cr and roughly 0.0025 g/kw-hr for Fe. This is a very small amount of wear metal, likely observed only because this was the non-DPF engine. These observations do highlight the capability of the DPF in capturing even small amounts of metals that might come from the engine, and reducing them to undetectable levels.

The reporting limit for the inorganic ions was 5 µg/filter for Cations and 1 µg/filter for Anions. For the 6.8L (DPF) engine there were no Inorganic Ions detected, either Cations or Anions. For the 4.5L (non-DPF) engine, no Cations were detected. There were a small number of incidental detections of Anions on the 4.5L engine. The Anion data are summarized in Table 16, although it should be noted that these values have a considerable CoV associated with them, generally in excess of 50%. The levels observed are at most on the order of ~0.005 g/kw-hr. The chloride data sets are the result of a single detection on a cold NRTC and therefore likely an anomaly. It is interesting to observe the detection of nitrate on the RMC tests, this could be related to high DEF rates on the higher load RMC, although it should be noted that these are still on the order of 0.001 to 0.002 g/kw-hr. As with the trace metals, it should be noted that although these periodic detections did occur on the 4.5L (non DPF) engine, the DPF eliminated all such incidences on the 6.8L engine. This indicates a qualitative improvement for the DPF-equipped engine in eliminating all traces of inorganic ions from the exhaust.

TABLE 16. INORGANIC ANIONS DETECTED ON 4.5L (NON-DPF ENGINE)

Anions, mg/kw-hr	CNRTC	HNRTC	RMC C1	RMC D2	LLAC
Engine 1					
All Anions	ND				
Engine 2					
Fluoride	ND	ND	ND	ND	ND
Chloride	3.3	4.8	ND	0.6	ND
Nitrate	ND	ND	1.2	2.8	ND
Bromide	ND	ND	ND	ND	ND
Nitrite	ND	ND	ND	ND	ND
Phosphate	ND	ND	ND	ND	ND
Sulfate	1.1	ND	ND	ND	0.6
ND = Not Detected					

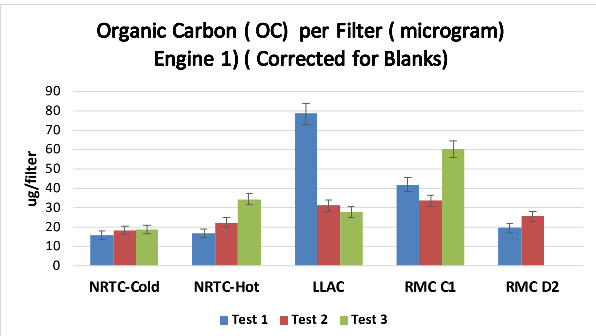
6.2.5 Water Soluble Organic Compounds (WSOCs) Results

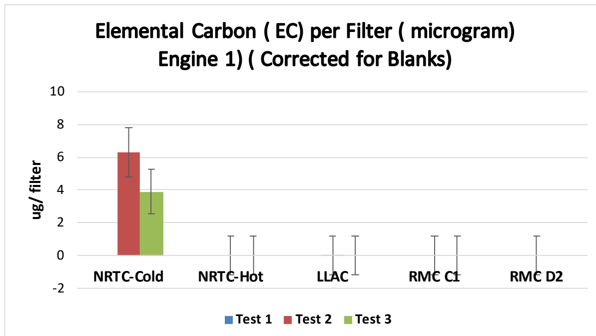
The reporting limit for WSOCs was 2 mg/kw-hr. No WSOCs were detected above this reporting limit on either engine. It should be noted that Diethylphthalate was detected on the 4.5L engine on a number of samples, but it was also detected at similar levels on the associated laboratory blank sample. Diethylphthalate is typically a laboratory contaminate, and would likely be eliminated by normal blank subtraction. Therefore, calculations of a brake-specific mass rate were not performed. The analysis note that several compounds were marked as "tentatively identified," but these could not be quantified above the reporting limit.

6.2.6 PM Elemental Carbon / Organic Carbon (EC/OC) Results

EC/OC analysis of the quartz filters produced two very different data sets for the two engines, as would be expected given that one engine had a DPF and the other did not.

EC / OC data for the 6.8L engine is summarized in Figure 49. For the 6.8L (DPF) engine, very little elemental carbon was identified on any samples, and the only samples which shows any elemental carbon were from the cold-start on two out of three samples at low levels. It is possible that this was related to analytical noise. The fact that the small amount of PM observed is dominated by the OC fraction is anticipated for DPF-out PM.





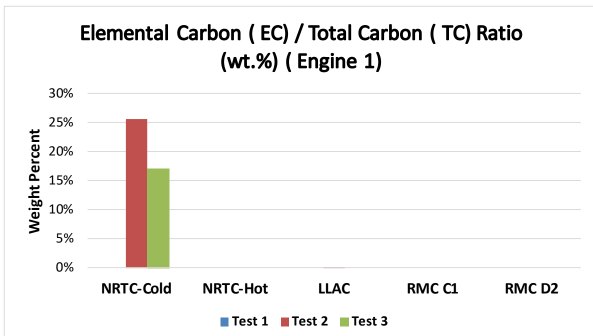


FIGURE 49. EC / OC SUMMARY FOR 6.8L (DPF) ENGINE

EC / OC data for the 4.5L (non-DPF) engine is summarized in Figure 50. The data indicate a fairly consistent elemental carbon portion of 55 to 65 percent, which is not atypical for a Tier 4 non-DPF engine the complies with the 0.02 g/kw-hr standard. Typically, on these engines, a good portion engine-out OC is removed by the DOC, and soot levels are usually relatively low in order to comply with the standard.

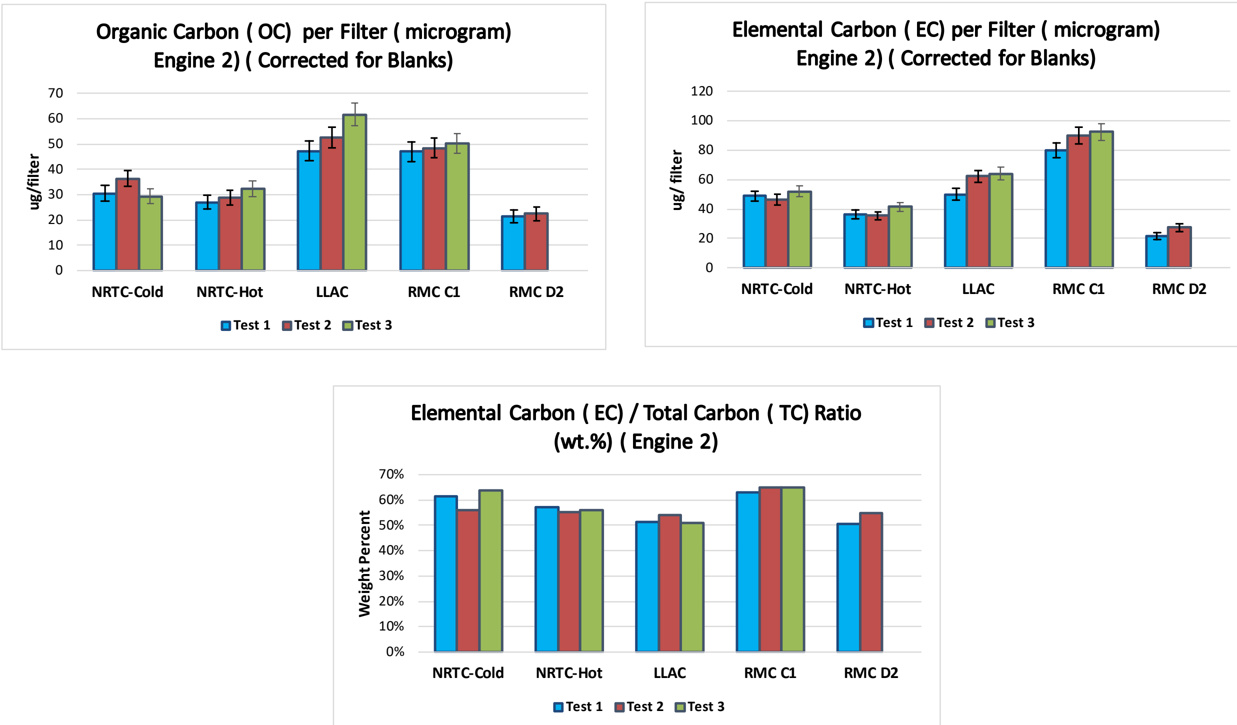


FIGURE 50. EC / OC SUMMARY FOR 4.5L (NON-DPF) ENGINE

6.2.7 SVOC / IVOC (GC x GC Analysis) Results

The analysis of SVOC and IVOC compounds by GCxGC-TOFMS produced a very large quantity of data characterizing semi-volatile and intermediate hydrocarbons, with reports often containing thousands of identified hydrocarbon compounds. To allow for interpretation, the data is generally collected into summaries by Carbon Number and Hydrocarbon class. Given the semi-volatile nature of the sampling, the bottom end range observed in these samples is around C_9, with the top end of compounds that could be classified being observed around C_{22}. It should be noted that heavier compounds are observed but they can no longer be effectively separated and are lumped into a general category of “heavy boilers > C_{26}.”

However, it is also useful to visualize the raw data in form of a graphical “heat map,” which shows the relative intensity of response in a particular region of the 2-D space mapped by the results obtained by the analysis. The x-axis of this map which corresponds to the first column separates the compounds by boiling point (analogous to Carbon Number) increasing from left-to-right, while the y-axis of the map depicts polarity of the HC compounds increasing from bottom-to-top. Comparison of these maps can help to identify. Figure 51 and Figure 52 show example maps for a cold-start NRTC sample from the 6.8L and 4.5L engines, respectively. For the 4.5L engine, there are several regions in the middle of the boiling point range that show much higher intensity than for the 6.8L engine. A look at the later summaries indicates significantly higher measured responses for substituted benzenes, PAHs, midrange compounds, and to some extent branched alkanes in the C_{18} to C_{20} range. This is one example of the many comparisons that can be made with this data. These comparisons are qualitative in nature, and can be useful for identifying large differences in response for a given group of hydrocarbons, composition differences, or classes of compounds that exist in one sample and not the other. Maps are provided for all of the test results were provided separately, only an example is show in this report for space reasons.

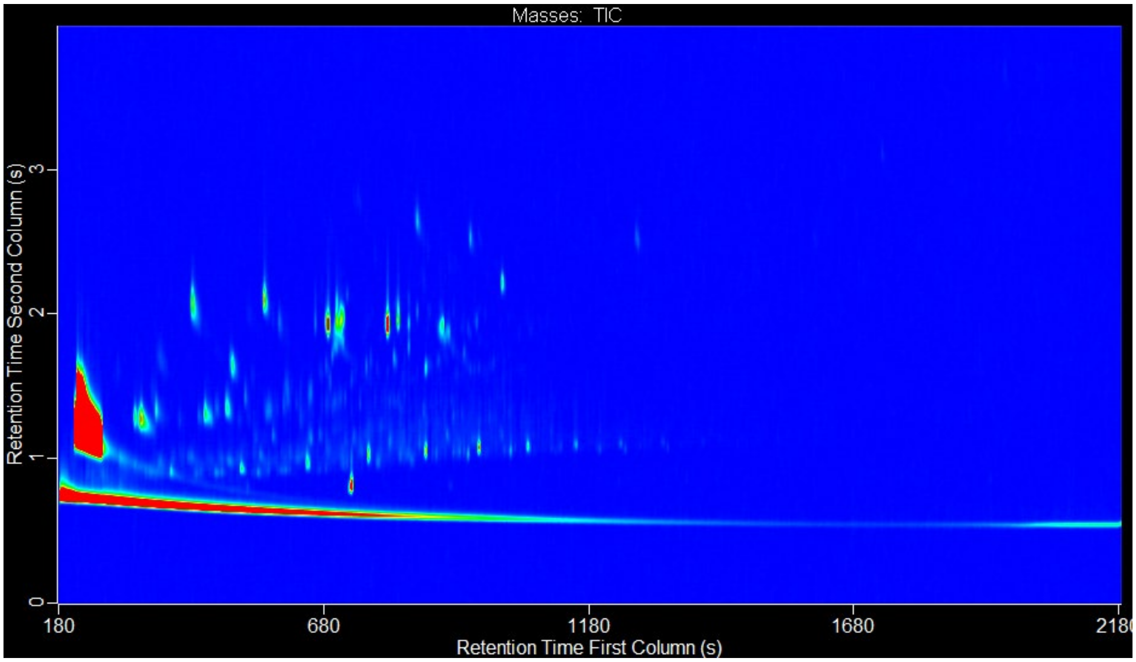


FIGURE 51. EXAMPLE GC X GC VISUALIZATION FOR 6.8L (DPF) ENGINE COLD NRTC

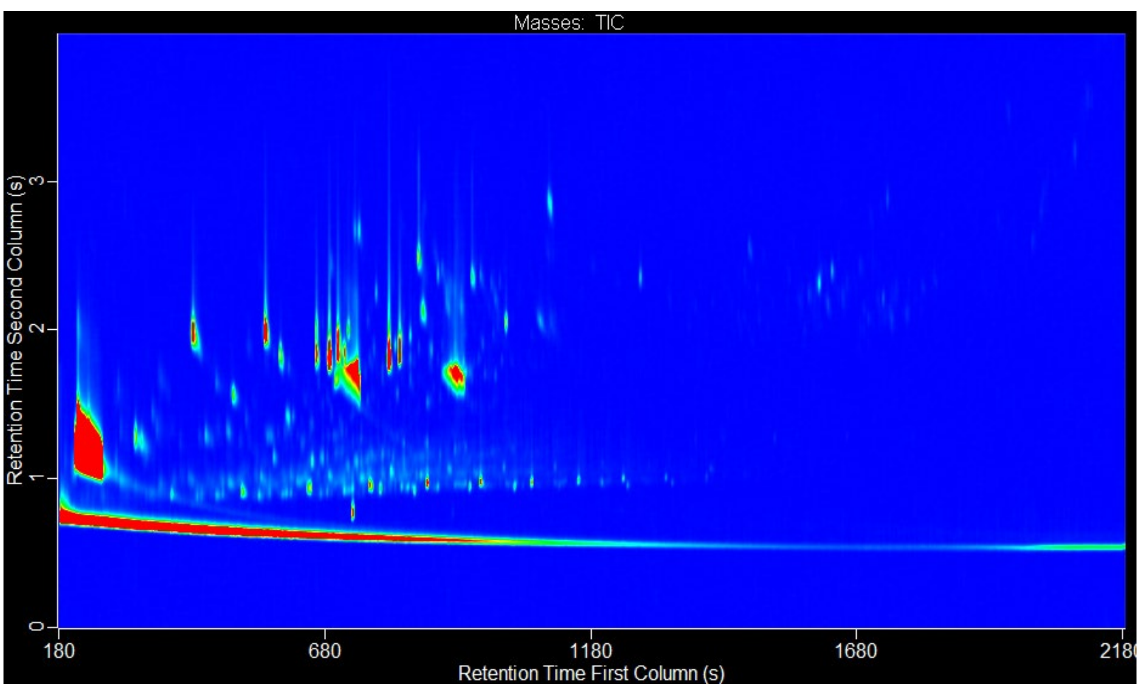


FIGURE 52. EXAMPLE GC X GC VISUALIZATION FOR 4.5L (NON-DPF) ENGINE COLD NRTC

Quantitative summary data for both engines is presented in the following charts, allowing for comparison of results between engines on the different test cycles. Results are shown in summed ng/kw-hr a given carbon number and HC class, and they are shown in a logarithmic scale given that the results span 4 to 5 orders of magnitude, with higher quantities generally seen at the lower end, though not always for certain classes of compounds. Overall, these values are on the order of 0.1 to 1 mg/kw-hr at the upper end, with summed total masses for all identified compounds on the order of between 0.01 g/kw-hr and 0.04 g/kw-hr, depending on test cycle and engine. These numbers are comparable to overall THC emission rates.

Summaries are given in Figure 53 for the cold-start NRTC cycle, Figure 54 for the hot-start NRTC cycle, Figure 55 for the RMC C1 cycle, Figure 56, for the RMC D2 cycle, and Figure 57 for the LLAC cycle respectively. Generally, the results indicate higher emission rates for some hydrocarbons the 4.5L engine on the cold-start NRTC, as noted earlier, but comparable or slightly lower rates on the hot-start NRTC, likely due to higher DOC temperatures. The RMC C1 cycle similarly shows lower HC rates for the 4.5L engine, though not in certain classes of compounds such as substituted benzenes and PAHs. Interestingly the RMC D2 cycle does not show this same trend, with HC rates between the two engines being similar, except for increases on the substituted benzenes and PAHs. The LLAC generally showed comparable results both engines on all classes of compounds. Given the sheer complexity of these results, significantly more analysis effort will be required to extract more detailed emission performance trends.

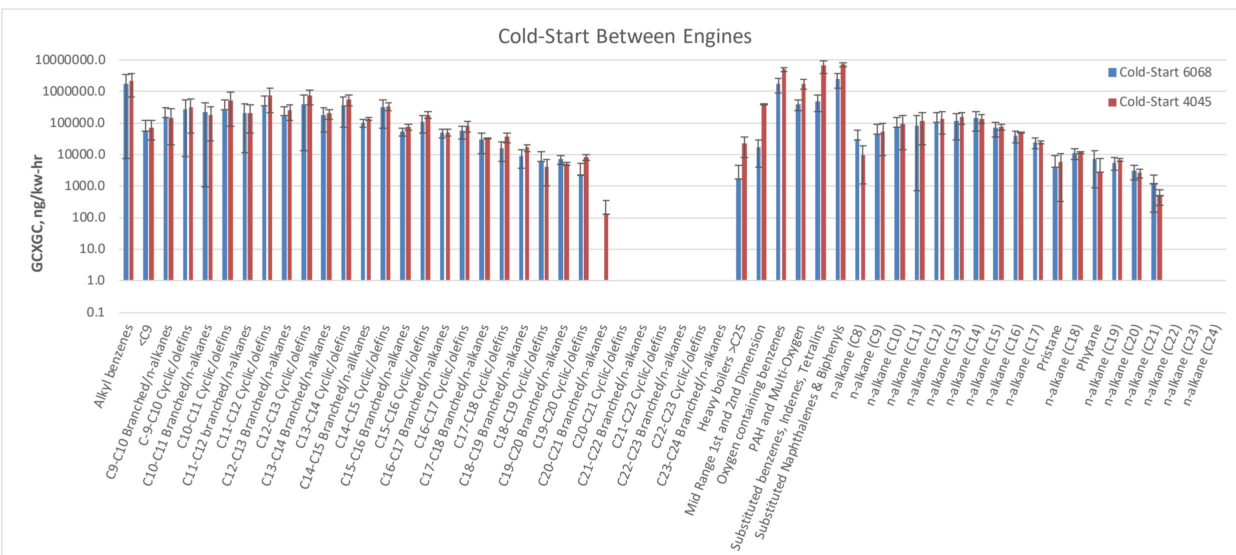


FIGURE 53. GC X GC RESULT BY HC CLASS FOR COLD NRTC – ENGINE COMPARISON

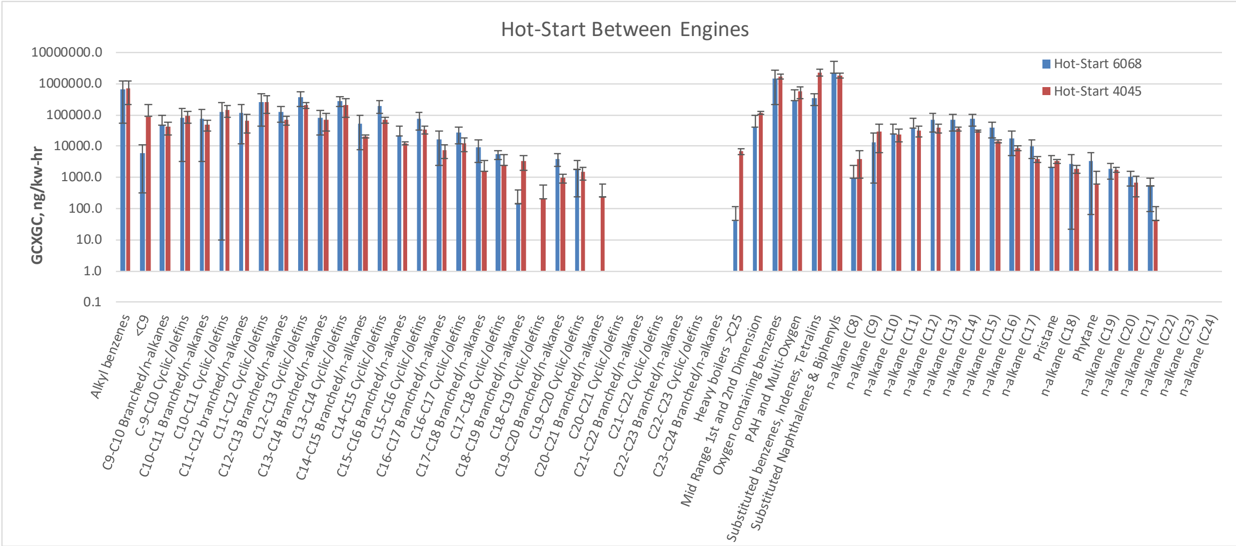


FIGURE 54. GC X GC RESULT BY HC CLASS FOR HOT NRTC – ENGINE COMPARISON

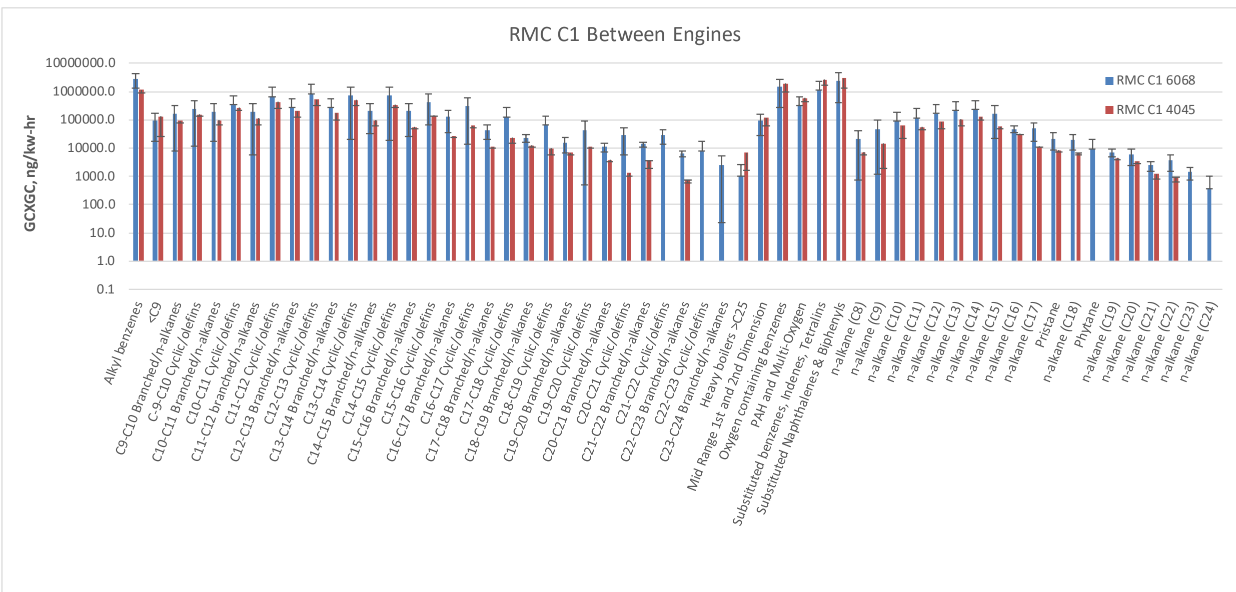


FIGURE 55. GC X GC RESULT BY HC CLASS FOR RMC C1 CYCLE – ENGINE COMPARISON

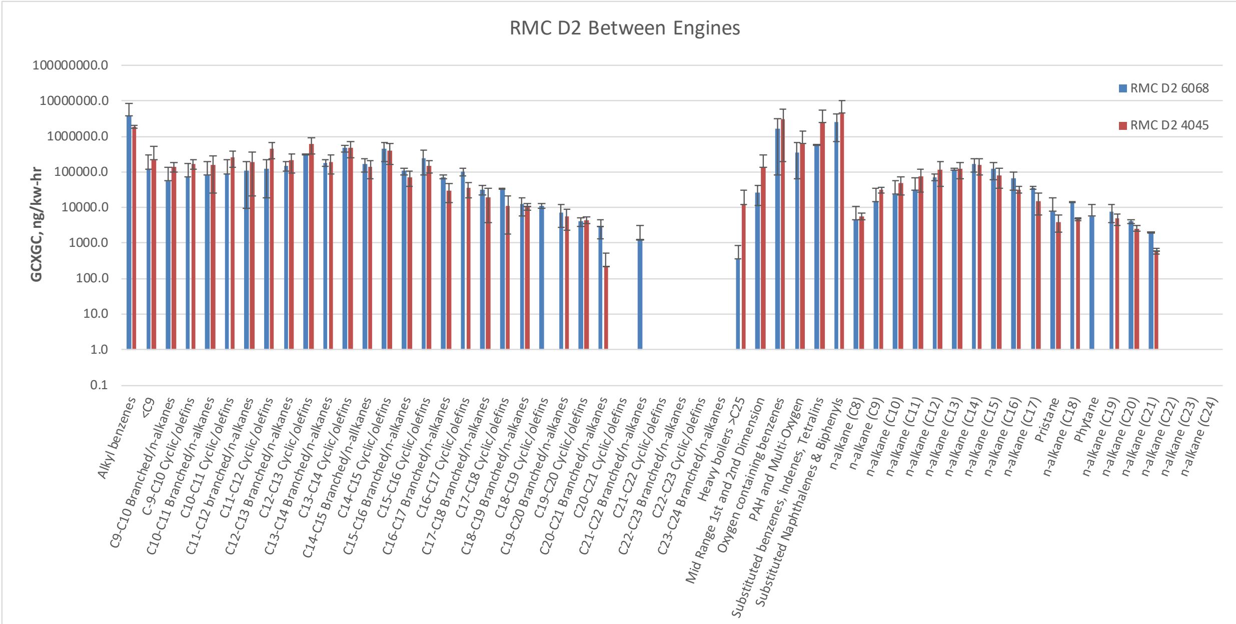


FIGURE 56. GC X GC RESULT BY HC CLASS FOR RMC D2 CYCLE – ENGINE COMPARISON

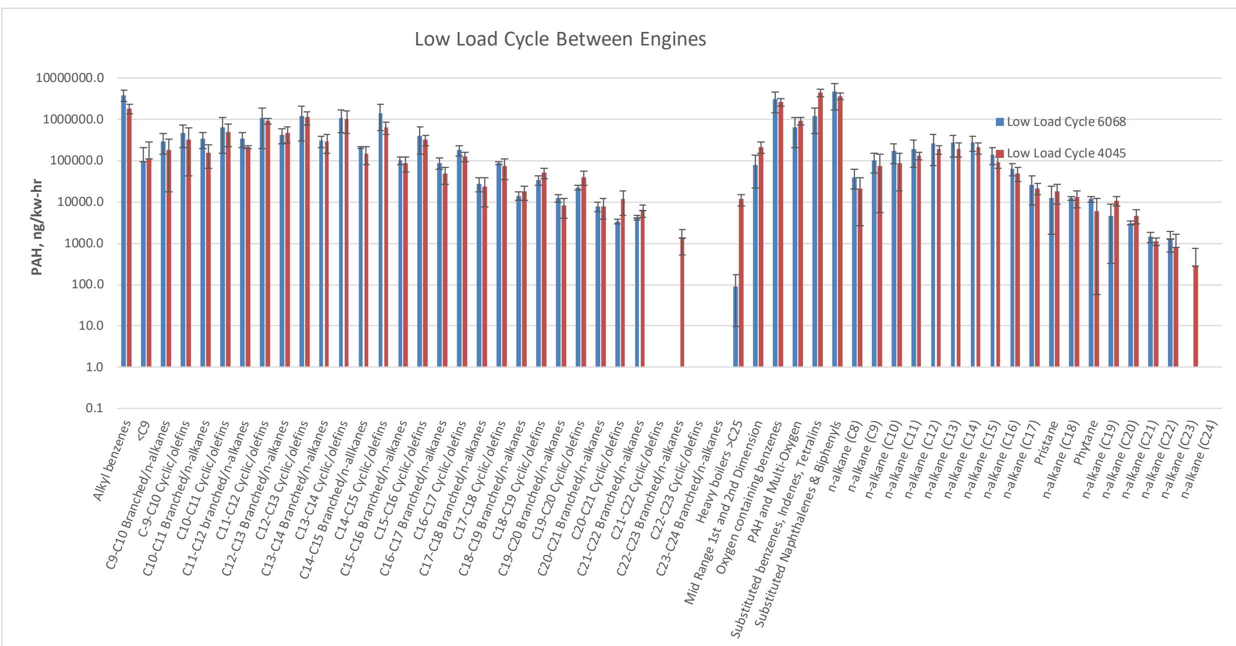


FIGURE 57. GC X GC RESULT BY HC CLASS FOR LLAC CYCLE – ENGINE COMPARISON

7.0 TASK 5 – NUMERICAL SIMULATION OF POTENTIAL LOW NO_X PATHWAYS

7.1 Modeling Background

This task of the program was focused on screening various aftertreatment system configurations and aftertreatment system sizes. The primary objective of the numerical simulation was to evaluate the benefits in-between the conventional aftertreatment system. All inputs for the numerical simulation were based on production or production intent devices and technologies. The simulation-optimization was based on a ranking system which included the following in the priority order:

- Tailpipe NO_X performance
- Aftertreatment System Complexity
- Aftertreatment System Durability
- The overall cost of the aftertreatment system

To examine pathways for a potential 90% reduction in NO_X from the current Tier 4 standards, it was necessary to establish tailpipe emission performance design targets for the modeling effort. The calculations for the base effort are described in Table 17 below. The calculation assumes a final end-of-life target with a 20% margin to the standard, and based on observations from the Stage 3 on-road program, builds in an assumption of 0.5% loss of NO_X conversion on the NRTC/RMC and 1% loss of NO_X conversion on an eventual low load cycle. For now, the LLAC is used as the surrogate for an eventual Off-road LLC. Based on these calculations target tailpipe levels of 0.12 g/kw-hr are set for the cold NRTC, 0.012 g/kw-hr for the hot NRTC, and 0.045 g/kw-hr for the LLAC.

TABLE 17. TAILPIPE TARGET CALCULATION FOR OFF-ROAD LOW NOX MODELING EFFORT

		NRTC			
		5%	95%		
		Cold	Hot	RMC	LLC
		g/kw-hr	g/kw-hr	g/kw-hr	g/kw-hr
	Standard	0.04		0.04	0.12
Certification Targets	Engine-Out	3.1	3.1	3.1	5.0
	Conversion	**96.0%**	**99.6%**	**99.6%**	**99.1%**
	Tailpipe	**0.124**	**0.012**	**0.012**	**0.045**
	TP Composite		**0.018**		
	EO Composite		**3.1**		
	Composite Conversion		**99.4%**		
FUL Compliance	FUL Conversion	**95.2%**	**99.2%**	**99.1%**	**98.1%**
	FUL Tailpipe	0.149	0.025	0.028	0.095
	FUL Composite Conversion		**99.0%**		
	IRAF		0.003	0.003	
	Final TP Composite		**0.034**	**0.031**	**0.095**
	Margin to Standard		16%	24%	21%
	FUL Durability Loss Margin		**0.40%**	**0.50%**	**1.00%**
Urea Consumption Relative to Fuel					2.6%

Table 18 shows the baseline engine out and tailpipe emissions collected in a dynamometer test cell for the John Deere 6.8L engine aftertreatment system. Under the Low NO_X emissions controls strategy, the cold-start emissions become a primary point of focus. To achieve Low NO_X emissions, cold-start NRTC emissions were targeted at 0.12 g/kW-hr at the tailpipe, while hot-start NRTC emissions were targeted at 0.012 g/kW-hr. No changes were made to the baseline engine exhaust conditions at the numerical simulation's initial stages.

TABLE 18. BASELINE NO_X ENGINE EMISSIONS AND CONVERSION EFFICIENCIES

Test Cycle	$BSNO_X$ [g/kW-hr]		NO_X Conversion Efficiency [%]
	Engine Out	Tailpipe	
Cold NRTC	**3.1**	**0.39**	**87.2%**
Hot NRTC	**3.0**	**0.08**	**97.3%**
LLAC	**5.2**	**1.7**	**67.3%**

The aftertreatment dimensions are shown in Table 19. Additional catalyst details and chemical kinetics are proprietary to the Original Equipment Manufacturer and were not shared in this report. It should be noted than an Ammonia Slip Catalysts (ASC) is also assumed to be part of the final configuration for real-world slip control, however this was not part of the simulation. Instead the approach was to target SCR-2 ammonia slip levels that were at or below levels that could easily be handled by a modern dual-layer ASC. This simplified the kinetic modeling effort.

TABLE 19. BASELINE AFTERTREATMENT SYSTEM CATALYST DIMENSIONS

Catalyst Substrate	Diameter	Length	Cell / $inch^2$
	(inches)		
DOC	9.5	5.25	400
DPF	9.5	7.0	200
DEF Mixer and Pipe	4	30	-
SCR-1	11.5	5	400
SCR-2	11.5	6.5	400

7.2 Simulation Approach

The numerical simulation task was divided into two major groups:

1. Thermal Model: Catalyst bed temperature based on an optimized GT-Suite based Thermal Modeling
2. Chemical Model: Chemical Modeling based on the Stage 3 Low NO_X controls developed by Southwest Research Institute

7.2.1 Thermal Model

GT Suite based default thermal model was optimized to account for the thermal variations from the ambient temperature, the specific heat capacity of the catalyst, insulation material, and metal cladding. An optimized thermal model will predict the catalyst bed temperatures close to a real-world operation, which will then be used for exhaust species reaction calculations to predict the simulated tailpipe emissions. Turbo Outlet chemical species and turbo outlet temperatures data set were used to predict the catalyst inlet and out temperatures. Figure 58 below depicts the comparison of the temperature profile from the GT-Suite based Thermal model vs. the dynamometer test cell data for a Light Load Application Cycle (LLAC), while Figure 59 and Figure 60 shows the Thermal Model accuracy for an NRTC cycle for the DOC and SCR catalysts, respectively.

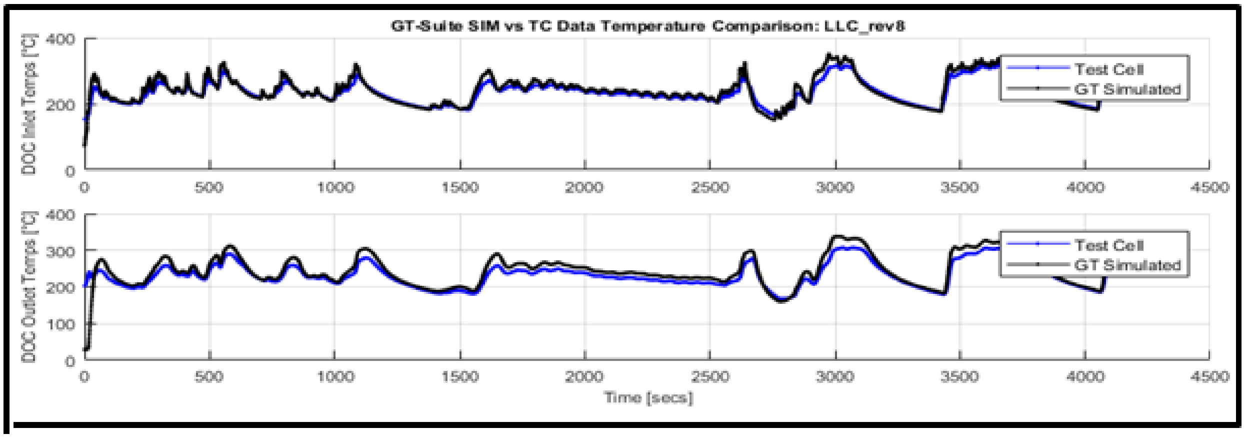


FIGURE 58. LLAC: GT SUITE THERMAL MODEL TEMPERATURE COMPARISON

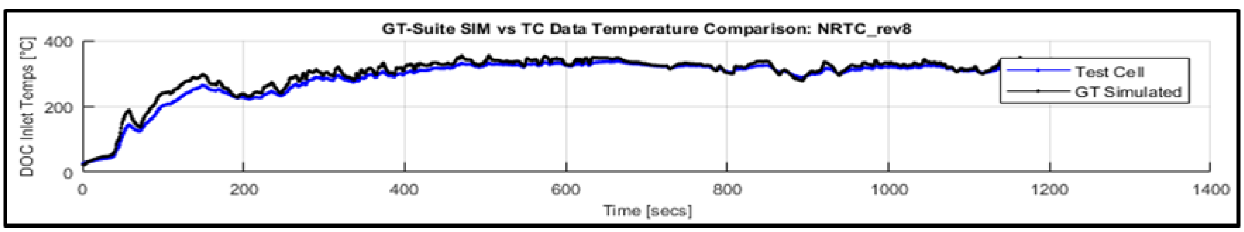


FIGURE 59. NRTC - DOC: GT SUITE THERMAL MODEL TEMPERATURE COMPARISON

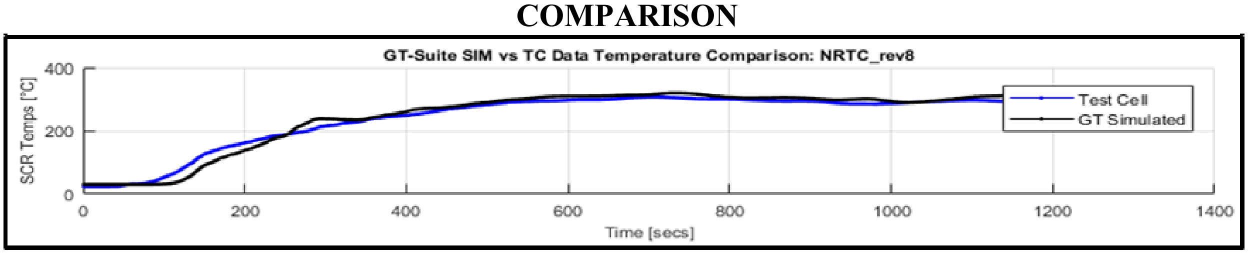


FIGURE 60. NRTC - SCR: GT SUITE THERMAL MODEL TEMPERATURE COMPARISON

Figure 61 below shows the schematic layout of the aftertreatment system thermal model in the GT-Suite. Catalyst substrate-specific heat capacity was modified from default material to mimic the real-world conditions closely. Insulation properties, aftertreatment system cones material, and Diesel Exhaust Fluid (DEF) decomposition pipe's backpressure were optimized based on the engine dynamometer test cell data.

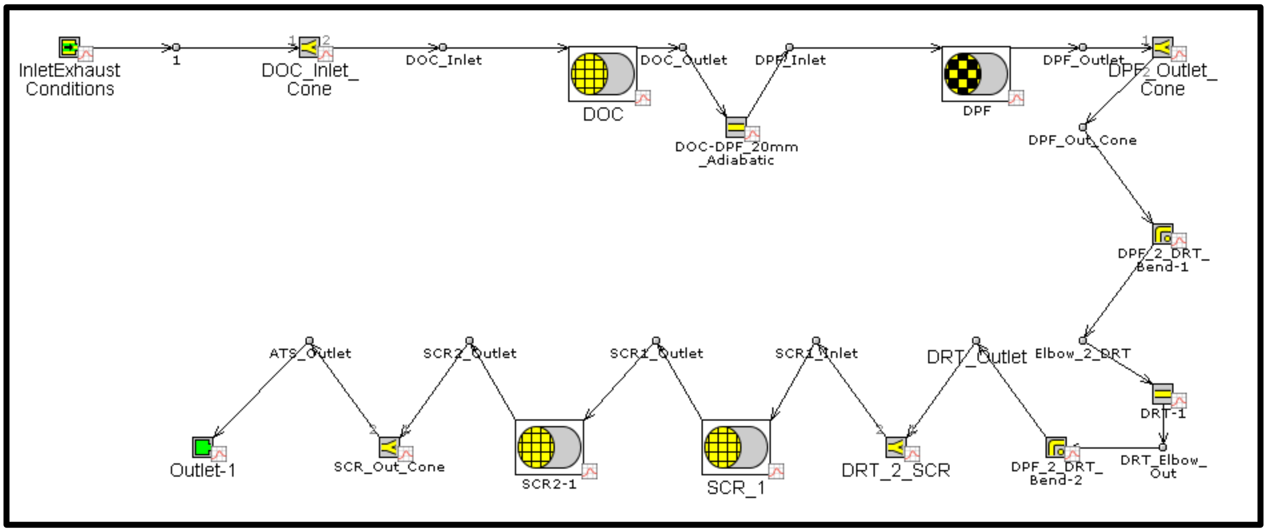


FIGURE 61. GT-SUITE BASED THERMAL MODEL LAYOUT FOR CONVENTIONAL SYSTEM ARCHITECTURE

Table 20, shown below, summarize the initial assumptions for the catalyst substrate inlet and outlet cones and the connecting pipes. ASTM standards and Thermophysical properties of stainless steels, AANL-75-55, was referenced to optimize the material properties to create a robust thermal model.

For the NRTC A 20-minute soak period was simulated between the cold-start and hot-start phases of the duty cycle to mimic the catalyst bed temperatures close to the real behavior in the transient cell. This same approach was used before the LLC to ensure accurate simulation of cycle starting conditions.

TABLE 20. BASELINE AFTERTREATMENT SYSTEM CATALYST DIMENSIONS

GT Input Properties	Metal	Insulation
Material	SS 316L	Fiber Glass
Thickness	12.7 mm	12.7 mm
Surface Emissivity	0.65	0.78

7.2.2 Chemical Model

ARB Stage3 Low NO_X controls model was modified to mimic the aftertreatment system DEF dosing and predict tailpipe NO_X emissions for the catalyst. Chemical Kinetics from Stage 3 catalysts were used to predict the tailpipe NO_X and NH_3 emissions. A schematic diagram for the overall SCR Controller for the modified Stage 3 Low NO_X controller is shown below in Figure 62 and Figure 63.

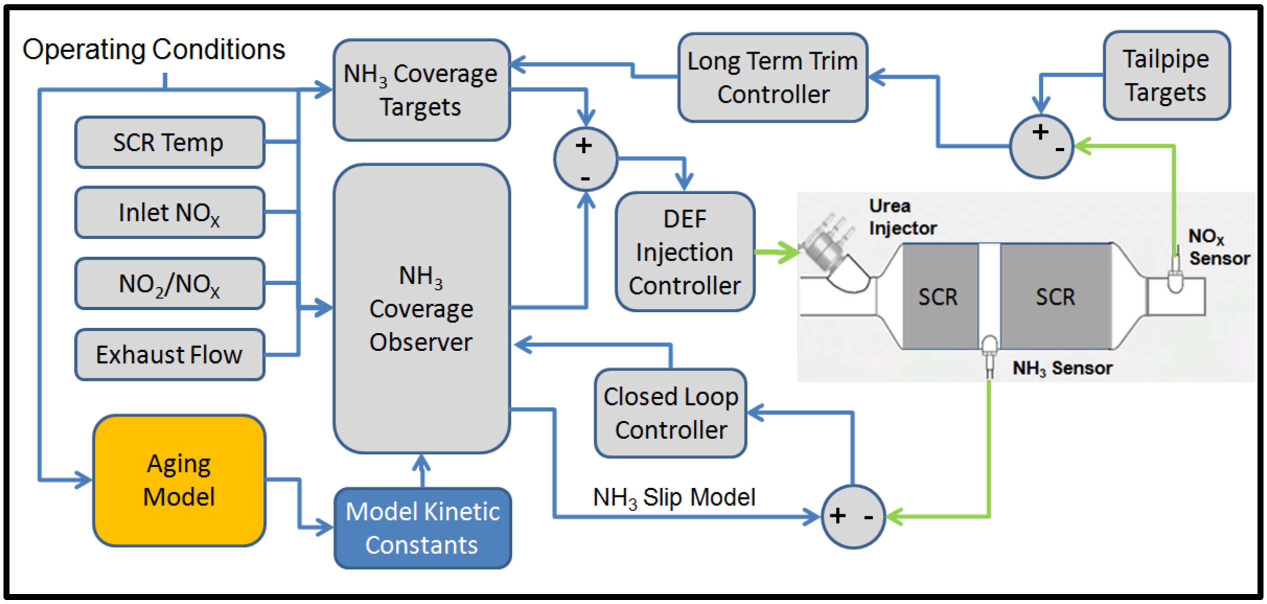


FIGURE 62. OVERALL LOW NOX CONTROLS SCHEMATIC DIAGRAM

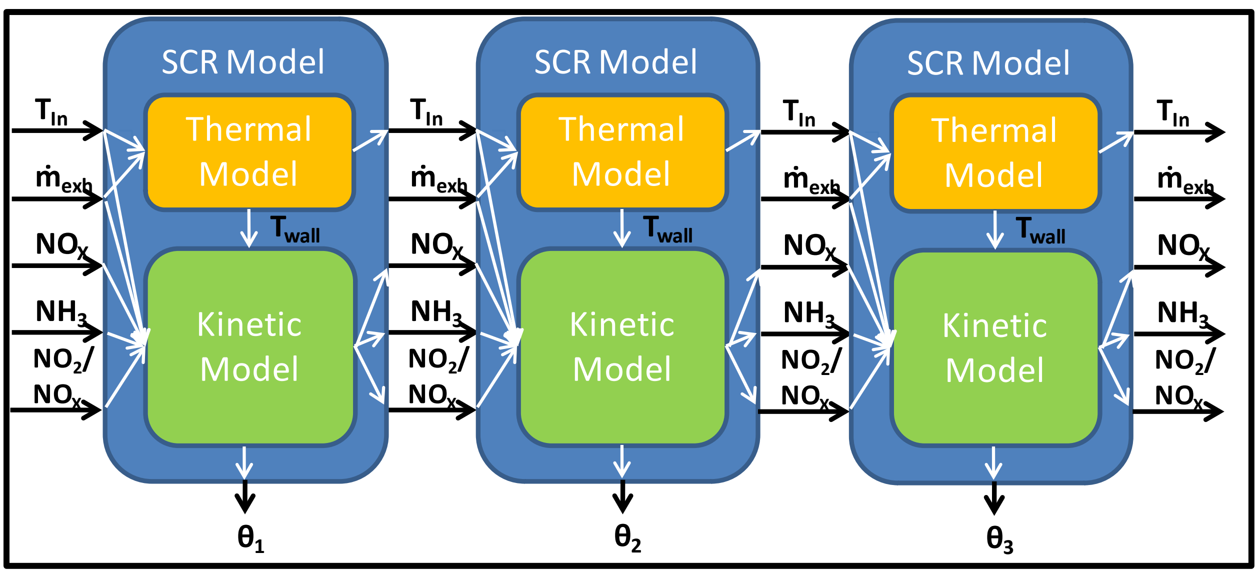


FIGURE 63. SCR CHEMICAL KINETICS BASED MODEL SCHEMATICS

As shown in these two figures, separate coverage observer models were used for each SCR catalyst substrate, with a target to maintain over 99.5% NO_X reduction whenever possible based on temperature and NO_X flux, throughout the cycle. The controller model was based on Matlab-Simulink, and the primary calibration parameters were controller gains and the coverage targets. The same calibrations were used for the cold NRTC, hot NRTC, and the LLAC cycles.

The Matlab-Simulink based Chemical kinetics model for Stage 3 was modified and validated with the Stage 3 data. Figure 64 shows the validation of the tailpipe NO_X comparison between the simulation and the tailpipe NO_X sensor. The simulation model was validated for multiple Cold FTPs, Hot FRP's and LLC cycles. Within accurate within 5% of the overall tailpipe NO_X emissions.

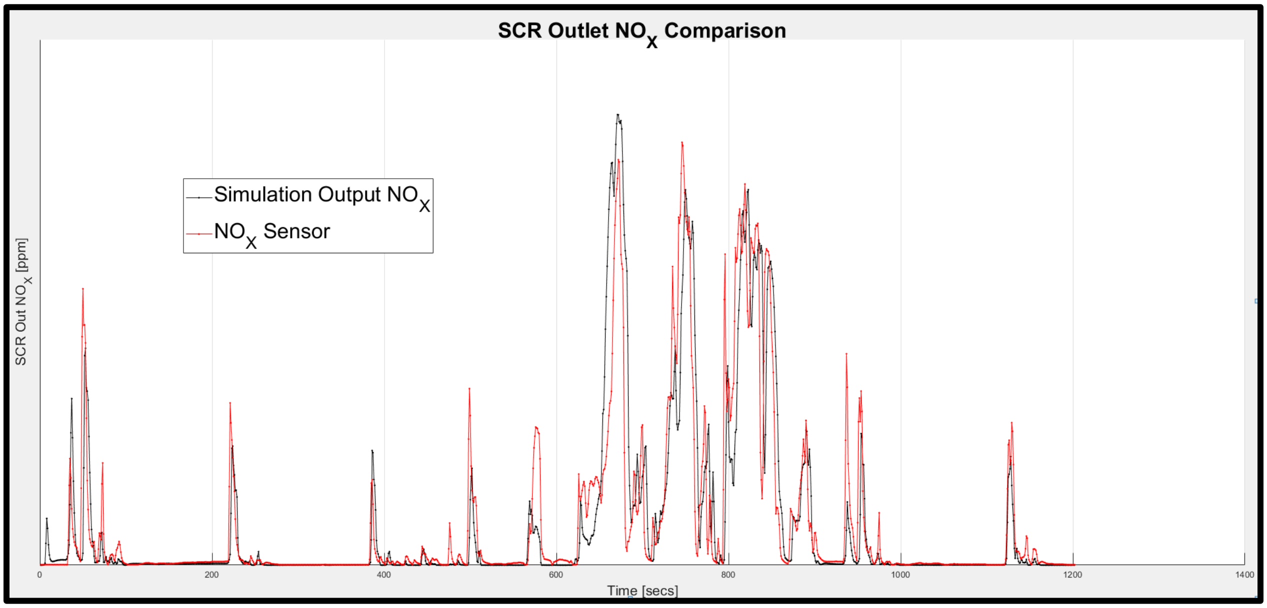


FIGURE 64. SCR OUTLET NO_X COMPARISON ON BASELINE SYSTEM FOR MODEL VALIDATION

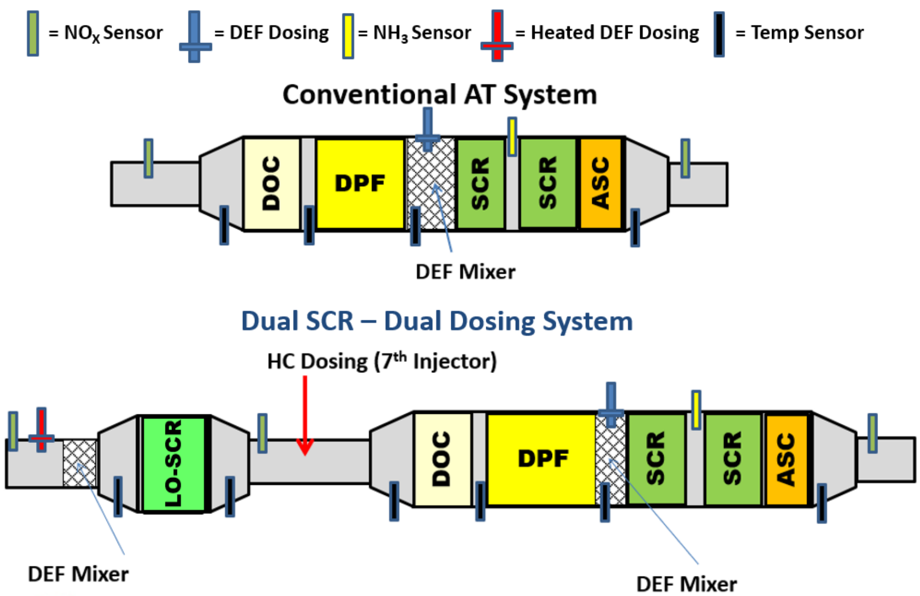
7.2.3 Aftertreatment Systems and Calibrations Modeled

Two different aftertreatment system architectures were modelled as part of this effort. Schematics for both systems are given in Figure 65. The initial Conventional system models were run using catalyst sizing similar to what was used on the Baseline system. However, following initial results, additional runs were made utilizing downsized versions of this system, with the SCR catalysts at between 70% and 90% of the Baseline catalyst size. For the Dual SCR-Dual Dosing version of the system, the final Conventional system model was the start point, and then a 9.5-in diameter by 4-in long LO-SCR catalyst with heated dosing was added in front of the system in a close-coupled location.

Modeling was conducted using two different engine calibration approaches. The first was to keep to engine calibration the same as the baseline calibration, apart from a few small modifications that would have minimal impact on CO_2 and fuel consumption. The second calibration involved increasing the engine-out NO_X level in an effort to reduce CO_2 and fuel consumption, so as to target modest potential future GHG reductions.

Results are presented for all of four potential combinations of these two parameters.

FIGURE 65. SCHEMATICS OF MODELED AT SYSTEMS



7.3 Modeling Results

7.3.1 Conventional Aftertreatment System

Upgrade of the DOC and SCR catalysts to the catalyst technology used in the Stage 3 on-highway Low NO_X program resulted in significant improvement over the Baseline system performance. Following initial runs, it was realized that the SCR catalysts could be downsized somewhat from the Baseline catalyst sizes, and additional model runs were conducted to optimize the final catalyst displacement. Results for the sizing study for the NRTC are illustrated below in Table 21. Based on the results of this sizing study, SCR catalyst size at 80% of the Baseline system was selected for continued modeling work.

Test Cycle	C-NRTC [g/kW-hr]	H-NRTC [g/kW-hr]	Catalyst Details / Storage
Engine Out	3.142	2.987	**Baseline**, 6.8L John Deere Production Aftertreatment System, NO_X emissions [g/kW-hr]
Tailpipe Out	0.39	0.08	
Tailpipe Out	0.12	0.009	"Low NOx" Catalyst; Same SCR volume as test SCR and following storage
Tailpipe Out	0.14	0.01	"Low NOx" Catalyst with optimized engine out NO_X, Exhaust Flows, and Temps
Tailpipe Out	0.13	0.004	"Low NOx" Catalyst; 10% SCR vol reduction as the test SCR, with initial storage
Tailpipe Out	0.14	0.009	"Low NOx" Catalyst; 20% SCR vol reduction as the test SCR and similar storage
Tailpipe Out	0.15	0.027	"Low NOx" Catalyst; 30% SCR vol reduction as the test SCR and similar storage

TABLE 21. SCR SIZING STUDY WITH CONVENTIONAL SYSTEM

Figure 66 shows model Cold-start NRTC temperatures on the Conventional system, while Figure 67 shows a comparison of emission results between the Baseline aftertreatment system and the model results for the updated Conventional system at 80% SCR volume. The updated Conventional System achieves NO_X light-off much more quickly than the Baseline system, primarily as a result of the improved low temperature performance of the updated SCR formulation, as well is improved feedgas optimization across the DOC.

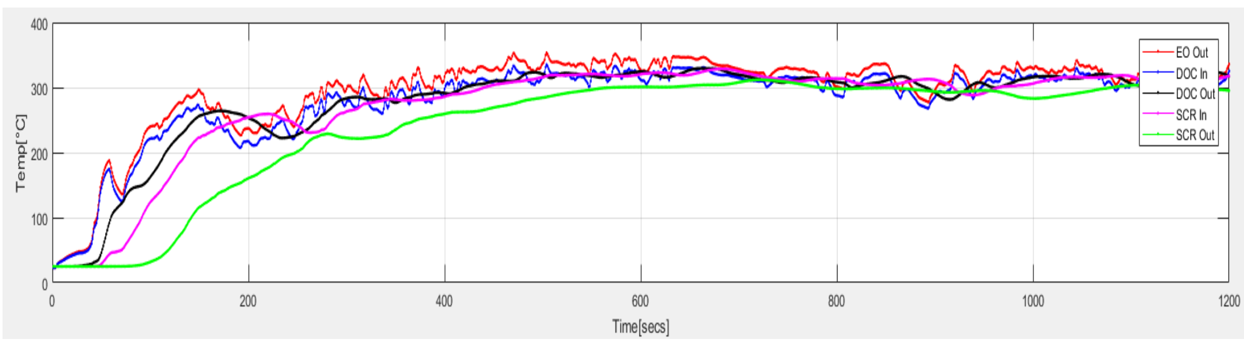


FIGURE 66. CONVENTIONAL AFTERTREATMENT SYSTEM MODEL TEMPERATURES FOR COLD NRTC

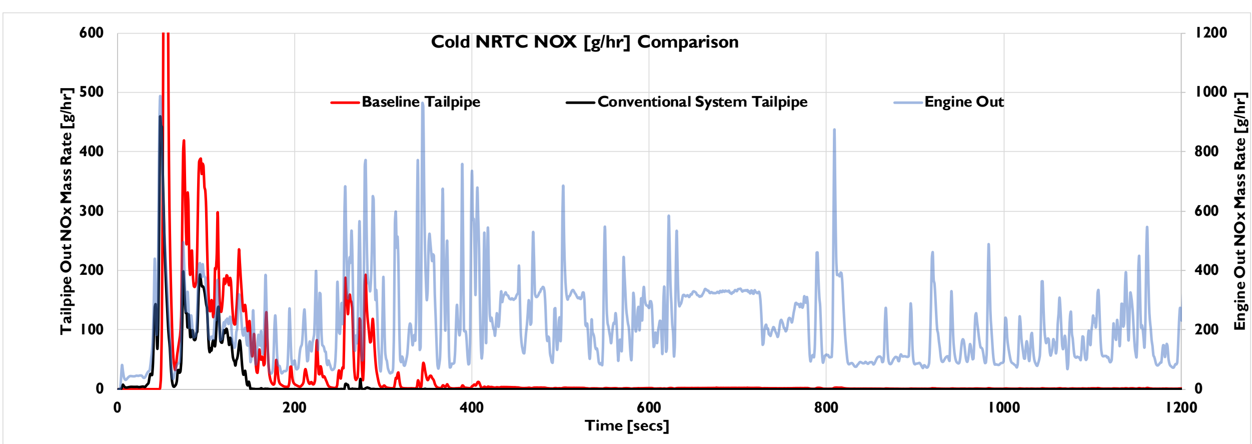


FIGURE 67. COLD NRTC TAILPIPE EMISSIONS SIMULATION FOR CONVENTIONAL SYSTEM

Hot NRTC system temperatures for the Conventional system are shown in Figure 68, while a similar comparison of emissions performance is depicted in Figure 69. An improvement of 2.4% in the NO_X reduction efficiency was observed by using an advanced catalyst formulation. As seen in the charts, SCR temperatures are above 200°C for entire hot NRTC cycle, therefore the updated formulations are able to maintain high conversion throughout the cycle. Further optimization of the dosing targets could likely achieve further improvement in NO_X conversion to 99.8%.

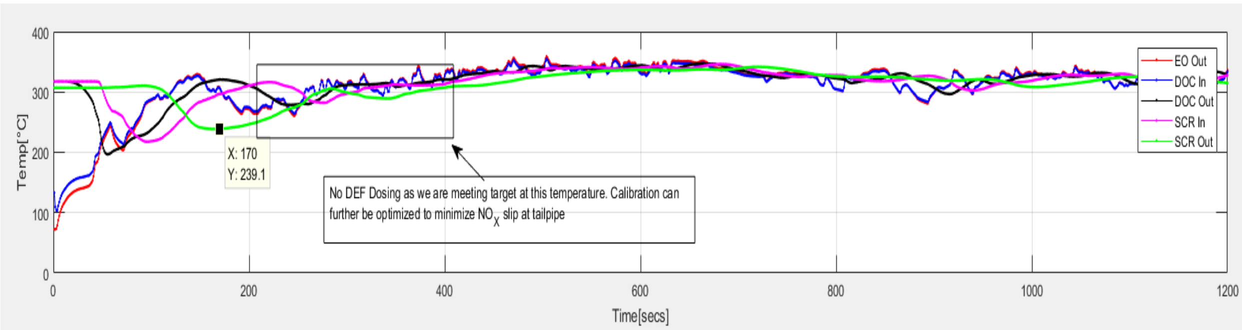


FIGURE 68. CONVENTIONAL AFTERTEATMENT SYSTEM MODEL TEMPERATURES FOR HOT NRTC

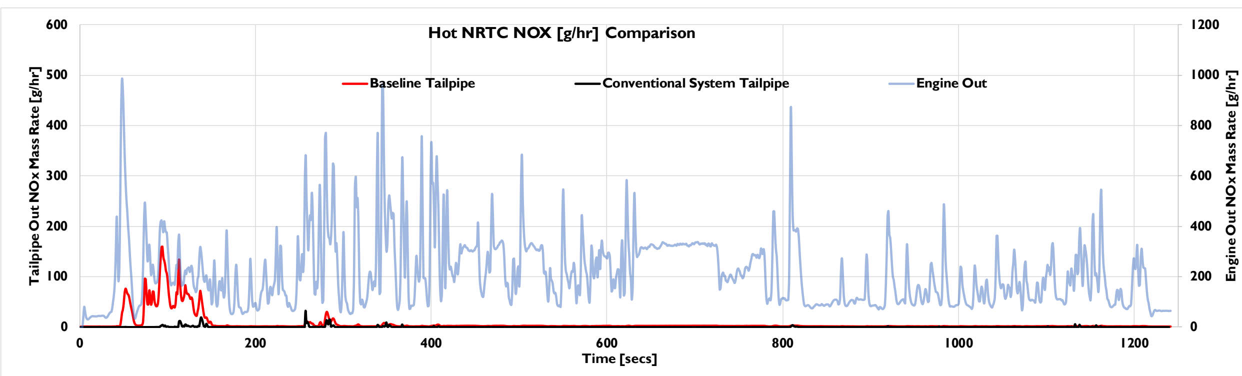


FIGURE 69. HOT NRTC TAILPIPE EMISSIONS SIMULATION FOR CONVENTIONAL SYSTEM

Light Load Application Cycle (LLAC) model temperatures are shown in Figure 70, while emission performance model results are given in Figure 71. A significant improvement of 32% in the NO_X reduction efficiency was observed by using the more advanced catalyst formulations. This improvement was due primarily to improved low temperature conversion between 190°C and 250°C. Small improvements were also made to the idle calibration to help preserve system heat, but it is already understood based on the Stage 2 on-highway work that these improvements can be made at idle without sacrificing idle fuel consumption. The final model performance at 0.025 g/kw-hr is well below the target of 0.045 g/kw-hr.

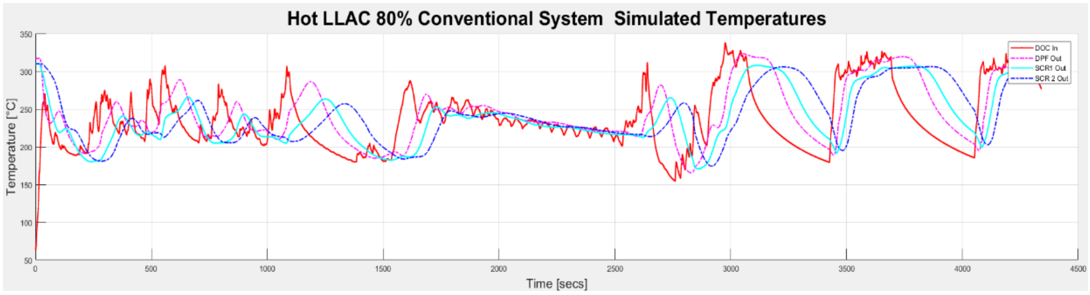


FIGURE 70. CONVENTIONAL AFTERTREATMENT SYSTEM MODEL TEMPERATURES FOR LLAC

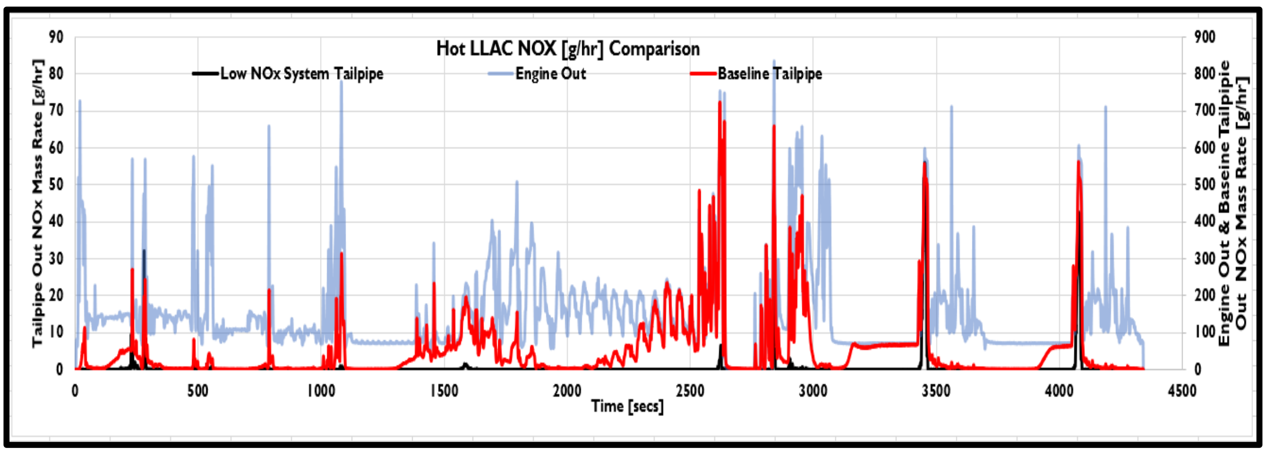


FIGURE 71. HOT LLAC TAILPIPE EMISSIONS SIMULATION FOR CONVENTIONAL SYSTEM

A summary table summarizing the catalyst deNO$_X$ efficiency is shown in Table 22 below. The final performance numbers achieved in simulation indicate that a Conventional DOC+DPF+SCR appears to be capable of reaching Low NO$_X$ targets without the need for major modifications to the engine calibration. As a result, it is likely that these targets can be reached without a significant GHG penalty.

TABLE 22. BASELINE CATALYST VS. THE ADVANCED CATALYST DENO$_X$ EFFICIENCY COMPARISON FOR CONVENTIONAL ARCHITECTURE

Test Cycle	BSNO$_X$ [g/kW-hr]			NO$_X$ Conversion Efficiency [%]	
	Engine Out	Baseline	Stage 3 Chemical kinetics	Baseline	Stage 3 Chemical Kinetics
Cold NRTC	3.1	0.39	0.14	87.2%	95.5%
Hot NRTC	3.0	0.08	0.009	97.3%	99.7%
LLAC	5.2	1.7	0.022	67.3%	99.6%

7.3.2 Dual SCR-Dual Dosing Aftertreatment System

A similar exercise was carried out using a dual-SCR dual-dosing architecture, wherein an LO-SCR was added to the Conventional system modeled above. An example of this is shown below for the Cold NRTC, with system temperatures shown in Figure 72, and emission performance shown in Figure 73. While the use of LO-SCR does result in a modest further improvement in cold NRTC conversion, it is not clear that this small change is worth the increase in system cost and complexity. Similar conclusions were drawn for the hot NRTC and LLAC.

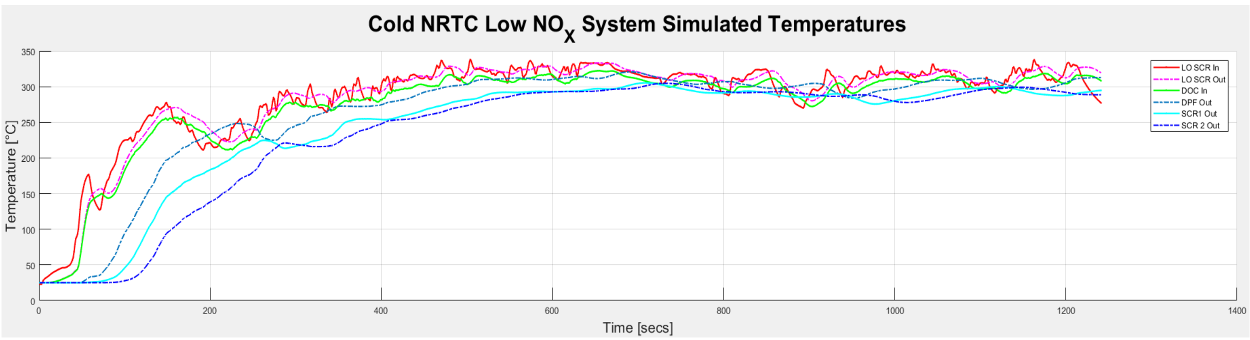


FIGURE 72. DUAL-SCR DUAL-DOSING AFTERTREATMENT MODEL TEMPERATURES FOR COLD NRTC

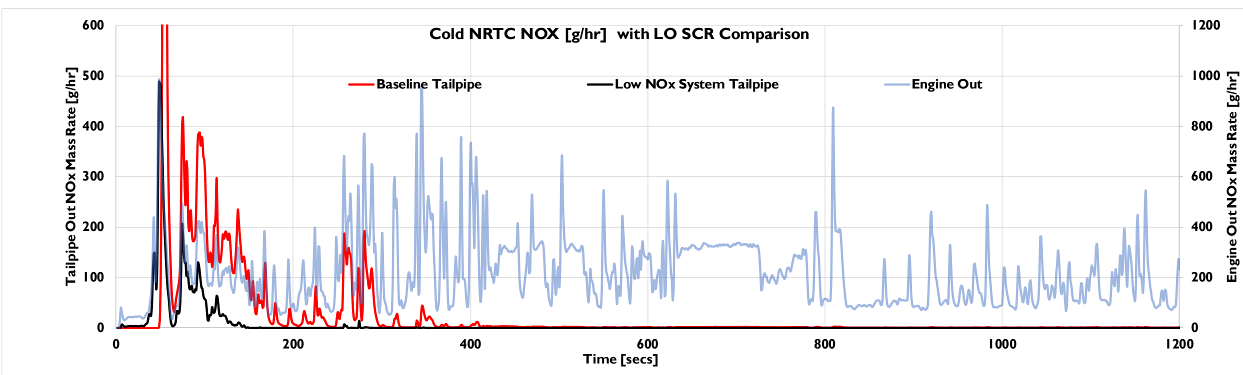


FIGURE 73. COLD NRTC EMISSION SIMUALTION FOR DUAL-SCR DUAL-DOSING SYSTEM

Table 23 shows a comparison of modeled emission performance between the dual-SCR dual-dosing architecture and a conventional system architecture, with both systems using Stage 3 kinetics. Modest performance improvements are seen on all cycles, but it appears that with current engine calibration and resulting system temperatures, there is not much opportunity for the LO-SCR to produce substantial system performance improvements.

TABLE 23. SUMMARY OF DUAL-SCR DUAL-DOSING ARCHITECTURE VERSUS CONVENTIONAL ARCHITECTURE WITH ADVANCED CATALYSTS

Test Cycle	BSNO$_X$ [g/kW-hr]			NO_X Conversion Efficiency [%]	
	Engine Out	Conventional	Dual- SCR Dual-Dosing	Conventional	Dual- SCR Dual-Dosing
Cold NRTC	3.1	0.14	0.10	95.5%	96.8%
Hot NRTC	3.0	0.009	0.008	99.7%	99.7%
LLAC	5.2	0.022	0.014	99.6%	99.7%

7.3 Modeling Conclusions

Conventional aftertreatment system architecture with the latest generation chemical kinetics used for the ARB Stage 3 On-Highway Low NO_X project reached low NO_X targets without significant modifications and optimization to the engine calibration. As no significant changes were made to the engine calibration, relatively little impact is anticipated on CO_2 emissions, compared to the baseline engines. A more complex aftertreatment architecture, such as that used for the on-highway program might allow room for increased engine-out NO_X, which could in turn enabled lower CO_2 emissions. However, it should be noted that off-road machines sometimes face unique cost and packaging challenges that may make such an architecture more difficult to adopt on all applications. Adoption of additional engine technologies could also help to enable CO_2 reductions at low tailpipe NO_X, but these were not part of the modeling scope of the program

8.0 SUMMARY AND CONCLUSIONS

Considering all of the tasks and results from this program, conclusions can be drawn in a number of different areas, and the results of several tasks can be used as a foundation for further efforts in the area of Off-road Low NO_X.

California Off-road Market

An overview of the off-road application data from the market survey is shown in Figure 74 and Figure 75, for 2019 and 2029 years, respectively. Generally, it was observed that a little over half of the all Off-road engines in California are in agricultural tractors, with significant portions of the population also present in Skid Steer Loaders (which are <56kw), construction machinery (such as backhoe loaders, excavators, track loaders, and wheel loaders). By 2029 the population is expected to grow by nearly 20 percent, with growth evident in most categories. Some categories, such as excavators and track loaders are may see growth rates as high as 50%.

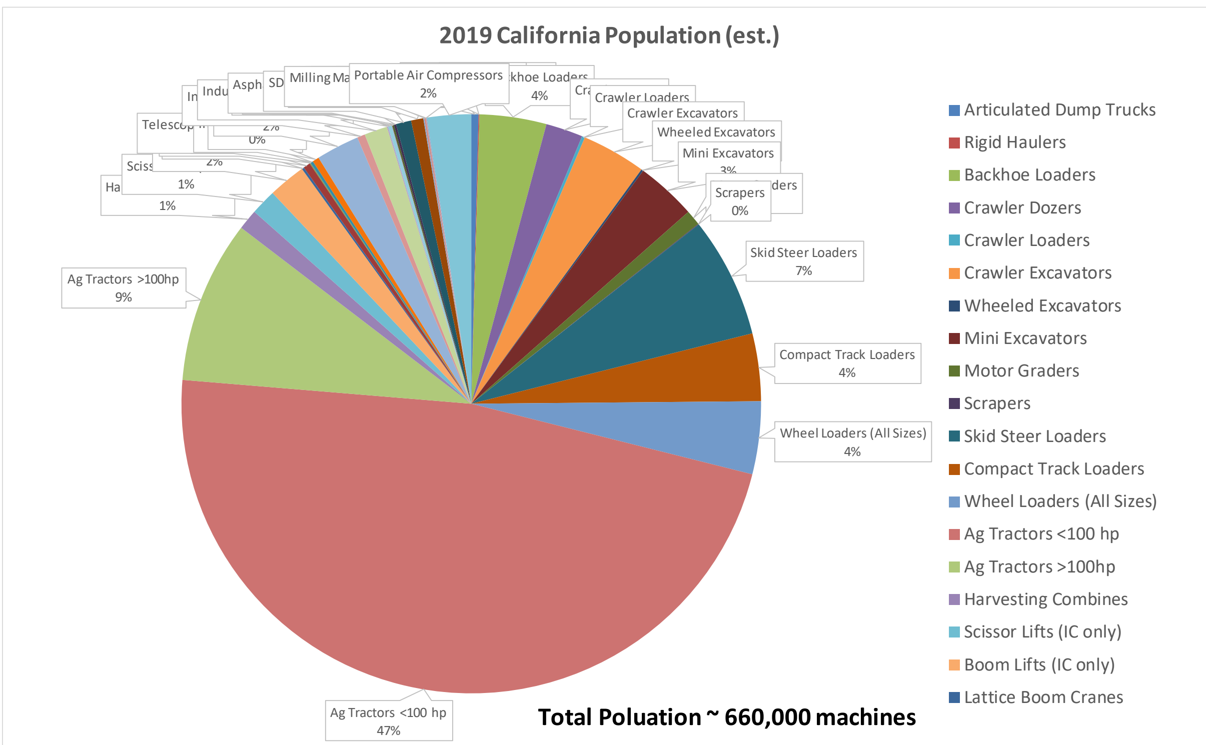


FIGURE 74. CALIFORNIA OFF-ROAD MACHINE POPULATION DATA BY APPLICATION – 2019

The full population breakdown spreadsheet also includes engine size data, annual average hours of operation, load factors, and many other parameters that should be useful in projecting emission trends and usage rates. The spreadsheet also includes some initial emission inventory projections by application, assuming Tier 4 emission rates over the entire fleet.

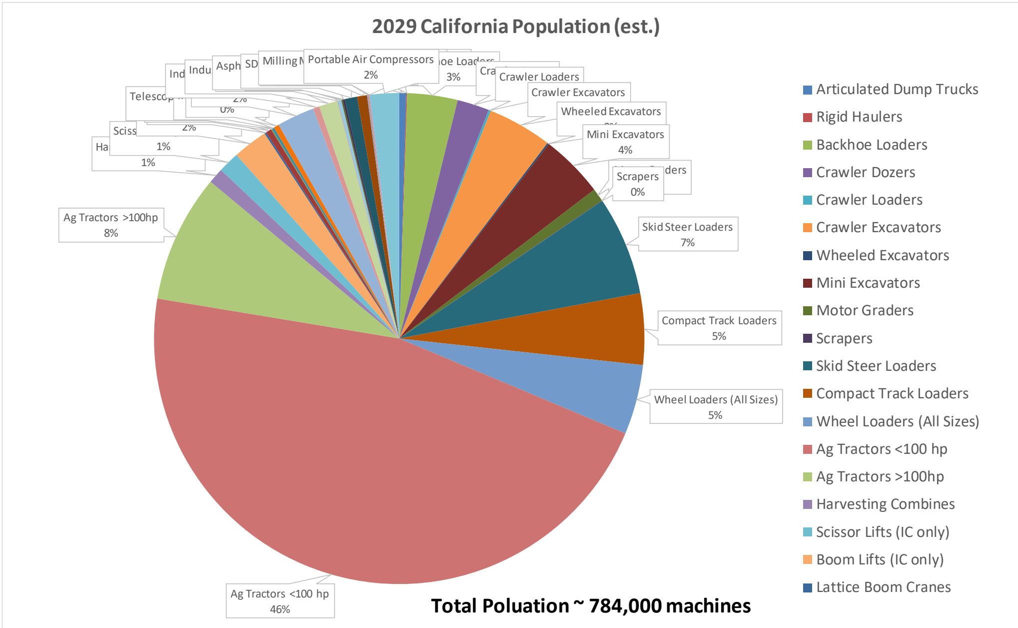


FIGURE 75. PROJECTED CALIFORNIA OFF-ROAD MACHINE POPULATION DATA BY APPLICATION – 2029

Baseline Emission Testing

The baseline results for both engines indicate that the engines met Tier 4 requirements on current regulatory with plenty of margin available for aftertreatment degradation and production variability. A summary of data for both engines is shown in Figure 76 and Figure 77, for NO_X and PM emissions, respectively. The levels observed on these engines with de-greened aftertreatment showed emissions levels of NO_X at less than half the current standards. PM for the non-DPF engine was at about half the standard, while the DPF engine was an order of magnitude below the standard, as expected. However, on the lower load LLAC cycle emission control was poor, resulting in emissions on the order of 1.5 g/kw-hr, more than 3 to 4 times the regulatory emission standards, and a factor of 10 X higher than tailpipe rates on the current regulatory cycles. This clearly indicates a gap in emissions control at lower loads for the current implementation.

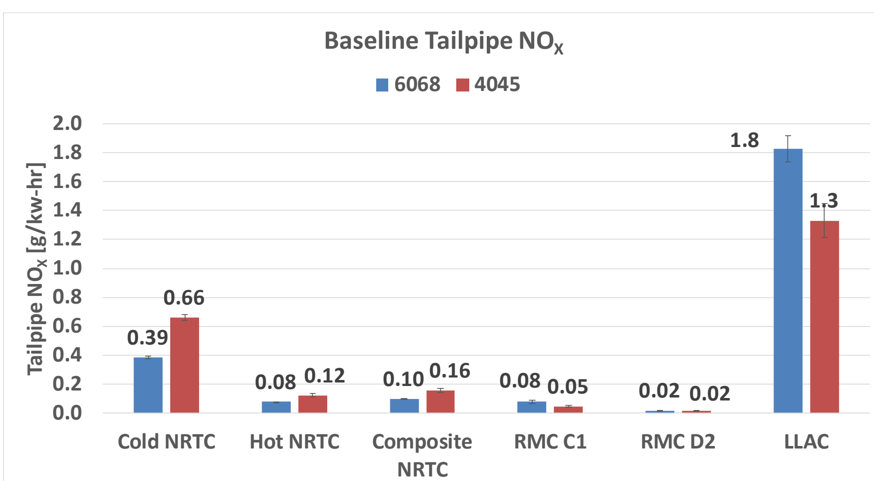


FIGURE 76. TAILIPE NO_X EMISSIONS FOR BOTH BASELINE ENGINES

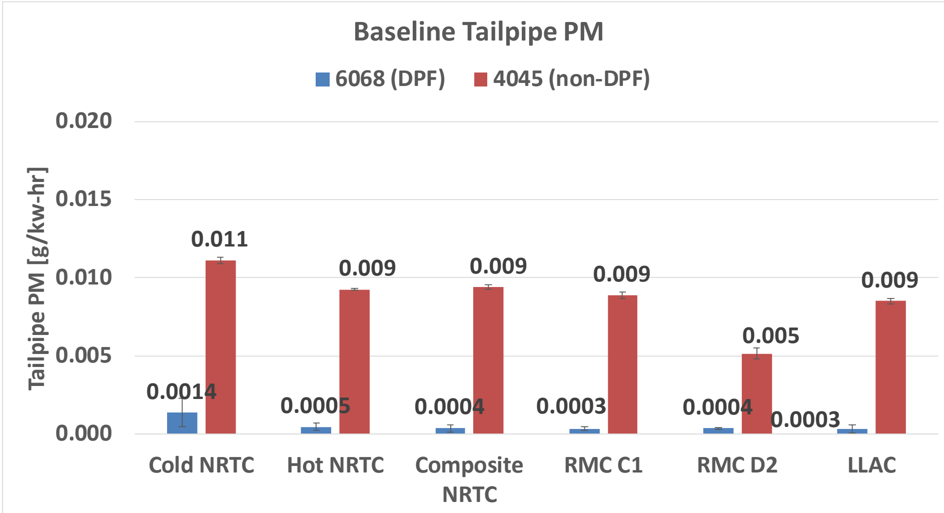


FIGURE 77. TAILPIPE PM EMISSIONS FOR BOTH BASELINE ENGINES

Although not currently regulated in the U.S., Particle number (PN) measurements were performed in according with the methodology currently associated with Stage V standards in Europe. These measurements, summarized in Figure 78, indicate the clear potential for reduction of PN by two orders of magnitude in the event that standards can be promulgated which effectively require the use of a high efficiency DPF.

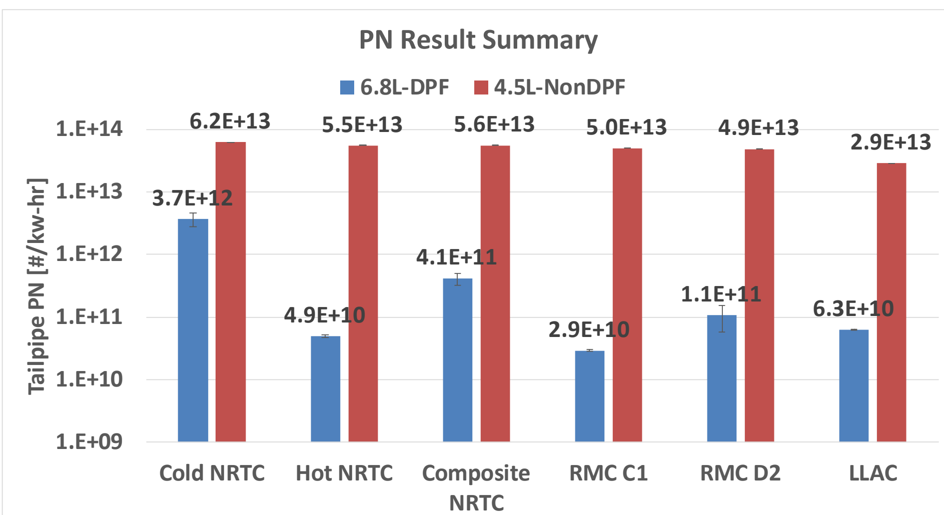


FIGURE 78. TAILPIPE PN EMISSIONS FOR BOTH BASELINE ENGINES

Detailed Chemical Characterizations

The detailed chemistry analyses generally indicated good control of unregulated HC emission species from both engines. The DPF equipped engine did demonstrate better control of heavier particle phase PAH compounds, and somewhat better control of light VOCs as well. N_2O emissions were substantially higher for the non-DPF engine, primarily as a result of the higher engine-out NO_X calibration in combination with the aftertreatment. That higher NO_X calibration is likely needed to help control engine-out PM levels, given that a DPF is not available to clean up engine-out PM, thus limiting the use of EGR as an in-cylinder NO_X control measure.

Wear metals, trace elements, inorganic ions, and WSOCs did not show significant levels for either engine. SVOC and IVOC analysis did indicate some trends between HC emissions for the two engines, but generally HC emissions were very low for both engines.

Low NO_X Pathway Modeling

Modeling results indicated that for the various duty cycles examined, including the LLAC, there is potential to reach Low NO_X levels using an aftertreatment system having a Conventional DOC+DPF+SCR architecture. It is not yet clear how much margin is needed for aftertreatment degradation, but the model results indicate that margins are available to sustain a 0.5% loss of NO_X conversion of the useful life of the aftertreatment (1% on the LLAC). This level of degradation is similar to what was observed during the Stage 3 on-highway program. This indicates that it is may be possible to achieve Low NO_X levels for Off-road regulatory cycles, including a projected low load cycle without a significant penalty to fuel consumption and GHG emissions. However, given the wide range of applications and torque-curves that some Off-road engines may have, there could potentially be some GHG impact in certain low-power rating applications.

Given the increase in cost and complexity, a dual-SCR dual-dosing aftertreatment system architecture was not indicated as preferred by the modeling for the cases involving current engine-out temperatures and NO_X levels. However, in the event of future GHG regulations that would require CO_2 reductions, a more complex aftertreatment architecture or other engine technology levels might be needed to achieve both Low NO_X and GHG reductions. This would require a higher initial system cost that would have to be weighed against potential fuel savings.

The modeling results from this program will find immediate application in provided data for aftertreatment system design in the upcoming Off-road Low NO_X technology demonstration efforts. In addition, the baseline results for the 6.8L engine will provide the point of comparison for assessing NO_X and GHG impacts during the upcoming demonstration programs.

APPENDIX - LOW LOAD APPLICATION CYCLE

Time	Speed	Torque
1	0.00	5.00
2	0.00	5.00
3	0.00	5.00
4	0.00	5.00
5	0.00	5.00
6	0.00	5.00
7	0.00	5.00
8	41.48	5.00
9	49.63	42.36
10	65.67	59.59
11	79.18	45.76
12	84.15	5.00
13	85.73	5.00
14	85.32	5.00
15	90.20	56.74
16	96.74	82.73
17	99.92	87.49
18	99.48	87.57
19	96.05	88.67
20	91.73	89.74
21	90.88	90.06
22	90.85	89.84
23	91.10	90.02
24	92.66	89.80
25	94.16	89.38
26	97.95	89.10
27	103.11	85.98
28	106.25	81.25
29	107.00	70.54
30	104.91	75.63
31	91.31	25.36
32	82.17	79.03
33	79.23	91.94
34	77.33	88.28
35	74.45	77.60
36	72.89	86.86
37	77.45	77.22
38	80.26	34.42
39	77.58	8.01
40	70.69	5.00
41	65.21	14.85

Time	Speed	Torque
42	65.31	32.96
43	66.95	30.03
44	68.51	28.35
45	69.57	23.78
46	69.74	23.20
47	69.44	25.34
48	67.70	12.97
49	65.96	10.96
50	63.62	5.00
51	61.79	5.00
52	59.94	5.00
53	58.14	5.00
54	58.53	5.00
55	58.67	5.00
56	56.50	5.00
57	55.06	5.00
58	53.52	5.00
59	52.51	5.00
60	51.72	5.00
61	51.28	5.00
62	51.60	5.00
63	52.50	5.00
64	53.36	5.00
65	54.00	5.00
66	53.44	5.00
67	50.64	5.00
68	46.35	5.00
69	41.86	5.00
70	36.68	5.00
71	31.34	5.00
72	25.77	5.00
73	24.28	18.65
74	21.58	5.00
75	19.39	5.00
76	36.73	6.72
77	46.58	39.85
78	54.75	32.72
79	60.67	21.71
80	62.43	13.96
81	63.21	13.60
82	64.22	10.76

Time	Speed	Torque
83	63.34	6.02
84	61.51	5.00
85	60.62	9.88
86	62.70	13.56
87	64.41	8.20
88	64.89	6.79
89	65.27	7.01
90	64.37	5.00
91	62.80	5.00
92	61.93	6.91
93	61.23	5.00
94	61.00	5.00
95	60.98	5.00
96	59.45	5.00
97	58.85	5.00
98	59.72	5.00
99	59.48	5.00
100	59.55	5.00
101	59.75	5.00
102	62.18	5.00
103	63.51	5.00
104	65.12	5.00
105	65.68	5.00
106	66.13	5.00
107	67.28	5.00
108	72.54	17.41
109	78.50	14.84
110	77.41	5.00
111	72.76	5.00
112	68.84	5.00
113	65.27	5.00
114	61.77	5.00
115	61.13	5.00
116	64.12	9.08
117	67.25	12.41
118	71.20	5.00
119	72.79	5.00
120	73.51	5.00
121	73.92	5.00
122	74.63	5.00
123	73.50	5.00

Time	Speed	Torque
124	73.18	5.00
125	73.28	5.00
126	72.74	5.00
127	73.46	5.00
128	73.60	5.00
129	73.43	5.00
130	73.10	5.00
131	72.65	5.00
132	72.23	5.00
133	71.79	5.00
134	71.12	5.00
135	71.38	5.00
136	71.54	5.00
137	71.59	5.00
138	72.49	5.00
139	72.50	5.00
140	73.01	5.00
141	73.55	5.00
142	73.76	5.00
143	73.20	5.00
144	72.67	5.00
145	72.19	5.00
146	71.51	5.00
147	71.94	5.00
148	74.09	5.00
149	74.98	5.00
150	74.24	5.00
151	72.89	5.00
152	73.41	5.00
153	73.50	5.00
154	72.51	5.00
155	71.73	5.00
156	70.38	5.00
157	69.85	5.00
158	70.74	5.00
159	70.15	5.00
160	72.17	5.00
161	72.40	5.00
162	71.54	5.00
163	71.76	5.00
164	72.51	5.00

Time	Speed	Torque
165	73.01	5.00
166	72.70	5.00
167	71.39	5.00
168	69.83	5.00
169	68.96	5.00
170	70.30	5.00
171	72.94	5.00
172	74.68	5.00
173	76.48	5.00
174	78.83	5.00
175	80.51	5.00
176	83.03	5.00
177	86.58	5.00
178	91.30	5.00
179	93.15	5.00
180	94.16	5.00
181	94.26	5.00
182	92.32	5.00
183	89.79	5.00
184	86.85	5.00
185	82.60	5.00
186	78.72	5.00
187	83.28	29.23
188	90.20	20.39
189	92.65	5.00
190	91.31	5.00
191	89.01	7.63
192	87.47	5.00
193	83.10	5.00
194	77.45	5.00
195	78.82	7.23
196	83.68	5.00
197	85.25	5.00
198	85.06	5.00
199	85.51	5.00
200	86.06	5.00
201	86.98	5.00
202	86.52	5.00
203	86.53	5.00
204	86.41	5.00
205	86.36	5.00

Time	Speed	Torque
206	85.83	5.00
207	85.84	5.00
208	87.34	5.00
209	87.69	5.00
210	87.43	5.00
211	87.96	5.00
212	88.11	5.00
213	89.46	5.00
214	90.11	5.00
215	88.25	5.00
216	87.01	5.00
217	87.38	5.00
218	86.79	5.00
219	86.28	6.23
220	86.26	10.03
221	86.50	10.66
222	86.87	9.11
223	90.51	21.20
224	93.68	10.97
225	95.31	5.00
226	95.33	5.00
227	73.21	9.60
228	64.19	55.73
229	78.62	72.97
230	94.48	85.06
231	103.63	31.02
232	102.29	5.00
233	99.83	5.00
234	98.36	5.00
235	96.70	8.30
236	95.09	13.05
237	93.25	10.75
238	90.12	5.00
239	87.09	10.28
240	86.31	10.71
241	86.68	10.88
242	87.49	8.18
243	88.85	15.19
244	92.56	35.40
245	94.58	23.76
246	95.46	16.02

Time	Speed	Torque	Time	Speed	Torque	Time	Speed	Torque
247	95.58	21.75	288	85.04	37.85	329	77.71	5.00
248	94.22	13.30	289	84.86	34.46	330	76.81	5.00
249	91.51	11.94	290	85.42	31.01	331	77.43	5.00
250	90.90	25.85	291	85.76	25.90	332	79.58	5.00
251	91.16	22.15	292	86.02	20.52	333	82.73	5.00
252	91.52	20.84	293	87.00	16.49	334	86.42	5.00
253	91.72	14.62	294	87.77	14.68	335	91.53	5.00
254	91.61	16.73	295	88.89	11.75	336	96.93	5.00
255	91.07	22.82	296	89.83	8.12	337	101.30	5.00
256	90.98	26.32	297	89.63	7.93	338	104.66	5.00
257	90.92	15.73	298	88.72	10.17	339	108.05	5.00
258	90.73	11.35	299	87.85	13.78	340	110.41	5.00
259	87.90	5.00	300	87.35	15.20	341	113.24	5.00
260	83.27	5.00	301	86.86	15.57	342	115.06	5.00
261	78.14	5.00	302	86.84	19.20	343	117.07	5.00
262	71.63	5.00	303	88.63	23.09	344	117.61	5.00
263	56.44	5.00	304	88.73	19.42	345	116.18	5.00
264	38.35	5.00	305	89.05	11.71	346	111.88	5.00
265	22.74	5.00	306	88.55	6.61	347	107.41	5.00
266	8.48	5.00	307	88.33	9.17	348	102.93	5.00
267	20.45	5.00	308	86.52	5.00	349	100.14	5.00
268	9.44	5.00	309	83.10	5.00	350	98.98	5.00
269	0.00	10.72	310	80.61	8.23	351	97.49	5.00
270	12.00	29.44	311	79.27	12.65	352	96.08	5.00
271	19.41	45.25	312	78.43	12.77	353	93.56	5.00
272	26.45	37.20	313	78.04	16.17	354	89.37	5.00
273	34.42	39.90	314	78.02	16.09	355	84.13	5.00
274	44.67	47.63	315	78.34	17.64	356	78.70	5.00
275	57.57	52.72	316	79.78	18.46	357	76.79	6.48
276	75.44	66.51	317	82.82	22.71	358	80.42	19.15
277	89.83	62.72	318	85.19	11.19	359	84.53	13.33
278	105.01	63.49	319	85.68	5.00	360	87.54	11.68
279	93.28	14.07	320	84.07	5.00	361	91.49	15.10
280	65.00	56.57	321	84.65	12.83	362	93.57	7.82
281	81.82	89.08	322	86.25	7.98	363	94.89	6.47
282	97.67	87.33	323	86.47	5.00	364	95.89	5.00
283	107.89	61.42	324	86.05	5.00	365	96.07	5.00
284	106.89	29.39	325	85.72	5.00	366	96.79	8.20
285	101.75	27.99	326	85.91	5.00	367	98.66	15.40
286	90.06	5.00	327	83.37	5.00	368	101.00	8.96
287	85.48	34.13	328	80.03	5.00	369	98.64	5.00

Time	Speed	Torque
370	94.15	5.00
371	93.81	15.08
372	94.53	12.16
373	93.38	5.00
374	88.18	5.00
375	83.36	5.00
376	80.50	5.00
377	79.24	5.00
378	79.51	5.00
379	81.25	5.00
380	82.91	5.00
381	83.96	5.00
382	84.29	5.00
383	83.78	5.00
384	82.11	5.00
385	79.59	5.00
386	76.54	5.00
387	73.72	5.00
388	71.23	5.00
389	68.78	5.00
390	66.99	5.00
391	74.87	25.76
392	78.88	5.00
393	79.81	5.00
394	81.65	9.53
395	83.74	5.00
396	86.69	13.81
397	90.74	18.87
398	93.08	6.67
399	92.53	10.38
400	92.16	16.82
401	92.24	19.67
402	92.48	22.54
403	92.56	25.68
404	92.15	27.65
405	91.83	31.22
406	91.73	32.02
407	91.24	30.53
408	89.69	21.55
409	80.84	5.00
410	70.86	5.00

Time	Speed	Torque
411	63.01	5.00
412	57.82	5.00
413	55.80	5.00
414	57.02	5.00
415	60.12	5.00
416	64.95	5.00
417	70.65	5.00
418	77.45	5.00
419	83.56	5.00
420	87.79	5.00
421	91.14	5.00
422	92.75	5.00
423	92.46	5.00
424	89.69	5.00
425	85.68	5.00
426	81.21	5.00
427	76.70	5.00
428	72.90	5.00
429	71.27	5.00
430	71.04	5.00
431	71.46	5.00
432	72.94	5.00
433	75.13	5.00
434	77.24	5.00
435	79.81	5.00
436	82.70	5.00
437	85.37	5.00
438	88.83	5.00
439	92.05	5.00
440	95.24	5.00
441	98.41	5.00
442	100.90	5.00
443	103.10	5.00
444	104.51	5.00
445	105.39	5.00
446	105.74	5.00
447	104.89	5.00
448	103.14	5.00
449	100.09	5.00
450	95.72	5.00
451	92.29	5.00

Time	Speed	Torque
452	89.27	5.00
453	88.22	5.00
454	88.11	5.00
455	88.36	5.00
456	89.06	5.00
457	89.62	5.00
458	90.26	5.00
459	90.21	5.00
460	89.63	5.00
461	88.61	5.00
462	86.50	5.00
463	82.71	5.00
464	78.00	5.00
465	71.76	5.00
466	64.72	5.00
467	57.07	5.00
468	48.54	5.00
469	47.39	29.73
470	56.06	33.64
471	47.63	5.00
472	25.74	50.94
473	28.37	58.61
474	32.30	62.40
475	37.17	64.60
476	45.68	66.72
477	59.15	73.40
478	76.44	86.70
479	94.22	89.34
480	106.30	69.30
481	108.46	5.00
482	104.06	13.63
483	104.65	55.01
484	107.37	52.71
485	107.55	29.93
486	106.00	25.36
487	106.19	26.01
488	106.08	25.37
489	105.44	32.53
490	105.56	41.30
491	99.14	5.00
492	89.27	5.00

Time	Speed	Torque
493	81.69	15.14
494	81.13	54.02
495	81.61	38.16
496	78.68	21.76
497	72.68	5.00
498	61.68	5.00
499	50.82	5.00
500	39.94	5.00
501	30.11	5.00
502	20.70	5.00
503	12.97	9.98
504	10.87	42.45
505	8.98	29.31
506	4.36	12.15
507	1.84	43.08
508	0.00	5.00
509	0.00	5.00
510	0.00	5.00
511	0.00	5.00
512	0.00	5.00
513	0.00	5.00
514	0.00	5.00
515	41.86	5.00
516	42.53	5.00
517	42.22	5.00
518	40.45	5.00
519	41.77	5.00
520	45.05	5.00
521	48.87	5.00
522	52.85	5.00
523	56.56	5.00
524	59.73	5.00
525	62.89	5.00
526	65.48	5.00
527	66.49	5.00
528	66.87	5.00
529	67.94	5.00
530	72.94	12.43
531	87.09	65.71
532	105.37	65.43
533	110.29	5.00

Time	Speed	Torque
534	106.85	5.00
535	102.92	28.30
536	101.51	83.53
537	99.93	87.25
538	96.18	88.48
539	92.30	89.28
540	91.99	89.73
541	92.10	89.78
542	92.48	89.90
543	94.29	89.33
544	96.25	88.78
545	100.32	86.95
546	105.20	81.83
547	107.23	70.85
548	106.40	60.67
549	102.99	82.21
550	99.67	89.41
551	94.27	90.65
552	83.28	42.54
553	73.43	89.37
554	71.79	91.63
555	74.54	92.09
556	82.83	79.34
557	80.53	8.28
558	80.12	24.32
559	81.65	31.32
560	80.62	14.78
561	74.94	5.00
562	68.74	5.00
563	64.72	10.45
564	62.87	16.33
565	62.17	20.88
566	63.30	31.64
567	63.61	15.33
568	63.38	6.31
569	64.98	15.08
570	65.45	5.00
571	63.24	5.00
572	61.27	5.00
573	59.38	5.00
574	57.58	5.00

Time	Speed	Torque
575	56.24	5.00
576	56.90	6.78
577	61.16	7.72
578	62.44	5.00
579	61.69	5.00
580	61.70	5.00
581	61.85	5.00
582	62.40	5.00
583	62.45	5.00
584	60.63	5.00
585	56.62	5.00
586	52.18	5.00
587	46.75	5.00
588	41.47	5.00
589	34.98	5.00
590	32.97	17.09
591	36.78	42.19
592	34.91	5.00
593	32.80	5.00
594	30.46	5.00
595	25.68	5.00
596	39.83	5.00
597	41.54	17.36
598	50.73	31.83
599	57.10	27.09
600	60.36	17.93
601	62.28	10.66
602	64.11	13.54
603	65.36	10.46
604	65.49	8.32
605	64.21	5.00
606	63.08	9.20
607	62.97	8.93
608	62.50	9.51
609	63.50	7.82
610	64.27	5.00
611	63.26	5.00
612	60.60	5.00
613	59.63	5.00
614	60.70	5.00
615	61.79	5.00

Time	Speed	Torque	Time	Speed	Torque	Time	Speed	Torque
616	61.74	5.00	657	79.89	5.00	698	77.03	5.00
617	61.89	5.00	658	78.38	5.00	699	72.97	5.00
618	62.90	5.00	659	77.67	5.00	700	70.28	5.00
619	64.29	5.00	660	77.38	5.00	701	70.38	9.37
620	67.22	5.00	661	77.43	5.00	702	72.54	13.58
621	68.40	5.00	662	78.25	5.00	703	73.42	12.37
622	68.56	5.00	663	80.18	5.00	704	73.57	13.33
623	67.98	5.00	664	81.31	5.00	705	74.95	21.00
624	66.06	5.00	665	81.83	5.00	706	79.66	33.04
625	65.66	5.00	666	81.10	5.00	707	82.68	19.64
626	68.37	5.00	667	80.79	5.00	708	83.22	5.00
627	68.60	5.00	668	80.06	5.00	709	83.74	5.00
628	68.07	5.00	669	79.40	5.00	710	86.64	5.65
629	69.06	5.00	670	79.37	5.00	711	88.28	5.00
630	69.84	5.00	671	78.98	5.00	712	88.52	5.00
631	70.02	5.00	672	77.60	5.00	713	87.79	5.00
632	70.44	5.00	673	74.62	5.00	714	86.63	5.00
633	71.12	5.00	674	74.43	5.00	715	86.08	5.00
634	73.64	11.44	675	74.73	5.00	716	86.64	5.00
635	76.41	5.00	676	75.02	5.00	717	86.93	5.00
636	74.73	5.00	677	75.33	5.00	718	86.76	5.00
637	74.23	5.00	678	75.84	5.00	719	85.87	5.00
638	73.42	5.00	679	76.39	5.00	720	86.01	5.00
639	74.68	5.00	680	76.55	5.00	721	84.90	5.00
640	76.28	5.00	681	75.94	5.00	722	85.19	5.00
641	76.04	5.00	682	74.63	5.00	723	85.78	5.00
642	75.38	5.00	683	73.81	5.00	724	85.87	5.00
643	75.31	5.00	684	73.29	5.00	725	85.07	5.00
644	75.45	5.00	685	73.24	5.00	726	85.26	5.00
645	75.43	5.00	686	74.37	5.00	727	85.29	5.00
646	75.07	5.00	687	76.38	5.00	728	84.69	5.00
647	75.14	5.00	688	78.75	5.00	729	84.19	5.00
648	75.38	5.00	689	80.53	5.00	730	83.26	5.00
649	77.73	5.00	690	82.83	5.00	731	82.27	5.00
650	80.43	5.00	691	84.48	5.00	732	80.09	5.00
651	81.45	5.00	692	86.57	5.00	733	76.52	5.00
652	80.68	5.00	693	87.61	5.00	734	72.84	5.00
653	80.41	5.00	694	87.18	5.00	735	72.64	5.00
654	81.43	5.00	695	86.61	5.00	736	75.19	14.48
655	80.92	5.00	696	84.45	5.00	737	77.43	12.87
656	80.91	5.00	697	80.92	5.00	738	78.08	10.64

Time	Speed	Torque	Time	Speed	Torque	Time	Speed	Torque
739	78.39	8.91	780	88.38	14.74	821	60.26	13.76
740	79.42	5.00	781	77.61	5.79	822	60.01	5.00
741	79.85	5.00	782	52.75	44.35	823	57.13	5.00
742	80.36	5.00	783	60.97	56.49	824	54.25	5.00
743	79.82	5.00	784	73.21	73.35	825	51.02	5.00
744	78.75	5.00	785	86.65	87.25	826	47.53	5.00
745	78.55	5.00	786	97.95	67.38	827	43.49	5.00
746	79.97	5.00	787	97.69	5.00	828	40.26	5.00
747	80.83	5.00	788	93.75	5.00	829	37.16	5.00
748	81.11	5.00	789	88.37	5.00	830	32.95	5.00
749	80.77	5.00	790	85.48	17.62	831	29.38	5.00
750	81.32	7.33	791	87.85	41.53	832	21.60	5.00
751	82.36	7.11	792	89.61	34.20	833	32.11	5.00
752	82.65	5.00	793	90.94	41.19	834	43.74	15.50
753	82.48	5.90	794	91.26	38.96	835	48.44	24.38
754	82.66	10.63	795	90.35	32.87	836	51.12	13.79
755	83.29	14.59	796	89.06	38.39	837	51.78	9.13
756	84.93	22.87	797	87.25	38.81	838	51.65	9.43
757	86.68	21.59	798	85.51	42.35	839	52.52	8.98
758	87.21	11.54	799	83.63	44.27	840	53.09	5.00
759	86.64	17.04	800	82.20	40.63	841	53.38	5.00
760	86.34	20.11	801	78.82	23.52	842	54.58	7.03
761	85.33	18.15	802	73.50	21.35	843	59.87	10.19
762	85.41	15.93	803	67.35	5.00	844	61.39	5.00
763	86.13	13.19	804	62.64	25.58	845	59.85	5.00
764	86.12	5.00	805	58.74	27.61	846	60.44	5.00
765	83.50	5.00	806	55.47	21.31	847	60.26	5.00
766	83.29	10.72	807	54.17	32.77	848	59.18	5.00
767	86.96	18.91	808	53.65	18.76	849	59.05	5.00
768	90.18	9.55	809	50.86	5.00	850	59.76	5.00
769	90.13	8.59	810	48.54	5.00	851	62.17	5.00
770	88.85	11.43	811	49.17	16.85	852	66.31	5.00
771	88.70	14.50	812	51.80	20.19	853	70.33	5.00
772	89.04	16.15	813	56.22	23.35	854	75.37	5.00
773	89.46	19.02	814	57.78	5.00	855	82.45	5.00
774	90.02	18.28	815	56.63	5.00	856	88.06	5.00
775	89.67	9.19	816	56.26	15.36	857	94.03	5.00
776	87.57	13.32	817	57.12	21.03	858	98.22	5.00
777	87.36	15.49	818	59.19	29.19	859	101.89	5.00
778	87.48	14.81	819	60.49	18.47	860	105.23	5.00
779	87.75	15.52	820	59.90	9.22	861	108.39	5.00

Time	Speed	Torque	Time	Speed	Torque	Time	Speed	Torque
862	111.38	5.00	903	89.06	5.00	944	87.87	5.00
863	113.18	5.00	904	86.49	5.00	945	84.14	5.00
864	115.19	5.00	905	83.42	5.00	946	79.57	5.00
865	114.91	5.00	906	79.96	5.00	947	76.64	5.00
866	111.92	5.00	907	77.03	5.00	948	75.33	5.00
867	107.65	5.00	908	73.93	5.00	949	75.46	5.00
868	103.55	5.00	909	72.39	5.00	950	76.42	5.00
869	100.20	5.00	910	77.96	21.58	951	78.69	5.00
870	98.64	5.00	911	84.41	20.08	952	80.09	5.00
871	98.13	5.00	912	88.72	5.00	953	82.61	5.00
872	97.39	5.00	913	87.70	5.00	954	84.93	5.00
873	95.29	5.00	914	88.18	5.55	955	87.51	5.00
874	91.78	5.00	915	90.20	9.32	956	90.73	5.00
875	86.49	5.00	916	91.26	5.00	957	94.15	5.00
876	81.79	5.00	917	90.68	6.00	958	97.03	5.00
877	85.81	32.48	918	90.50	13.63	959	100.49	5.00
878	93.13	29.16	919	91.53	18.26	960	103.25	5.00
879	96.36	5.00	920	91.93	17.25	961	105.57	5.00
880	94.45	5.00	921	91.87	19.04	962	107.72	5.00
881	93.40	5.00	922	91.54	26.74	963	108.88	5.00
882	93.83	5.00	923	89.64	18.08	964	109.55	5.00
883	94.52	5.00	924	85.77	10.49	965	109.31	5.00
884	95.24	5.00	925	83.24	21.76	966	99.06	5.00
885	95.94	8.08	926	81.97	23.56	967	67.69	5.00
886	97.52	9.45	927	80.35	14.29	968	70.93	5.00
887	98.60	7.92	928	75.18	5.00	969	82.46	5.00
888	99.05	8.08	929	68.76	5.00	970	77.29	5.00
889	99.07	9.36	930	64.96	5.00	971	68.09	5.00
890	98.74	10.78	931	60.89	5.00	972	60.57	5.00
891	98.44	10.24	932	58.84	5.00	973	53.89	5.00
892	97.73	7.07	933	59.47	5.00	974	48.30	5.00
893	95.25	5.00	934	62.68	5.00	975	44.64	5.00
894	92.77	5.00	935	67.11	5.00	976	41.89	5.00
895	90.17	5.00	936	72.59	5.00	977	39.03	5.00
896	87.81	5.00	937	79.24	5.00	978	34.42	5.00
897	86.82	5.00	938	86.17	5.00	979	24.56	5.00
898	87.44	5.00	939	90.62	5.00	980	24.27	5.00
899	89.04	5.00	940	93.86	5.00	981	21.39	5.00
900	90.06	5.00	941	95.73	5.00	982	28.92	5.00
901	90.50	5.00	942	94.91	5.00	983	48.77	5.00
902	90.20	5.00	943	91.62	5.00	984	63.78	5.00

Time	Speed	Torque
985	61.34	5.00
986	62.00	5.00
987	62.09	5.00
988	62.20	5.00
989	62.16	6.57
990	61.61	7.72
991	61.14	10.86
992	61.65	8.01
993	60.94	5.00
994	62.51	15.57
995	63.01	10.91
996	61.23	12.32
997	61.16	21.51
998	63.10	21.75
999	64.80	24.92
1000	65.45	24.25
1001	64.99	23.47
1002	62.07	17.31
1003	35.90	40.46
1004	40.04	57.29
1005	50.22	58.06
1006	60.42	40.10
1007	67.39	22.22
1008	69.96	5.00
1009	71.19	5.00
1010	71.55	5.00
1011	71.24	5.00
1012	70.17	6.09
1013	68.97	10.90
1014	66.86	5.00
1015	58.71	5.00
1016	53.16	9.39
1017	51.18	11.60
1018	50.11	15.99
1019	53.17	32.63
1020	59.75	35.05
1021	67.37	31.83
1022	72.32	26.09
1023	75.23	17.46
1024	68.11	5.00
1025	44.85	52.53

Time	Speed	Torque
1026	53.30	60.65
1027	62.75	56.83
1028	66.93	27.35
1029	66.90	24.12
1030	65.77	14.43
1031	59.10	5.00
1032	49.34	5.00
1033	39.82	5.00
1034	32.20	5.00
1035	30.71	42.71
1036	33.11	48.36
1037	35.29	44.60
1038	36.59	37.70
1039	36.87	32.08
1040	35.77	24.13
1041	33.24	19.08
1042	30.09	15.59
1043	26.91	19.30
1044	22.89	6.52
1045	16.18	5.00
1046	12.74	31.15
1047	9.97	30.36
1048	6.59	31.78
1049	6.22	51.51
1050	5.99	56.57
1051	4.29	59.16
1052	2.93	59.53
1053	4.18	61.02
1054	7.87	61.44
1055	12.08	59.65
1056	18.18	59.82
1057	23.80	65.07
1058	29.68	66.73
1059	34.35	48.28
1060	34.28	30.27
1061	29.90	17.71
1062	26.71	26.23
1063	26.03	38.10
1064	28.35	45.13
1065	30.41	40.36
1066	31.26	34.34

Time	Speed	Torque
1067	32.28	39.81
1068	35.67	48.49
1069	38.19	46.83
1070	40.45	48.67
1071	37.37	19.06
1072	32.32	33.99
1073	29.37	57.06
1074	26.99	65.16
1075	23.74	74.92
1076	20.26	63.58
1077	32.65	57.53
1078	49.66	72.53
1079	72.98	83.16
1080	92.88	85.19
1081	100.80	81.81
1082	104.42	77.77
1083	104.54	77.55
1084	104.24	77.85
1085	103.93	77.94
1086	100.04	81.80
1087	96.29	83.64
1088	85.70	85.47
1089	89.18	85.84
1090	97.67	83.62
1091	100.24	77.61
1092	91.10	61.30
1093	81.03	64.94
1094	29.57	9.71
1095	0.00	10.17
1096	0.00	10.07
1097	0.00	11.48
1098	0.00	13.32
1099	0.00	13.44
1100	0.00	13.43
1101	0.00	13.44
1102	0.00	13.45
1103	0.00	13.65
1104	0.00	14.09
1105	0.00	14.60
1106	0.00	14.78
1107	0.00	14.08

Time	Speed	Torque	Time	Speed	Torque	Time	Speed	Torque
1108	0.00	14.55	1149	0.00	8.73	1190	0.00	8.63
1109	0.00	14.36	1150	0.00	8.81	1191	0.00	8.81
1110	0.00	14.02	1151	0.00	8.78	1192	0.00	8.80
1111	0.00	14.02	1152	0.00	8.86	1193	0.00	8.82
1112	0.00	14.27	1153	0.00	8.87	1194	0.00	8.92
1113	0.00	14.35	1154	0.00	8.77	1195	0.00	8.89
1114	0.00	13.97	1155	0.00	8.79	1196	0.00	8.88
1115	0.00	14.14	1156	0.00	8.84	1197	0.00	8.83
1116	7.34	5.00	1157	0.00	8.82	1198	0.00	8.85
1117	0.00	17.10	1158	0.00	8.78	1199	0.00	8.84
1118	0.00	17.66	1159	0.00	8.94	1200	0.00	8.83
1119	0.00	9.47	1160	0.00	9.09	1201	0.00	8.83
1120	0.00	8.48	1161	0.00	11.33	1202	0.00	8.84
1121	0.00	9.13	1162	0.00	11.16	1203	0.00	8.78
1122	0.00	8.11	1163	0.00	11.07	1204	0.00	8.79
1123	0.00	8.33	1164	0.00	11.05	1205	0.00	10.35
1124	0.00	8.37	1165	0.00	10.96	1206	0.00	11.30
1125	0.00	8.28	1166	0.00	8.67	1207	0.00	11.24
1126	0.00	8.48	1167	0.00	8.58	1208	0.00	11.04
1127	0.00	8.61	1168	0.00	8.63	1209	0.00	11.00
1128	0.00	8.59	1169	0.00	8.68	1210	0.00	9.75
1129	0.00	8.62	1170	0.00	8.73	1211	0.00	8.63
1130	0.00	8.55	1171	0.00	8.77	1212	0.00	8.56
1131	0.00	8.58	1172	0.00	8.73	1213	0.00	8.67
1132	0.00	8.63	1173	0.00	8.86	1214	0.00	8.83
1133	0.00	8.66	1174	0.00	8.80	1215	0.00	8.88
1134	0.00	8.65	1175	0.00	8.82	1216	0.00	8.87
1135	0.00	8.70	1176	0.00	8.81	1217	0.00	8.88
1136	0.00	8.72	1177	0.00	8.78	1218	0.00	8.98
1137	0.00	9.61	1178	0.00	8.82	1219	0.00	8.97
1138	0.00	11.24	1179	0.00	8.97	1220	0.00	8.93
1139	0.00	11.07	1180	0.00	8.88	1221	0.00	8.92
1140	0.00	10.84	1181	0.00	8.87	1222	0.00	8.93
1141	0.00	10.91	1182	0.00	8.89	1223	0.00	8.88
1142	0.00	10.74	1183	0.00	11.14	1224	0.00	8.89
1143	0.00	8.57	1184	0.00	11.30	1225	0.00	8.86
1144	0.00	8.55	1185	0.00	11.20	1226	0.00	8.93
1145	0.00	8.53	1186	0.00	11.11	1227	0.00	9.80
1146	0.00	8.55	1187	0.00	11.02	1228	0.00	11.42
1147	0.00	8.76	1188	0.00	9.19	1229	0.00	11.20
1148	0.00	8.72	1189	0.00	8.57	1230	0.00	11.13

Time	Speed	Torque
1231	0.00	11.11
1232	0.00	11.02
1233	0.00	10.33
1234	0.00	8.58
1235	0.00	8.62
1236	0.00	8.68
1237	0.00	8.73
1238	0.00	8.76
1239	0.00	8.72
1240	0.00	8.75
1241	0.00	8.86
1242	0.00	8.76
1243	0.00	8.80
1244	0.00	8.86
1245	0.00	8.74
1246	0.00	8.84
1247	0.00	8.88
1248	0.00	8.83
1249	0.00	8.82
1250	0.00	8.98
1251	0.00	8.99
1252	0.00	11.44
1253	0.00	11.25
1254	0.00	11.03
1255	0.00	10.92
1256	0.00	10.91
1257	0.00	10.88
1258	0.00	8.66
1259	0.00	8.55
1260	0.00	8.60
1261	0.00	8.72
1262	0.00	8.73
1263	0.00	8.74
1264	0.00	8.81
1265	0.00	8.88
1266	0.00	8.74
1267	0.00	8.85
1268	0.00	8.77
1269	0.00	8.90
1270	0.00	8.93
1271	0.00	8.85

Time	Speed	Torque
1272	0.00	8.77
1273	0.00	9.00
1274	0.00	8.84
1275	0.00	8.79
1276	0.00	11.15
1277	0.00	11.22
1278	0.00	11.34
1279	0.00	11.15
1280	0.00	10.99
1281	0.00	11.08
1282	0.00	9.05
1283	0.00	8.48
1284	0.00	8.70
1285	0.00	8.79
1286	0.00	8.78
1287	0.00	8.89
1288	0.00	8.77
1289	0.00	8.83
1290	0.00	8.87
1291	0.00	8.76
1292	0.00	8.78
1293	0.00	8.82
1294	0.00	8.83
1295	0.00	8.85
1296	0.00	8.81
1297	0.00	8.93
1298	0.00	8.83
1299	0.00	8.91
1300	0.00	10.50
1301	0.00	11.43
1302	0.00	11.32
1303	0.00	11.06
1304	0.00	11.04
1305	0.00	10.88
1306	0.00	9.65
1307	0.00	8.52
1308	0.00	8.63
1309	0.00	8.59
1310	0.00	8.66
1311	0.00	8.90
1312	0.00	8.80

Time	Speed	Torque
1313	0.00	8.91
1314	0.00	8.87
1315	0.00	8.80
1316	0.00	8.86
1317	0.00	8.90
1318	0.00	8.86
1319	0.00	8.76
1320	0.00	8.94
1321	0.00	8.91
1322	0.00	8.83
1323	0.00	8.89
1324	0.00	9.70
1325	0.00	11.43
1326	0.00	11.26
1327	0.00	11.17
1328	0.00	11.21
1329	0.00	10.95
1330	0.00	10.35
1331	0.00	8.54
1332	0.00	8.54
1333	0.00	8.66
1334	0.00	8.85
1335	0.00	8.77
1336	0.00	8.91
1337	0.00	8.98
1338	0.00	8.93
1339	0.00	8.95
1340	0.00	8.95
1341	0.00	8.86
1342	0.00	8.93
1343	0.00	8.99
1344	0.00	8.97
1345	0.00	9.02
1346	0.00	9.06
1347	0.00	8.97
1348	0.00	9.27
1349	0.00	11.68
1350	0.00	11.31
1351	0.00	11.30
1352	0.00	11.12
1353	0.00	11.13

Time	Speed	Torque
1354	0.00	11.05
1355	0.00	8.71
1356	0.00	8.56
1357	0.00	8.70
1358	0.00	8.81
1359	0.00	8.75
1360	0.00	8.93
1361	0.00	8.87
1362	0.00	8.95
1363	0.00	8.89
1364	0.00	8.97
1365	0.00	8.91
1366	0.00	8.95
1367	0.00	8.97
1368	0.00	8.88
1369	0.00	8.91
1370	0.00	8.90
1371	0.00	8.91
1372	0.00	8.97
1373	0.00	11.14
1374	0.00	11.44
1375	0.00	11.32
1376	0.00	11.17
1377	0.00	11.49
1378	0.00	11.01
1379	0.00	9.73
1380	0.00	11.55
1381	0.00	16.59
1382	0.00	68.15
1383	0.00	74.44
1384	0.00	24.43
1385	0.00	30.56
1386	2.14	13.12
1387	1.49	11.12
1388	0.00	12.34
1389	1.34	13.75
1390	3.43	21.22
1391	0.00	22.56
1392	0.00	33.98
1393	0.00	31.51
1394	0.00	26.11

Time	Speed	Torque
1395	0.00	24.67
1396	1.89	12.76
1397	0.00	13.81
1398	0.00	14.86
1399	0.00	13.02
1400	0.00	15.33
1401	0.00	16.28
1402	0.00	13.58
1403	0.00	10.51
1404	0.00	11.36
1405	0.00	9.93
1406	0.00	9.95
1407	0.00	10.44
1408	0.00	10.69
1409	0.00	9.99
1410	0.00	10.32
1411	0.00	10.64
1412	0.00	13.60
1413	0.00	23.92
1414	0.00	22.95
1415	0.00	13.19
1416	0.00	15.98
1417	0.00	19.79
1418	0.00	17.00
1419	0.00	15.46
1420	0.00	13.16
1421	2.11	18.37
1422	14.46	19.80
1423	25.04	15.19
1424	33.89	21.58
1425	39.64	20.19
1426	42.54	17.83
1427	44.83	17.93
1428	45.59	16.32
1429	46.74	15.07
1430	51.88	17.53
1431	56.49	15.57
1432	62.51	15.06
1433	62.83	13.15
1434	58.83	8.83
1435	56.80	16.49

Time	Speed	Torque
1436	59.38	15.75
1437	59.47	16.07
1438	58.53	22.42
1439	50.27	5.85
1440	9.95	5.00
1441	0.00	14.20
1442	0.00	17.26
1443	0.00	14.21
1444	0.00	14.13
1445	0.00	14.37
1446	0.00	11.78
1447	0.00	11.41
1448	0.00	8.67
1449	0.00	9.27
1450	0.00	10.83
1451	0.00	18.25
1452	0.00	33.90
1453	0.00	47.67
1454	18.02	46.72
1455	34.30	27.61
1456	34.90	15.02
1457	7.83	5.00
1458	0.00	15.05
1459	1.06	11.25
1460	0.00	25.48
1461	0.00	16.35
1462	0.00	15.57
1463	0.00	17.69
1464	0.00	22.23
1465	0.00	15.21
1466	0.00	12.31
1467	0.00	15.06
1468	0.00	15.01
1469	0.00	12.48
1470	0.00	13.74
1471	0.00	15.36
1472	0.00	12.33
1473	0.00	10.84
1474	0.00	8.53
1475	0.00	8.17
1476	0.00	10.57

Time	Speed	Torque	Time	Speed	Torque	Time	Speed	Torque
1477	0.00	11.10	1518	0.00	12.07	1559	53.41	29.40
1478	0.00	11.37	1519	0.00	13.10	1560	53.64	29.81
1479	0.00	10.72	1520	0.00	14.49	1561	53.93	28.84
1480	0.00	10.76	1521	0.00	9.51	1562	53.65	30.57
1481	0.00	10.60	1522	0.00	16.68	1563	53.72	30.86
1482	0.00	8.97	1523	0.00	15.56	1564	53.67	31.95
1483	0.00	8.43	1524	0.00	16.09	1565	53.79	32.03
1484	0.00	8.33	1525	0.00	18.06	1566	53.36	35.45
1485	0.00	8.46	1526	0.00	12.26	1567	53.45	36.64
1486	0.00	8.65	1527	0.00	15.52	1568	53.73	35.91
1487	0.00	8.66	1528	0.00	13.58	1569	53.79	36.05
1488	0.00	9.46	1529	0.00	14.02	1570	53.59	37.34
1489	0.00	9.01	1530	0.00	14.64	1571	53.65	38.46
1490	0.00	10.22	1531	0.00	15.09	1572	53.56	39.42
1491	0.00	10.14	1532	1.36	19.53	1573	53.90	38.24
1492	0.00	9.56	1533	42.19	32.39	1574	53.73	39.27
1493	0.00	9.19	1534	59.62	15.36	1575	53.70	40.48
1494	0.00	8.87	1535	60.09	13.46	1576	54.51	36.20
1495	0.00	8.88	1536	59.82	13.07	1577	53.86	38.45
1496	0.00	9.10	1537	59.64	13.18	1578	54.01	37.98
1497	0.00	9.03	1538	59.23	14.90	1579	53.84	38.54
1498	0.00	11.16	1539	58.99	16.38	1580	53.37	42.05
1499	0.00	10.69	1540	59.10	16.48	1581	53.66	41.46
1500	0.00	13.61	1541	58.87	15.88	1582	53.15	45.13
1501	0.00	15.46	1542	55.90	15.49	1583	53.33	46.33
1502	0.00	15.18	1543	54.23	18.92	1584	53.07	48.95
1503	0.00	12.43	1544	54.20	20.27	1585	53.62	48.60
1504	0.00	12.97	1545	54.08	22.16	1586	53.79	47.99
1505	0.00	12.12	1546	54.39	21.40	1587	54.07	47.29
1506	0.00	12.54	1547	54.37	22.44	1588	54.54	44.12
1507	0.00	11.97	1548	54.37	23.14	1589	53.82	47.60
1508	0.00	21.64	1549	54.26	24.48	1590	53.92	47.68
1509	0.00	25.84	1550	54.29	25.10	1591	54.59	43.53
1510	0.00	19.31	1551	54.44	24.96	1592	53.90	45.94
1511	0.00	25.81	1552	54.37	25.58	1593	54.02	45.47
1512	8.95	24.65	1553	54.45	24.67	1594	53.59	47.64
1513	7.23	7.58	1554	53.70	26.19	1595	53.63	43.19
1514	0.00	17.77	1555	54.00	24.60	1596	53.45	42.41
1515	0.00	21.71	1556	53.55	27.30	1597	47.57	39.00
1516	0.00	16.20	1557	53.97	25.77	1598	44.97	42.34
1517	0.00	16.52	1558	53.94	25.92	1599	45.28	42.43

Time	Speed	Torque
1600	45.24	43.00
1601	45.14	43.90
1602	45.28	43.64
1603	44.94	46.35
1604	45.83	37.79
1605	40.23	39.67
1606	38.41	45.06
1607	38.30	47.33
1608	38.38	48.74
1609	38.75	48.05
1610	36.67	47.35
1611	35.01	47.18
1612	35.40	45.06
1613	35.02	46.29
1614	36.41	38.08
1615	36.55	33.60
1616	35.61	35.60
1617	35.40	35.43
1618	35.17	34.96
1619	32.97	34.63
1620	33.96	27.59
1621	33.99	22.52
1622	32.62	26.94
1623	31.49	35.93
1624	33.45	25.08
1625	33.57	23.00
1626	32.87	24.81
1627	32.41	27.27
1628	32.54	27.24
1629	32.79	25.68
1630	33.99	19.09
1631	37.36	18.57
1632	42.41	8.37
1633	33.58	10.71
1634	33.01	12.45
1635	33.07	11.53
1636	33.33	8.58
1637	33.50	5.83
1638	32.93	7.41
1639	32.47	9.46
1640	32.62	9.40
1641	32.66	9.15
1642	32.62	9.34
1643	32.49	10.27
1644	32.15	12.99
1645	32.69	11.00
1646	32.57	11.45
1647	31.84	15.75
1648	30.71	26.32
1649	32.79	17.88
1650	33.03	15.49
1651	32.69	17.44
1652	33.27	13.33
1653	33.48	10.30
1654	33.25	9.81
1655	32.27	14.28
1656	32.16	16.19
1657	31.94	18.82
1658	31.89	20.59
1659	31.43	25.63
1660	32.23	23.58
1661	32.22	24.73
1662	32.25	25.39
1663	32.56	24.96
1664	32.56	24.89
1665	32.56	25.22
1666	32.49	25.84
1667	32.37	26.99
1668	32.44	27.27
1669	32.65	26.42
1670	32.63	26.60
1671	32.50	27.60
1672	32.31	29.42
1673	32.58	28.54
1674	32.69	27.89
1675	32.91	26.40
1676	32.68	27.28
1677	32.18	30.41
1678	32.47	29.94
1679	32.82	28.26
1680	32.57	29.34
1681	32.33	31.25
1682	32.71	29.70
1683	32.22	32.52
1684	32.33	33.15
1685	32.45	33.14
1686	32.69	32.43
1687	32.37	33.84
1688	32.83	32.26
1689	31.98	36.93
1690	32.06	38.52
1691	32.10	39.37
1692	32.87	36.64
1693	33.15	33.73
1694	33.05	33.57
1695	32.33	37.10
1696	32.69	35.44
1697	32.99	34.14
1698	34.54	23.85
1699	32.67	30.25
1700	31.49	37.98
1701	31.55	40.63
1702	33.02	34.24
1703	33.57	29.42
1704	33.25	29.40
1705	34.85	18.15
1706	34.48	14.72
1707	33.97	14.04
1708	33.75	12.25
1709	31.75	21.77
1710	33.08	16.47
1711	33.64	11.46
1712	33.31	11.08
1713	32.80	12.73
1714	31.83	18.49
1715	31.25	23.94
1716	31.71	24.82
1717	31.68	27.19
1718	31.96	28.04
1719	31.86	30.26
1720	32.21	39.26
1721	36.58	43.26
1722	39.37	38.24

Time	Speed	Torque	Time	Speed	Torque	Time	Speed	Torque
1723	36.97	40.28	1764	31.94	23.03	1805	33.68	18.02
1724	39.03	36.93	1765	31.63	26.51	1806	35.86	21.30
1725	37.93	30.21	1766	31.60	29.64	1807	44.77	23.23
1726	33.77	27.98	1767	32.00	29.25	1808	49.43	20.48
1727	34.60	20.67	1768	32.03	30.81	1809	49.83	18.14
1728	34.83	13.96	1769	32.06	32.05	1810	49.46	19.17
1729	34.02	13.79	1770	32.76	29.20	1811	48.97	21.80
1730	33.61	13.15	1771	32.74	28.85	1812	49.75	18.26
1731	33.17	13.67	1772	32.75	28.94	1813	49.30	19.51
1732	32.69	15.52	1773	33.12	26.24	1814	49.89	16.30
1733	33.37	11.01	1774	32.54	28.56	1815	49.98	14.32
1734	32.46	14.56	1775	32.65	28.45	1816	49.43	16.29
1735	31.66	20.70	1776	32.17	31.36	1817	49.70	14.39
1736	32.30	19.40	1777	32.82	28.70	1818	50.35	9.63
1737	32.80	16.96	1778	32.74	28.68	1819	49.61	11.52
1738	33.07	15.15	1779	32.66	29.11	1820	49.62	9.89
1739	32.41	18.16	1780	32.55	29.79	1821	46.80	6.79
1740	32.46	18.69	1781	32.39	30.97	1822	43.97	7.63
1741	32.74	17.37	1782	32.86	28.83	1823	35.11	5.00
1742	32.84	16.51	1783	32.39	31.28	1824	31.91	12.75
1743	32.76	16.50	1784	32.53	31.13	1825	31.23	19.08
1744	32.75	16.33	1785	32.77	29.80	1826	32.36	15.19
1745	32.92	15.24	1786	31.81	35.65	1827	32.38	15.92
1746	33.18	12.83	1787	32.14	35.53	1828	31.96	19.00
1747	33.32	10.89	1788	31.69	39.77	1829	31.87	21.45
1748	33.14	10.75	1789	32.30	38.14	1830	30.13	34.64
1749	33.20	8.80	1790	31.48	44.11	1831	31.35	32.59
1750	33.03	8.75	1791	31.06	49.91	1832	32.18	30.73
1751	32.64	9.98	1792	31.33	51.95	1833	32.53	29.78
1752	32.22	12.51	1793	33.42	42.55	1834	32.85	28.10
1753	32.58	12.28	1794	34.25	34.82	1835	32.83	28.25
1754	32.58	11.83	1795	34.31	30.68	1836	32.72	28.19
1755	32.09	15.25	1796	33.89	29.32	1837	32.69	28.35
1756	32.68	13.20	1797	33.29	29.78	1838	32.78	27.67
1757	32.22	15.20	1798	32.39	34.19	1839	32.75	27.68
1758	32.18	17.12	1799	32.99	31.42	1840	32.50	28.99
1759	32.26	17.51	1800	33.79	25.48	1841	32.56	28.97
1760	32.01	19.95	1801	35.00	14.92	1842	32.68	28.48
1761	32.55	18.38	1802	32.99	20.50	1843	32.58	29.05
1762	32.50	19.20	1803	31.75	31.47	1844	32.52	29.70
1763	32.67	18.39	1804	33.63	21.38	1845	32.41	30.97

Time	Speed	Torque
1846	32.81	28.99
1847	32.28	31.95
1848	32.44	32.00
1849	32.30	32.98
1850	31.46	39.62
1851	32.38	36.66
1852	32.59	36.24
1853	32.40	37.76
1854	32.73	36.16
1855	33.03	34.16
1856	33.26	32.02
1857	32.83	33.19
1858	33.24	30.57
1859	32.91	31.01
1860	32.48	33.32
1861	32.77	32.02
1862	32.92	30.48
1863	31.98	35.57
1864	33.90	26.18
1865	34.94	15.78
1866	33.00	21.90
1867	33.51	18.04
1868	33.22	17.84
1869	33.29	16.18
1870	33.22	15.09
1871	32.96	15.29
1872	31.61	22.77
1873	33.09	16.41
1874	32.86	16.62
1875	32.68	17.28
1876	32.86	16.26
1877	32.97	15.07
1878	32.93	14.48
1879	32.68	15.44
1880	33.03	13.45
1881	33.17	11.46
1882	33.10	10.63
1883	32.83	11.17
1884	32.29	13.80
1885	32.24	15.99
1886	32.71	13.18

Time	Speed	Torque
1887	31.30	21.78
1888	31.36	25.15
1889	31.94	24.27
1890	31.50	29.15
1891	32.45	25.99
1892	32.35	27.25
1893	32.78	25.25
1894	32.65	25.90
1895	32.45	27.07
1896	32.66	26.35
1897	32.47	27.45
1898	32.64	27.13
1899	32.77	26.24
1900	32.58	27.31
1901	32.88	25.58
1902	32.91	24.88
1903	32.89	24.44
1904	32.88	23.88
1905	32.68	24.81
1906	33.81	18.11
1907	33.54	16.63
1908	33.49	14.53
1909	27.50	20.57
1910	32.60	18.74
1911	33.10	15.85
1912	32.85	16.37
1913	33.04	14.85
1914	33.05	13.73
1915	32.80	14.47
1916	33.08	12.31
1917	33.14	11.04
1918	33.18	9.54
1919	33.10	8.88
1920	32.43	11.68
1921	32.44	12.42
1922	32.13	14.66
1923	32.45	14.23
1924	32.97	13.09
1925	52.50	23.19
1926	55.53	17.08
1927	55.54	23.98

Time	Speed	Torque
1928	56.68	17.92
1929	56.59	17.40
1930	49.86	11.84
1931	37.06	14.08
1932	32.91	14.80
1933	32.12	19.20
1934	35.34	17.03
1935	59.64	22.68
1936	64.87	11.36
1937	62.49	22.36
1938	58.23	27.95
1939	54.30	20.03
1940	48.62	19.89
1941	37.61	24.04
1942	33.65	16.19
1943	31.43	29.67
1944	34.03	14.92
1945	33.36	16.07
1946	33.17	15.65
1947	30.36	9.39
1948	26.68	12.06
1949	22.04	15.59
1950	22.00	16.90
1951	21.80	18.59
1952	21.61	21.45
1953	21.14	25.83
1954	21.74	25.58
1955	20.91	32.67
1956	21.79	30.09
1957	21.54	33.29
1958	21.26	37.04
1959	22.03	35.05
1960	27.21	35.29
1961	30.84	20.56
1962	23.17	25.13
1963	22.81	24.98
1964	22.38	26.95
1965	22.52	25.62
1966	21.92	29.32
1967	25.24	33.30
1968	28.63	22.25

Time	Speed	Torque
1969	23.14	22.13
1970	22.69	22.98
1971	21.91	27.18
1972	24.05	14.87
1973	23.45	13.41
1974	22.99	15.21
1975	22.08	17.67
1976	20.85	27.73
1977	21.78	25.55
1978	22.79	20.27
1979	23.94	11.84
1980	21.96	18.40
1981	21.44	25.23
1982	23.26	15.43
1983	22.13	20.41
1984	22.56	18.27
1985	22.44	18.18
1986	22.30	18.74
1987	22.07	20.89
1988	22.21	19.90
1989	22.67	17.73
1990	22.11	20.55
1991	22.43	19.23
1992	23.25	13.49
1993	22.75	12.02
1994	18.04	7.31
1995	16.76	8.39
1996	16.74	7.76
1997	16.74	7.00
1998	16.55	6.97
1999	14.25	21.81
2000	16.01	17.23
2001	16.13	16.90
2002	18.36	22.57
2003	23.18	16.16
2004	12.73	19.20
2005	13.68	32.13
2006	15.99	25.93
2007	16.21	27.24
2008	17.62	25.60
2009	17.38	27.14

Time	Speed	Torque
2010	17.44	27.83
2011	17.76	26.09
2012	17.47	27.66
2013	17.36	29.02
2014	17.32	30.08
2015	17.57	29.31
2016	17.58	29.43
2017	17.60	29.74
2018	17.86	28.05
2019	18.00	26.53
2020	17.87	26.63
2021	17.93	25.67
2022	17.66	26.76
2023	17.34	28.88
2024	17.52	28.70
2025	17.76	27.51
2026	18.10	25.10
2027	18.25	22.75
2028	18.46	19.68
2029	17.91	19.92
2030	16.90	26.94
2031	17.71	24.01
2032	18.67	17.36
2033	18.35	16.50
2034	17.80	18.60
2035	17.54	20.24
2036	17.99	17.28
2037	17.27	21.53
2038	17.65	19.80
2039	17.52	21.02
2040	17.95	18.49
2041	17.77	18.78
2042	17.28	21.99
2043	18.20	17.48
2044	18.96	10.61
2045	18.35	11.45
2046	18.31	10.09
2047	18.52	6.80
2048	17.61	10.89
2049	18.08	7.40
2050	15.10	26.72

Time	Speed	Torque
2051	17.78	17.48
2052	17.21	19.68
2053	17.32	20.21
2054	16.74	25.05
2055	17.36	23.48
2056	17.31	24.23
2057	17.10	26.77
2058	17.47	25.47
2059	17.25	27.40
2060	17.30	28.20
2061	17.07	30.64
2062	17.31	30.69
2063	17.45	30.68
2064	17.49	30.86
2065	17.56	30.82
2066	17.72	30.14
2067	17.82	29.24
2068	18.08	27.19
2069	17.65	29.03
2070	18.16	25.79
2071	17.80	26.65
2072	17.83	26.30
2073	17.55	27.53
2074	17.90	25.83
2075	17.66	26.57
2076	17.80	25.69
2077	17.84	25.44
2078	19.51	12.90
2079	17.83	19.76
2080	16.91	25.48
2081	17.00	27.17
2082	18.63	18.12
2083	18.15	18.52
2084	17.84	19.35
2085	17.83	19.35
2086	17.60	19.83
2087	17.58	20.59
2088	18.17	16.79
2089	18.07	16.22
2090	18.01	15.61
2091	18.02	14.60

Time	Speed	Torque
2092	18.02	13.78
2093	18.42	10.34
2094	17.92	11.57
2095	18.08	9.91
2096	18.42	6.76
2097	18.12	7.14
2098	16.03	18.42
2099	16.13	27.38
2100	17.28	22.02
2101	17.42	21.51
2102	16.70	27.10
2103	18.34	19.46
2104	17.57	21.97
2105	17.50	22.73
2106	17.70	21.94
2107	17.45	23.42
2108	17.79	21.71
2109	17.49	23.28
2110	17.39	24.13
2111	17.33	25.01
2112	17.77	23.03
2113	17.64	23.77
2114	17.78	22.77
2115	17.87	22.03
2116	17.66	22.80
2117	15.86	34.66
2118	16.80	33.05
2119	17.76	28.82
2120	17.74	28.32
2121	16.88	34.18
2122	17.09	35.00
2123	18.60	26.13
2124	18.41	25.11
2125	17.83	27.06
2126	17.78	26.34
2127	17.02	26.49
2128	14.85	28.40
2129	15.12	27.10
2130	15.02	27.40
2131	15.00	27.51
2132	14.89	28.30

Time	Speed	Torque
2133	15.17	26.76
2134	15.16	26.23
2135	14.78	28.46
2136	14.96	27.83
2137	14.90	28.45
2138	14.97	28.15
2139	14.58	30.86
2140	14.82	30.47
2141	15.19	28.27
2142	15.43	26.29
2143	15.36	25.33
2144	15.15	26.01
2145	16.79	15.27
2146	16.22	13.63
2147	13.28	30.25
2148	13.71	32.29
2149	14.04	33.47
2150	14.49	32.91
2151	15.21	29.78
2152	17.17	15.80
2153	15.12	24.04
2154	14.06	31.13
2155	15.27	25.15
2156	15.91	20.20
2157	15.08	23.06
2158	15.53	19.54
2159	14.69	23.74
2160	14.96	23.01
2161	15.58	18.85
2162	14.89	21.76
2163	15.42	19.06
2164	15.25	18.68
2165	15.68	15.30
2166	15.37	15.40
2167	15.16	16.39
2168	15.81	11.49
2169	15.41	12.07
2170	15.71	8.97
2171	15.98	5.79
2172	15.24	7.59
2173	12.63	24.64

Time	Speed	Torque
2174	14.05	23.99
2175	14.81	20.69
2176	13.82	28.14
2177	14.15	29.04
2178	14.83	26.45
2179	14.91	26.44
2180	14.62	28.56
2181	14.98	27.32
2182	14.77	28.56
2183	14.49	31.27
2184	14.76	30.84
2185	15.04	29.56
2186	14.94	30.04
2187	14.93	30.33
2188	15.24	28.44
2189	15.19	28.18
2190	15.20	27.35
2191	14.73	30.20
2192	15.51	25.68
2193	15.10	26.88
2194	14.65	29.67
2195	14.80	29.78
2196	15.41	26.13
2197	15.37	25.35
2198	15.26	24.97
2199	15.23	25.11
2200	15.83	18.88
2201	14.26	28.27
2202	15.59	21.79
2203	16.83	10.71
2204	14.41	22.49
2205	14.00	27.23
2206	15.16	21.89
2207	15.79	17.40
2208	15.59	16.36
2209	14.59	21.62
2210	14.98	20.58
2211	15.40	17.39
2212	15.12	18.21
2213	15.15	18.22
2214	15.41	15.51

Time	Speed	Torque	Time	Speed	Torque	Time	Speed	Torque
2215	15.30	15.59	2256	14.76	26.06	2297	15.33	26.91
2216	15.29	14.75	2257	15.70	20.52	2298	15.25	26.25
2217	15.16	14.92	2258	15.80	17.85	2299	15.14	26.62
2218	15.60	11.79	2259	15.60	16.78	2300	15.01	27.03
2219	15.64	9.70	2260	15.16	18.33	2301	15.16	26.27
2220	15.25	10.87	2261	15.05	18.70	2302	14.81	27.84
2221	15.52	8.27	2262	15.38	16.17	2303	14.94	27.91
2222	15.50	6.98	2263	15.04	17.36	2304	14.83	28.46
2223	15.11	8.52	2264	15.22	16.22	2305	14.67	30.09
2224	12.59	25.83	2265	15.02	16.86	2306	16.75	17.46
2225	13.82	27.36	2266	15.15	15.86	2307	16.41	12.86
2226	14.61	23.42	2267	15.28	14.69	2308	14.44	23.42
2227	14.69	24.02	2268	15.34	13.44	2309	14.63	24.12
2228	14.49	26.32	2269	15.22	13.59	2310	14.87	23.56
2229	14.91	24.64	2270	15.63	10.17	2311	15.58	19.00
2230	14.85	25.30	2271	15.50	9.43	2312	15.70	16.73
2231	14.16	30.45	2272	15.27	9.54	2313	15.07	19.04
2232	14.60	29.75	2273	15.56	7.15	2314	14.77	20.96
2233	14.74	29.67	2274	15.22	7.65	2315	15.31	18.10
2234	14.77	30.21	2275	14.11	14.08	2316	15.38	16.58
2235	14.88	30.00	2276	14.37	15.07	2317	15.33	16.04
2236	15.08	29.07	2277	14.96	11.71	2318	15.42	14.63
2237	15.26	27.51	2278	13.45	23.75	2319	15.31	14.32
2238	15.07	28.15	2279	14.06	23.38	2320	15.23	14.04
2239	15.08	27.85	2280	14.42	23.30	2321	15.32	12.87
2240	15.37	25.72	2281	13.90	28.27	2322	15.12	13.25
2241	15.10	26.50	2282	14.61	26.59	2323	15.57	10.04
2242	15.25	25.38	2283	15.01	24.63	2324	15.25	10.76
2243	15.14	25.39	2284	14.91	25.35	2325	15.36	9.26
2244	15.06	25.59	2285	14.75	26.55	2326	15.20	9.47
2245	14.99	25.82	2286	14.43	29.62	2327	14.98	10.07
2246	14.64	28.41	2287	14.76	28.76	2328	15.21	8.92
2247	15.16	25.78	2288	14.78	29.26	2329	14.67	11.89
2248	15.11	25.75	2289	14.70	30.30	2330	13.99	17.99
2249	15.32	24.14	2290	14.85	30.12	2331	14.34	18.19
2250	14.97	25.38	2291	14.94	30.02	2332	14.63	18.17
2251	14.90	26.35	2292	15.02	29.52	2333	14.78	18.05
2252	17.35	10.32	2293	15.06	29.42	2334	14.88	17.99
2253	15.47	15.85	2294	14.93	29.99	2335	16.34	9.15
2254	14.29	22.77	2295	15.19	28.36	2336	13.78	22.28
2255	13.42	30.90	2296	15.03	28.93	2337	14.59	19.69

Time	Speed	Torque
2338	14.15	24.63
2339	15.19	20.02
2340	14.53	23.90
2341	14.61	24.54
2342	14.71	24.94
2343	14.70	25.72
2344	14.49	28.11
2345	14.64	28.39
2346	14.83	28.11
2347	15.04	27.14
2348	15.02	27.19
2349	14.83	28.29
2350	14.61	30.37
2351	14.75	30.37
2352	14.88	30.25
2353	14.94	30.07
2354	15.08	29.21
2355	15.15	28.56
2356	15.59	25.13
2357	15.26	25.90
2358	15.13	26.04
2359	14.84	27.61
2360	14.90	27.89
2361	15.23	25.82
2362	15.30	24.82
2363	15.34	23.63
2364	14.86	25.85
2365	15.61	22.02
2366	16.73	10.57
2367	14.30	23.59
2368	14.54	23.90
2369	14.94	22.61
2370	15.86	16.44
2371	15.43	16.79
2372	14.91	19.37
2373	14.70	21.45
2374	15.68	15.31
2375	14.99	18.16
2376	15.11	17.59
2377	15.24	16.19
2378	15.18	15.89
2379	15.20	15.51
2380	15.35	13.97
2381	15.59	11.54
2382	15.43	10.69
2383	15.53	9.19
2384	15.28	9.40
2385	15.46	7.30
2386	15.14	8.41
2387	15.55	5.00
2388	14.17	12.13
2389	13.33	25.35
2390	14.77	18.42
2391	14.25	22.40
2392	15.96	28.41
2393	20.56	27.24
2394	21.11	25.41
2395	21.34	24.35
2396	21.26	24.99
2397	20.89	27.63
2398	20.80	29.13
2399	21.07	28.89
2400	21.23	28.16
2401	20.94	30.45
2402	21.32	28.98
2403	21.47	27.95
2404	21.41	28.11
2405	21.59	26.88
2406	22.50	27.23
2407	22.98	25.41
2408	22.55	27.46
2409	23.06	24.46
2410	22.72	25.65
2411	22.39	27.73
2412	22.65	27.09
2413	23.05	24.16
2414	23.03	23.31
2415	20.51	19.89
2416	14.77	25.62
2417	17.12	10.58
2418	15.29	15.87
2419	14.80	19.25
2420	14.63	21.09
2421	15.38	16.85
2422	15.66	13.96
2423	15.33	14.30
2424	14.70	17.71
2425	14.16	22.09
2426	15.07	18.58
2427	15.31	16.55
2428	15.27	16.10
2429	14.91	17.51
2430	15.53	14.04
2431	15.19	14.61
2432	15.17	14.39
2433	15.39	12.56
2434	15.09	13.31
2435	14.96	14.08
2436	15.44	11.22
2437	15.10	12.09
2438	15.10	12.00
2439	14.67	14.12
2440	13.37	23.70
2441	13.72	27.12
2442	14.03	27.79
2443	14.38	28.01
2444	14.41	29.37
2445	15.12	26.11
2446	14.81	27.88
2447	14.72	29.08
2448	14.54	30.86
2449	14.73	31.14
2450	14.84	31.08
2451	14.95	30.73
2452	15.08	29.84
2453	15.27	28.53
2454	15.05	29.08
2455	15.01	29.42
2456	15.36	27.21
2457	15.15	27.45
2458	14.71	30.09
2459	14.94	29.51
2460	15.47	26.06

Time	Speed	Torque
2461	15.44	24.99
2462	15.29	24.84
2463	15.12	25.48
2464	15.01	25.59
2465	17.33	9.87
2466	15.53	14.73
2467	14.49	21.04
2468	15.07	18.61
2469	15.52	15.37
2470	15.67	13.02
2471	15.03	15.48
2472	14.74	17.42
2473	14.91	17.22
2474	15.00	16.61
2475	15.06	16.30
2476	15.23	14.89
2477	15.07	15.30
2478	15.20	14.14
2479	14.94	15.64
2480	14.97	15.32
2481	15.15	14.34
2482	15.13	13.89
2483	15.27	12.66
2484	15.54	10.16
2485	15.12	11.53
2486	15.29	10.28
2487	15.32	9.15
2488	15.60	6.51
2489	15.26	7.27
2490	15.15	7.33
2491	15.25	6.06
2492	14.83	8.29
2493	28.82	29.58
2494	57.59	15.60
2495	51.89	12.14
2496	28.09	5.00
2497	19.41	38.99
2498	15.60	19.23
2499	15.61	16.28
2500	11.70	43.85
2501	16.44	21.59

Time	Speed	Torque
2502	16.09	19.75
2503	15.75	20.24
2504	15.89	17.41
2505	15.88	15.12
2506	15.26	17.38
2507	15.63	14.11
2508	15.50	13.20
2509	15.16	14.33
2510	15.31	13.10
2511	15.90	8.29
2512	4.26	5.00
2513	0.00	16.37
2514	0.00	11.68
2515	0.00	8.92
2516	0.00	11.61
2517	0.00	6.03
2518	0.00	5.64
2519	0.00	5.60
2520	0.00	5.00
2521	0.00	5.00
2522	0.00	5.00
2523	0.00	5.00
2524	0.00	5.00
2525	0.00	5.00
2526	0.00	5.00
2527	0.00	5.00
2528	0.00	18.40
2529	10.15	41.57
2530	14.99	34.81
2531	17.96	29.82
2532	29.89	62.64
2533	33.45	46.00
2534	29.07	28.40
2535	27.05	26.40
2536	21.19	27.20
2537	18.52	30.40
2538	16.13	36.70
2539	20.87	40.40
2540	20.93	42.30
2541	21.33	41.90
2542	21.84	44.40

Time	Speed	Torque
2543	23.06	39.10
2544	22.59	40.60
2545	20.86	35.60
2546	14.03	29.30
2547	6.90	19.19
2548	0.00	17.00
2549	0.00	19.00
2550	0.00	17.40
2551	0.00	31.07
2552	0.00	30.80
2553	4.46	31.60
2554	7.35	31.50
2555	31.58	39.70
2556	48.28	21.90
2557	35.20	22.19
2558	38.78	28.10
2559	34.61	17.20
2560	27.95	28.60
2561	28.02	28.60
2562	28.52	25.50
2563	28.71	18.20
2564	28.05	16.10
2565	27.84	16.60
2566	27.84	17.00
2567	27.86	17.00
2568	27.87	17.70
2569	26.46	24.30
2570	28.32	19.70
2571	28.13	17.00
2572	26.98	22.38
2573	26.95	43.60
2574	27.72	46.60
2575	28.23	44.40
2576	28.25	43.40
2577	8.81	28.59
2578	0.00	25.50
2579	0.00	33.70
2580	0.00	28.00
2581	2.71	40.50
2582	7.78	32.40
2583	6.87	33.90

Time	Speed	Torque
2584	6.12	35.57
2585	2.29	31.20
2586	4.18	32.90
2587	5.46	35.20
2588	20.40	48.93
2589	28.63	45.20
2590	31.88	51.60
2591	36.29	44.40
2592	31.57	40.00
2593	30.13	47.00
2594	29.99	39.80
2595	27.16	43.70
2596	28.10	43.30
2597	28.01	43.90
2598	28.04	42.70
2599	14.67	22.27
2600	1.03	22.80
2601	1.83	17.00
2602	4.41	28.98
2603	9.92	35.50
2604	18.52	34.60
2605	19.80	35.60
2606	23.13	34.20
2607	25.49	33.00
2608	26.65	28.50
2609	22.59	18.46
2610	12.82	21.60
2611	22.20	32.30
2612	31.87	58.26
2613	41.19	85.30
2614	44.59	99.70
2615	43.11	100.00
2616	46.09	100.00
2617	54.25	100.00
2618	63.07	100.00
2619	68.86	100.00
2620	73.36	100.00
2621	76.40	100.00
2622	79.54	100.00
2623	80.59	100.00
2624	80.39	99.50

Time	Speed	Torque
2625	78.70	94.26
2626	75.59	99.30
2627	71.76	94.90
2628	61.96	31.95
2629	52.83	-1.00
2630	48.39	-1.00
2631	45.37	-1.00
2632	42.22	56.33
2633	41.26	98.80
2634	44.78	100.00
2635	53.65	100.00
2636	64.20	91.96
2637	57.06	27.04
2638	47.80	-1.00
2639	45.15	-1.00
2640	43.93	-1.00
2641	42.46	-1.00
2642	41.23	-1.00
2643	40.24	-1.00
2644	39.00	-1.00
2645	37.07	-1.00
2646	36.31	-1.00
2647	34.40	-1.00
2648	34.45	-1.00
2649	34.09	-1.00
2650	33.53	-1.00
2651	33.73	-1.00
2652	33.33	-1.00
2653	34.59	-1.00
2654	37.63	-1.00
2655	40.88	-1.00
2656	44.07	-1.00
2657	50.06	-1.00
2658	70.38	-1.00
2659	93.74	-1.00
2660	90.44	-1.00
2661	85.52	-1.00
2662	86.81	-1.00
2663	89.10	-1.00
2664	89.95	-1.00
2665	91.71	-1.00

Time	Speed	Torque
2666	92.92	-1.00
2667	93.98	-1.00
2668	94.83	-1.00
2669	94.94	-1.00
2670	94.21	-1.00
2671	93.36	-1.00
2672	93.21	-1.00
2673	93.54	-1.00
2674	94.49	-1.00
2675	94.40	-1.00
2676	95.31	-1.00
2677	94.71	-1.00
2678	95.10	-1.00
2679	94.30	-1.00
2680	95.17	-1.00
2681	96.32	-1.00
2682	96.38	-1.00
2683	96.70	-1.00
2684	97.41	-1.00
2685	97.22	-1.00
2686	94.66	-1.00
2687	90.01	-1.00
2688	84.42	-1.00
2689	78.06	-1.00
2690	72.23	-1.00
2691	67.07	-1.00
2692	62.51	-1.00
2693	58.94	-1.00
2694	56.17	-1.00
2695	54.10	-1.00
2696	52.54	-1.00
2697	51.66	-1.00
2698	51.15	-1.00
2699	51.47	-1.00
2700	53.53	-1.00
2701	56.76	-1.00
2702	61.34	-1.00
2703	64.16	-1.00
2704	69.09	-1.00
2705	72.32	-1.00
2706	73.47	-1.00

Time	Speed	Torque	Time	Speed	Torque	Time	Speed	Torque
2707	73.30	-1.00	2748	54.65	-1.00	2789	34.39	-1.00
2708	72.60	-1.00	2749	54.19	-1.00	2790	32.86	-1.00
2709	73.76	-1.00	2750	54.02	-1.00	2791	31.43	-1.00
2710	75.18	-1.00	2751	54.98	-1.00	2792	30.33	-1.00
2711	70.31	-1.00	2752	50.42	-1.00	2793	29.68	-1.00
2712	57.16	-1.00	2753	25.71	-1.00	2794	27.76	-1.00
2713	52.13	-1.00	2754	15.05	-1.00	2795	25.78	-1.00
2714	52.26	-1.00	2755	22.71	-1.00	2796	22.47	-1.00
2715	52.89	-1.00	2756	32.23	-1.00	2797	17.98	-1.00
2716	54.94	-1.00	2757	36.55	19.60	2798	12.59	-1.00
2717	57.45	-1.00	2758	40.60	71.71	2799	14.67	17.68
2718	61.00	-1.00	2759	52.74	38.00	2800	20.13	9.00
2719	63.69	-1.00	2760	55.43	35.84	2801	24.22	28.10
2720	66.16	-1.00	2761	52.59	-1.00	2802	29.03	44.66
2721	68.03	-1.00	2762	48.58	-1.00	2803	30.86	39.00
2722	69.66	-1.00	2763	45.43	-1.00	2804	29.12	29.00
2723	71.30	-1.00	2764	43.33	-1.00	2805	28.20	40.80
2724	73.41	-1.00	2765	45.89	-1.00	2806	30.01	20.00
2725	75.23	-1.00	2766	49.83	-1.00	2807	26.85	35.60
2726	75.31	-1.00	2767	51.98	-1.00	2808	30.67	39.31
2727	74.49	-1.00	2768	53.12	-1.00	2809	29.97	15.52
2728	72.58	-1.00	2769	53.16	-1.00	2810	29.66	7.90
2729	70.93	-1.00	2770	53.04	-1.00	2811	27.95	11.10
2730	69.36	-1.00	2771	52.33	-1.00	2812	28.70	5.70
2731	67.83	-1.00	2772	52.62	-1.00	2813	27.69	7.70
2732	66.30	-1.00	2773	53.25	-1.00	2814	28.02	10.50
2733	64.55	-1.00	2774	51.96	-1.00	2815	28.60	-1.00
2734	64.05	-1.00	2775	48.78	-1.00	2816	27.40	8.50
2735	62.77	-1.00	2776	45.02	-1.00	2817	28.86	9.50
2736	62.29	-1.00	2777	43.54	-1.00	2818	31.83	29.76
2737	63.02	-1.00	2778	52.22	-1.00	2819	40.97	51.10
2738	63.65	-1.00	2779	45.15	-1.00	2820	46.35	21.30
2739	64.00	-1.00	2780	31.81	-1.00	2821	52.49	56.90
2740	64.38	-1.00	2781	25.92	64.59	2822	58.59	-1.00
2741	64.06	-1.00	2782	32.51	76.76	2823	51.29	-1.00
2742	63.92	-1.00	2783	35.86	20.76	2824	31.55	-1.00
2743	63.50	-1.00	2784	37.55	-1.00	2825	19.08	-1.00
2744	61.54	-1.00	2785	39.01	16.00	2826	17.69	-1.00
2745	59.11	-1.00	2786	40.65	70.05	2827	16.46	-1.00
2746	56.68	-1.00	2787	41.48	28.31	2828	14.92	-1.00
2747	55.44	-1.00	2788	35.70	-1.00	2829	22.38	20.10

Time	Speed	Torque	Time	Speed	Torque	Time	Speed	Torque
2830	25.06	21.20	2871	28.00	10.40	2912	34.79	55.90
2831	26.14	40.40	2872	28.47	7.20	2913	35.02	57.50
2832	27.49	47.50	2873	27.87	7.50	2914	35.52	55.50
2833	30.69	65.90	2874	27.88	7.90	2915	35.19	56.90
2834	39.68	63.21	2875	28.04	8.20	2916	35.60	54.90
2835	44.31	73.99	2876	28.03	7.60	2917	35.22	54.00
2836	53.89	90.61	2877	27.73	9.10	2918	34.23	54.20
2837	64.90	94.31	2878	28.12	7.60	2919	32.29	56.10
2838	73.46	100.00	2879	27.92	8.70	2920	32.08	54.30
2839	80.43	100.00	2880	28.03	7.20	2921	30.50	54.30
2840	82.93	99.70	2881	27.86	8.70	2922	29.57	52.30
2841	88.34	71.61	2882	28.12	7.00	2923	28.21	50.20
2842	77.41	45.28	2883	27.80	8.30	2924	29.74	36.90
2843	62.79	36.76	2884	27.99	7.90	2925	26.61	45.10
2844	45.47	27.20	2885	27.95	7.80	2926	27.00	56.10
2845	31.58	28.30	2886	27.89	8.90	2927	27.96	62.30
2846	22.46	24.40	2887	28.01	8.90	2928	29.77	67.30
2847	13.13	-1.00	2888	27.92	8.20	2929	31.21	54.00
2848	11.40	28.41	2889	28.18	6.40	2930	30.25	57.90
2849	22.99	34.31	2890	27.59	9.10	2931	32.17	62.20
2850	26.47	21.80	2891	27.87	8.80	2932	33.29	52.70
2851	28.10	23.60	2892	27.75	12.30	2933	32.58	46.60
2852	27.63	34.00	2893	27.74	12.60	2934	28.91	47.60
2853	28.35	30.20	2894	27.28	18.20	2935	27.64	53.60
2854	28.21	28.90	2895	27.06	27.20	2936	28.54	50.00
2855	29.07	22.90	2896	27.45	35.00	2937	27.36	57.10
2856	28.26	19.60	2897	27.07	42.20	2938	28.87	54.90
2857	27.65	22.80	2898	27.50	52.80	2939	28.54	51.80
2858	28.37	21.00	2899	31.15	55.91	2940	27.80	58.30
2859	28.95	15.00	2900	31.04	47.60	2941	31.15	60.80
2860	28.42	10.30	2901	30.97	75.50	2942	31.20	54.10
2861	27.58	13.50	2902	39.91	64.20	2943	31.79	55.50
2862	27.83	15.60	2903	41.70	51.90	2944	32.22	43.10
2863	28.36	14.70	2904	40.38	54.70	2945	27.33	50.60
2864	28.47	10.10	2905	39.40	52.00	2946	28.19	51.60
2865	27.58	12.60	2906	36.03	56.50	2947	28.01	51.20
2866	28.22	13.00	2907	36.07	42.10	2948	28.38	50.40
2867	28.33	9.70	2908	30.59	60.60	2949	28.17	52.60
2868	27.55	11.60	2909	33.39	54.40	2950	24.60	69.10
2869	28.43	11.80	2910	32.63	53.80	2951	35.99	72.82
2870	28.08	8.40	2911	32.98	61.00	2952	42.40	48.73

Time	Speed	Torque
2953	41.87	52.68
2954	40.14	74.52
2955	42.62	54.94
2956	39.92	50.52
2957	37.64	54.40
2958	37.88	47.80
2959	32.00	62.30
2960	34.43	59.90
2961	34.33	48.90
2962	33.13	60.60
2963	35.71	59.20
2964	35.80	53.00
2965	33.76	68.90
2966	36.59	68.80
2967	34.45	68.40
2968	35.12	66.98
2969	37.61	75.95
2970	39.55	74.80
2971	43.92	86.00
2972	45.02	85.80
2973	46.22	83.40
2974	45.20	82.10
2975	43.85	85.10
2976	44.39	85.20
2977	44.54	83.70
2978	44.35	84.60
2979	44.43	84.60
2980	44.56	83.90
2981	44.55	82.00
2982	44.29	82.20
2983	44.44	82.00
2984	44.71	79.50
2985	44.47	77.90
2986	44.36	79.20
2987	44.29	80.10
2988	44.96	77.00
2989	44.39	75.20
2990	44.24	77.40
2991	44.46	76.50
2992	44.40	76.50
2993	44.64	74.90

Time	Speed	Torque
2994	44.73	72.00
2995	44.43	72.90
2996	44.71	69.20
2997	45.57	62.10
2998	43.10	60.50
2999	44.45	61.80
3000	43.56	63.30
3001	43.15	59.40
3002	42.58	61.50
3003	40.83	54.70
3004	39.95	59.20
3005	40.81	53.70
3006	37.58	40.20
3007	30.30	20.90
3008	26.53	23.90
3009	26.83	35.80
3010	25.11	23.80
3011	21.97	31.70
3012	24.94	29.10
3013	23.32	26.30
3014	20.78	23.30
3015	18.95	27.30
3016	19.07	31.70
3017	20.90	29.80
3018	22.21	33.80
3019	27.93	32.60
3020	27.90	36.80
3021	27.70	41.00
3022	27.42	48.70
3023	27.23	56.10
3024	29.15	51.80
3025	29.22	46.60
3026	27.32	51.80
3027	28.89	55.30
3028	29.10	45.40
3029	27.69	56.80
3030	30.19	56.30
3031	31.86	49.80
3032	33.29	60.10
3033	35.67	68.94
3034	39.36	42.70

Time	Speed	Torque
3035	37.28	32.00
3036	30.31	50.90
3037	37.81	73.60
3038	42.22	52.47
3039	38.50	29.80
3040	31.35	26.40
3041	25.20	55.72
3042	29.92	37.75
3043	27.42	26.60
3044	26.19	45.30
3045	28.22	48.90
3046	27.50	54.70
3047	28.09	55.30
3048	28.24	57.05
3049	21.57	35.94
3050	20.82	39.80
3051	22.71	38.60
3052	23.53	35.20
3053	22.96	39.50
3054	24.76	37.80
3055	21.73	40.20
3056	19.68	49.70
3057	22.62	55.80
3058	26.12	47.80
3059	26.48	50.60
3060	27.08	48.30
3061	27.88	49.70
3062	27.67	46.30
3063	25.86	42.00
3064	25.30	44.30
3065	11.04	28.70
3066	8.45	23.30
3067	3.55	17.60
3068	0.00	17.00
3069	0.00	16.90
3070	0.00	5.69
3071	0.00	5.00
3072	0.00	5.00
3073	0.00	5.00
3074	0.00	5.00
3075	0.00	5.00

Time	Speed	Torque
3076	0.00	5.00
3077	0.00	5.00
3078	0.00	5.00
3079	0.00	5.00
3080	0.00	5.00
3081	0.00	5.00
3082	0.00	5.00
3083	0.00	5.00
3084	0.00	5.00
3085	0.00	5.00
3086	0.00	5.00
3087	0.00	5.00
3088	0.00	5.00
3089	0.00	5.00
3090	0.00	5.00
3091	0.00	5.00
3092	0.00	5.00
3093	0.00	5.00
3094	0.00	5.00
3095	0.00	5.00
3096	0.00	5.00
3097	0.00	5.00
3098	0.00	5.00
3099	0.00	5.00
3100	0.00	5.00
3101	0.00	5.00
3102	0.00	5.00
3103	0.00	5.00
3104	0.00	5.00
3105	0.00	5.00
3106	0.00	5.00
3107	0.00	5.00
3108	0.00	5.00
3109	0.00	5.00
3110	0.00	5.00
3111	0.00	5.00
3112	0.00	5.00
3113	0.00	5.00
3114	0.00	5.00
3115	0.00	5.00
3116	0.00	5.00
3117	0.00	5.00
3118	0.00	5.00
3119	0.00	5.00
3120	0.00	5.00
3121	0.00	5.00
3122	0.00	5.00
3123	0.00	5.00
3124	0.00	5.00
3125	0.00	5.00
3126	0.00	5.00
3127	0.00	5.00
3128	0.00	5.00
3129	0.00	5.00
3130	0.00	5.00
3131	0.00	5.00
3132	0.00	5.00
3133	0.00	5.00
3134	0.00	5.00
3135	0.00	5.00
3136	0.00	5.00
3137	0.00	5.00
3138	0.00	5.00
3139	0.00	5.00
3140	0.00	5.00
3141	0.00	5.00
3142	0.00	5.00
3143	0.00	5.00
3144	0.00	5.00
3145	0.00	5.00
3146	0.00	5.00
3147	0.00	5.00
3148	0.00	5.00
3149	0.00	5.00
3150	0.00	5.00
3151	0.00	5.00
3152	0.00	5.00
3153	0.00	5.00
3154	0.00	5.00
3155	0.00	5.00
3156	0.00	5.00
3157	0.00	5.00
3158	0.00	5.00
3159	0.00	5.00
3160	0.00	5.00
3161	0.00	5.00
3162	0.00	5.00
3163	0.00	5.00
3164	0.00	5.00
3165	0.00	5.00
3166	0.00	5.00
3167	0.00	5.00
3168	0.00	5.00
3169	0.00	5.00
3170	0.00	5.00
3171	0.00	5.00
3172	0.00	5.00
3173	0.00	5.00
3174	0.00	5.00
3175	0.00	5.00
3176	0.00	5.00
3177	0.00	5.00
3178	0.00	5.00
3179	0.00	5.00
3180	0.00	5.00
3181	0.00	5.00
3182	0.00	5.00
3183	0.00	5.00
3184	0.00	5.00
3185	0.00	5.00
3186	0.00	5.00
3187	0.00	5.00
3188	0.00	5.00
3189	0.00	5.00
3190	0.00	5.00
3191	0.00	5.00
3192	0.00	5.00
3193	0.00	5.00
3194	0.00	5.00
3195	0.00	5.00
3196	0.00	5.00
3197	0.00	5.00
3198	0.00	5.00

Time	Speed	Torque	Time	Speed	Torque	Time	Speed	Torque
3199	0.00	5.00	3240	0.00	5.00	3281	0.00	5.00
3200	0.00	5.00	3241	0.00	5.00	3282	0.00	5.00
3201	0.00	5.00	3242	0.00	5.00	3283	0.00	5.00
3202	0.00	5.00	3243	0.00	5.00	3284	0.00	5.00
3203	0.00	5.00	3244	0.00	5.00	3285	0.00	5.00
3204	0.00	5.00	3245	0.00	5.00	3286	0.00	5.00
3205	0.00	5.00	3246	0.00	5.00	3287	0.00	5.00
3206	0.00	5.00	3247	0.00	5.00	3288	0.00	5.00
3207	0.00	5.00	3248	0.00	5.00	3289	0.00	5.00
3208	0.00	5.00	3249	0.00	5.00	3290	0.00	5.00
3209	0.00	5.00	3250	0.00	5.00	3291	0.00	5.00
3210	0.00	5.00	3251	0.00	5.00	3292	0.00	5.00
3211	0.00	5.00	3252	0.00	5.00	3293	0.00	5.00
3212	0.00	5.00	3253	0.00	5.00	3294	0.00	5.00
3213	0.00	5.00	3254	0.00	5.00	3295	0.00	5.00
3214	0.00	5.00	3255	0.00	5.00	3296	0.00	5.00
3215	0.00	5.00	3256	0.00	5.00	3297	0.00	5.00
3216	0.00	5.00	3257	0.00	5.00	3298	0.00	5.00
3217	0.00	5.00	3258	0.00	5.00	3299	0.00	5.00
3218	0.00	5.00	3259	0.00	5.00	3300	0.00	5.00
3219	0.00	5.00	3260	0.00	5.00	3301	0.00	5.00
3220	0.00	5.00	3261	0.00	5.00	3302	0.00	5.00
3221	0.00	5.00	3262	0.00	5.00	3303	0.00	5.00
3222	0.00	5.00	3263	0.00	5.00	3304	0.00	5.00
3223	0.00	5.00	3264	0.00	5.00	3305	0.00	5.00
3224	0.00	5.00	3265	0.00	5.00	3306	0.00	5.00
3225	0.00	5.00	3266	0.00	5.00	3307	0.00	5.00
3226	0.00	5.00	3267	0.00	5.00	3308	0.00	5.00
3227	0.00	5.00	3268	0.00	5.00	3309	0.00	5.00
3228	0.00	5.00	3269	0.00	5.00	3310	0.00	5.00
3229	0.00	5.00	3270	0.00	5.00	3311	0.00	5.00
3230	0.00	5.00	3271	0.00	5.00	3312	0.00	5.00
3231	0.00	5.00	3272	0.00	5.00	3313	0.00	5.00
3232	0.00	5.00	3273	0.00	5.00	3314	0.00	5.00
3233	0.00	5.00	3274	0.00	5.00	3315	0.00	5.00
3234	0.00	5.00	3275	0.00	5.00	3316	0.00	5.00
3235	0.00	5.00	3276	0.00	5.00	3317	0.00	5.00
3236	0.00	5.00	3277	0.00	5.00	3318	0.00	5.00
3237	0.00	5.00	3278	0.00	5.00	3319	0.00	5.00
3238	0.00	5.00	3279	0.00	5.00	3320	0.00	5.00
3239	0.00	5.00	3280	0.00	5.00	3321	0.00	5.00

Time	Speed	Torque
3322	0.00	5.00
3323	0.00	5.00
3324	0.00	5.00
3325	0.00	5.00
3326	0.00	5.00
3327	0.00	5.00
3328	0.00	5.00
3329	0.00	5.00
3330	0.00	5.00
3331	0.00	5.00
3332	0.00	5.00
3333	0.00	5.00
3334	0.00	5.00
3335	0.00	5.00
3336	0.00	5.00
3337	0.00	5.00
3338	0.00	5.00
3339	0.00	5.00
3340	0.00	5.00
3341	0.00	5.00
3342	0.00	5.00
3343	0.00	5.00
3344	0.00	5.00
3345	0.00	5.00
3346	0.00	5.00
3347	0.00	5.00
3348	0.00	5.00
3349	0.00	5.00
3350	0.00	5.00
3351	0.00	5.00
3352	0.00	5.00
3353	0.00	5.00
3354	0.00	5.00
3355	0.00	5.00
3356	0.00	5.00
3357	0.00	5.00
3358	0.00	5.00
3359	0.00	5.00
3360	0.00	5.00
3361	0.00	5.00
3362	0.00	5.00

Time	Speed	Torque
3363	0.00	5.00
3364	0.00	5.00
3365	0.00	5.00
3366	0.00	5.00
3367	0.00	5.00
3368	0.00	5.00
3369	0.00	5.00
3370	0.00	5.00
3371	0.00	5.00
3372	0.00	5.00
3373	0.00	5.00
3374	0.00	5.00
3375	0.00	5.00
3376	0.00	5.00
3377	0.00	5.00
3378	0.00	5.00
3379	0.00	5.00
3380	0.00	5.00
3381	0.00	5.00
3382	0.00	5.00
3383	0.00	5.00
3384	0.00	5.00
3385	0.00	5.00
3386	0.00	5.00
3387	0.00	5.00
3388	0.00	5.00
3389	0.00	5.00
3390	0.00	5.00
3391	0.00	5.00
3392	0.00	5.00
3393	0.00	5.00
3394	0.00	5.00
3395	0.00	5.00
3396	0.00	5.00
3397	0.00	5.00
3398	0.00	5.00
3399	0.00	5.00
3400	0.00	5.00
3401	0.00	5.00
3402	0.00	5.00
3403	0.00	5.00

Time	Speed	Torque
3404	0.00	5.00
3405	0.00	5.00
3406	0.00	5.00
3407	0.00	5.00
3408	0.00	5.00
3409	0.00	5.00
3410	0.00	5.00
3411	0.00	5.00
3412	0.00	5.00
3413	0.00	5.00
3414	0.00	5.00
3415	0.00	5.00
3416	0.00	5.00
3417	0.00	5.00
3418	0.00	5.00
3419	0.00	5.00
3420	0.00	5.00
3421	0.00	5.00
3422	12.29	18.64
3423	59.98	15.33
3424	81.06	23.70
3425	109.48	25.09
3426	108.71	39.15
3427	106.77	60.65
3428	108.81	53.31
3429	110.24	30.37
3430	109.69	34.94
3431	109.48	36.93
3432	109.83	34.73
3433	110.58	26.61
3434	110.15	25.54
3435	108.55	43.19
3436	107.42	56.66
3437	106.76	69.30
3438	108.09	58.90
3439	106.98	64.89
3440	106.99	67.23
3441	105.69	78.24
3442	105.71	84.11
3443	105.96	80.36
3444	104.86	89.10

Time	Speed	Torque
3445	100.79	97.87
3446	96.59	100.00
3447	90.92	100.00
3448	89.98	100.00
3449	98.56	100.00
3450	100.80	100.00
3451	100.86	100.00
3452	98.33	100.00
3453	97.00	100.00
3454	95.94	100.00
3455	96.21	100.00
3456	95.92	100.00
3457	94.75	100.00
3458	97.50	100.00
3459	88.09	100.00
3460	88.75	100.00
3461	93.38	100.00
3462	107.19	75.07
3463	109.88	39.39
3464	107.78	55.24
3465	107.39	60.87
3466	108.66	54.23
3467	110.48	33.77
3468	110.25	28.64
3469	110.18	28.40
3470	109.74	31.74
3471	103.64	30.43
3472	99.61	53.74
3473	111.20	30.32
3474	100.83	49.39
3475	109.80	44.92
3476	109.86	40.11
3477	110.45	30.15
3478	106.65	29.56
3479	105.59	68.76
3480	110.87	36.91
3481	110.04	33.18
3482	110.04	32.01
3483	109.82	34.66
3484	102.19	51.83
3485	110.89	48.72
3486	108.80	40.40
3487	110.34	32.45
3488	109.73	34.40
3489	102.68	54.27
3490	110.79	66.11
3491	109.93	30.86
3492	110.09	32.59
3493	108.71	27.44
3494	106.35	46.31
3495	110.40	32.97
3496	109.84	33.42
3497	109.97	33.10
3498	109.85	33.36
3499	108.70	34.45
3500	99.75	37.16
3501	104.96	66.90
3502	110.88	33.34
3503	106.89	38.36
3504	100.88	84.52
3505	108.45	63.91
3506	109.28	43.17
3507	108.51	49.10
3508	108.56	49.42
3509	108.80	48.42
3510	108.74	48.48
3511	109.00	46.74
3512	108.88	46.26
3513	108.49	47.81
3514	109.06	44.44
3515	109.25	40.54
3516	108.65	45.80
3517	108.76	46.81
3518	109.25	43.87
3519	108.89	44.59
3520	108.86	45.53
3521	108.72	47.35
3522	109.03	44.12
3523	109.10	44.54
3524	108.59	47.09
3525	107.44	57.38
3526	108.68	51.59
3527	108.53	51.43
3528	109.39	44.70
3529	108.09	51.03
3530	108.71	51.54
3531	108.90	44.90
3532	108.62	49.57
3533	109.05	43.04
3534	109.05	45.96
3535	108.75	44.86
3536	108.76	45.29
3537	108.43	48.69
3538	104.49	42.34
3539	80.36	5.00
3540	72.65	35.48
3541	72.34	42.77
3542	74.34	36.22
3543	72.25	41.51
3544	73.55	40.63
3545	73.81	33.50
3546	73.48	35.13
3547	74.22	32.21
3548	75.45	34.51
3549	88.60	10.15
3550	74.07	12.25
3551	72.72	38.14
3552	71.86	46.39
3553	61.19	25.95
3554	62.98	35.64
3555	60.91	18.86
3556	53.83	40.70
3557	60.76	60.42
3558	83.50	85.87
3559	107.31	72.03
3560	116.96	43.40
3561	108.78	43.12
3562	108.20	55.65
3563	110.23	36.72
3564	109.73	36.07
3565	109.88	34.46
3566	109.89	33.66
3567	127.42	31.55

Time	Speed	Torque	Time	Speed	Torque	Time	Speed	Torque
3568	113.91	20.04	3609	109.89	31.28	3650	110.02	33.17
3569	109.23	38.51	3610	110.36	28.94	3651	109.51	37.53
3570	109.63	35.57	3611	110.24	28.94	3652	109.80	35.51
3571	109.66	36.25	3612	110.42	28.86	3653	109.96	33.67
3572	109.83	35.02	3613	107.91	23.80	3654	109.95	33.84
3573	109.17	40.09	3614	75.45	5.00	3655	109.86	34.37
3574	109.44	40.57	3615	64.93	27.26	3656	109.92	33.59
3575	108.51	45.08	3616	67.12	19.24	3657	109.65	35.25
3576	107.06	61.13	3617	64.36	30.97	3658	109.34	39.40
3577	107.10	65.39	3618	64.81	33.99	3659	109.59	38.05
3578	108.59	54.53	3619	65.39	29.02	3660	109.80	35.57
3579	109.30	44.12	3620	56.60	25.10	3661	109.78	35.01
3580	108.40	45.81	3621	53.99	32.91	3662	109.71	35.13
3581	107.26	61.58	3622	57.74	25.70	3663	109.66	35.98
3582	105.71	71.12	3623	87.78	47.87	3664	109.73	35.76
3583	104.75	91.01	3624	110.96	32.76	3665	109.40	38.74
3584	108.43	65.50	3625	102.40	40.64	3666	109.66	37.15
3585	106.80	64.32	3626	111.20	42.15	3667	109.80	35.40
3586	108.26	61.20	3627	106.22	47.45	3668	109.67	36.28
3587	107.99	52.01	3628	111.91	29.34	3669	109.80	35.83
3588	107.17	63.95	3629	110.13	29.72	3670	109.66	36.55
3589	108.69	56.12	3630	110.24	28.19	3671	109.57	36.68
3590	109.25	44.23	3631	110.67	26.14	3672	109.62	37.29
3591	108.68	46.68	3632	110.47	25.31	3673	109.89	34.78
3592	108.08	53.46	3633	103.80	45.45	3674	109.69	35.48
3593	108.44	52.89	3634	111.89	36.44	3675	109.64	36.71
3594	108.48	51.13	3635	109.69	31.88	3676	109.71	36.01
3595	109.35	45.73	3636	110.56	27.36	3677	109.83	35.26
3596	110.26	33.49	3637	107.08	35.00	3678	110.06	32.55
3597	110.24	29.94	3638	110.39	36.76	3679	109.94	32.39
3598	108.76	40.30	3639	110.00	29.39	3680	109.93	33.36
3599	108.93	47.28	3640	101.66	29.70	3681	110.01	33.05
3600	107.74	54.16	3641	106.56	57.36	3682	110.05	32.17
3601	108.35	56.39	3642	110.32	27.86	3683	109.97	32.56
3602	109.91	40.57	3643	102.89	63.36	3684	110.03	32.00
3603	110.20	30.40	3644	110.35	41.62	3685	109.99	32.43
3604	109.73	35.64	3645	101.57	40.86	3686	109.93	33.32
3605	110.45	30.68	3646	109.16	44.62	3687	109.88	33.60
3606	110.21	30.14	3647	110.51	60.74	3688	110.08	32.10
3607	110.98	23.73	3648	103.06	98.81	3689	101.89	5.00
3608	110.49	22.53	3649	110.31	53.49	3690	79.87	5.00

Time	Speed	Torque
3691	37.15	5.00
3692	46.31	5.00
3693	0.00	6.03
3694	0.00	5.64
3695	0.00	5.60
3696	0.00	5.69
3697	0.00	5.00
3698	0.00	5.00
3699	0.00	5.00
3700	0.00	5.00
3701	0.00	5.00
3702	0.00	5.00
3703	0.00	5.00
3704	0.00	5.00
3705	0.00	5.00
3706	0.00	5.00
3707	0.00	5.00
3708	0.00	5.00
3709	0.00	5.00
3710	0.00	5.00
3711	0.00	5.00
3712	0.00	5.00
3713	0.00	5.00
3714	0.00	5.00
3715	0.00	5.00
3716	0.00	5.00
3717	0.00	5.00
3718	0.00	5.00
3719	0.00	5.00
3720	0.00	5.00
3721	0.00	5.00
3722	0.00	5.00
3723	0.00	5.00
3724	0.00	5.00
3725	0.00	5.00
3726	0.00	5.00
3727	0.00	5.00
3728	0.00	5.00
3729	0.00	5.00
3730	0.00	5.00
3731	0.00	5.00

Time	Speed	Torque
3732	0.00	5.00
3733	0.00	5.00
3734	0.00	5.00
3735	0.00	5.00
3736	0.00	5.00
3737	0.00	5.00
3738	0.00	5.00
3739	0.00	5.00
3740	0.00	5.00
3741	0.00	5.00
3742	0.00	5.00
3743	0.00	5.00
3744	0.00	5.00
3745	0.00	5.00
3746	0.00	5.00
3747	0.00	5.00
3748	0.00	5.00
3749	0.00	5.00
3750	0.00	5.00
3751	0.00	5.00
3752	0.00	5.00
3753	0.00	5.00
3754	0.00	5.00
3755	0.00	5.00
3756	0.00	5.00
3757	0.00	5.00
3758	0.00	5.00
3759	0.00	5.00
3760	0.00	5.00
3761	0.00	5.00
3762	0.00	5.00
3763	0.00	5.00
3764	0.00	5.00
3765	0.00	5.00
3766	0.00	5.00
3767	0.00	5.00
3768	0.00	5.00
3769	0.00	5.00
3770	0.00	5.00
3771	0.00	5.00
3772	0.00	5.00

Time	Speed	Torque
3773	0.00	5.00
3774	0.00	5.00
3775	0.00	5.00
3776	0.00	5.00
3777	0.00	5.00
3778	0.00	5.00
3779	0.00	5.00
3780	0.00	5.00
3781	0.00	5.00
3782	0.00	5.00
3783	0.00	5.00
3784	0.00	5.00
3785	0.00	5.00
3786	0.00	5.00
3787	0.00	5.00
3788	0.00	5.00
3789	0.00	5.00
3790	0.00	5.00
3791	0.00	5.00
3792	0.00	5.00
3793	0.00	5.00
3794	0.00	5.00
3795	0.00	5.00
3796	0.00	5.00
3797	0.00	5.00
3798	0.00	5.00
3799	0.00	5.00
3800	0.00	5.00
3801	0.00	5.00
3802	0.00	5.00
3803	0.00	5.00
3804	0.00	5.00
3805	0.00	5.00
3806	0.00	5.00
3807	0.00	5.00
3808	0.00	5.00
3809	0.00	5.00
3810	0.00	5.00
3811	0.00	5.00
3812	0.00	5.00
3813	0.00	5.00

Time	Speed	Torque
3814	0.00	5.00
3815	0.00	5.00
3816	0.00	5.00
3817	0.00	5.00
3818	0.00	5.00
3819	0.00	5.00
3820	0.00	5.00
3821	0.00	5.00
3822	0.00	5.00
3823	0.00	5.00
3824	0.00	5.00
3825	0.00	5.00
3826	0.00	5.00
3827	0.00	5.00
3828	0.00	5.00
3829	0.00	5.00
3830	0.00	5.00
3831	0.00	5.00
3832	0.00	5.00
3833	0.00	5.00
3834	0.00	5.00
3835	0.00	5.00
3836	0.00	5.00
3837	0.00	5.00
3838	0.00	5.00
3839	0.00	5.00
3840	0.00	5.00
3841	0.00	5.00
3842	0.00	5.00
3843	0.00	5.00
3844	0.00	5.00
3845	0.00	5.00
3846	0.00	5.00
3847	0.00	5.00
3848	0.00	5.00
3849	0.00	5.00
3850	0.00	5.00
3851	0.00	5.00
3852	0.00	5.00
3853	0.00	5.00
3854	0.00	5.00
3855	0.00	5.00
3856	0.00	5.00
3857	0.00	5.00
3858	0.00	5.00
3859	0.00	5.00
3860	0.00	5.00
3861	0.00	5.00
3862	0.00	5.00
3863	0.00	5.00
3864	0.00	5.00
3865	0.00	5.00
3866	0.00	5.00
3867	0.00	5.00
3868	0.00	5.00
3869	0.00	5.00
3870	0.00	5.00
3871	0.00	5.00
3872	0.00	5.00
3873	0.00	5.00
3874	0.00	5.00
3875	0.00	5.00
3876	0.00	5.00
3877	0.00	5.00
3878	0.00	5.00
3879	0.00	5.00
3880	0.00	5.00
3881	0.00	5.00
3882	0.00	5.00
3883	0.00	5.00
3884	0.00	5.00
3885	0.00	5.00
3886	0.00	5.00
3887	0.00	5.00
3888	0.00	5.00
3889	0.00	5.00
3890	0.00	5.00
3891	0.00	5.00
3892	0.00	5.00
3893	0.00	5.00
3894	0.00	5.00
3895	0.00	5.00
3896	0.00	5.00
3897	0.00	5.00
3898	0.00	5.00
3899	0.00	5.00
3900	0.00	5.00
3901	0.00	5.00
3902	0.00	5.00
3903	0.00	5.00
3904	0.00	5.00
3905	0.00	5.00
3906	0.00	5.00
3907	0.00	5.00
3908	0.00	5.00
3909	0.00	5.00
3910	0.00	5.00
3911	0.00	5.00
3912	0.00	5.00
3913	0.00	5.00
3914	0.00	5.00
3915	0.00	5.00
3916	0.00	5.00
3917	0.00	5.00
3918	0.00	5.00
3919	0.00	5.00
3920	0.00	5.00
3921	0.00	5.00
3922	0.00	5.00
3923	0.00	5.00
3924	0.00	5.00
3925	0.00	5.00
3926	0.00	5.00
3927	0.00	5.00
3928	0.00	5.00
3929	0.00	5.00
3930	0.00	5.00
3931	0.00	5.00
3932	0.00	5.00
3933	0.00	5.00
3934	0.00	5.00
3935	0.00	5.00
3936	0.00	5.00

Time	Speed	Torque
3937	0.00	5.00
3938	0.00	5.00
3939	0.00	5.00
3940	0.00	5.00
3941	0.00	5.00
3942	0.00	5.00
3943	0.00	5.00
3944	0.00	5.00
3945	0.00	5.00
3946	0.00	5.00
3947	0.00	5.00
3948	0.00	5.00
3949	0.00	5.00
3950	0.00	5.00
3951	0.00	5.00
3952	0.00	5.00
3953	0.00	5.00
3954	0.00	5.00
3955	0.00	5.00
3956	0.00	5.00
3957	0.00	5.00
3958	0.00	5.00
3959	0.00	5.00
3960	0.00	5.00
3961	0.00	5.00
3962	0.00	5.00
3963	0.00	5.00
3964	0.00	5.00
3965	0.00	5.00
3966	0.00	5.00
3967	0.00	5.00
3968	0.00	5.00
3969	0.00	5.00
3970	0.00	5.00
3971	0.00	5.00
3972	0.00	5.00
3973	0.00	5.00
3974	0.00	5.00
3975	0.00	5.00
3976	0.00	5.00
3977	0.00	5.00
3978	0.00	5.00
3979	0.00	5.00
3980	0.00	5.00
3981	0.00	5.00
3982	0.00	5.00
3983	0.00	5.00
3984	0.00	5.00
3985	0.00	5.00
3986	0.00	5.00
3987	0.00	5.00
3988	0.00	5.00
3989	0.00	5.00
3990	0.00	5.00
3991	0.00	5.00
3992	0.00	5.00
3993	0.00	5.00
3994	0.00	5.00
3995	0.00	5.00
3996	0.00	5.00
3997	0.00	5.00
3998	0.00	5.00
3999	0.00	5.00
4000	0.00	5.00
4001	0.00	5.00
4002	0.00	5.00
4003	0.00	5.00
4004	0.00	5.00
4005	0.00	5.00
4006	0.00	5.00
4007	0.00	5.00
4008	0.00	5.00
4009	0.00	5.00
4010	0.00	5.00
4011	0.00	5.00
4012	0.00	5.00
4013	0.00	5.00
4014	0.00	5.00
4015	0.00	5.00
4016	0.00	5.00
4017	0.00	5.00
4018	0.00	5.00
4019	0.00	5.00
4020	0.00	5.00
4021	0.00	5.00
4022	0.00	5.00
4023	0.00	5.00
4024	0.00	5.00
4025	0.00	5.00
4026	0.00	5.00
4027	0.00	5.00
4028	0.00	5.00
4029	0.00	5.00
4030	0.00	5.00
4031	0.00	5.00
4032	0.00	5.00
4033	0.00	5.00
4034	0.00	5.00
4035	0.00	5.00
4036	0.00	5.00
4037	0.00	5.00
4038	0.00	5.00
4039	0.00	5.00
4040	0.00	5.00
4041	0.00	5.00
4042	0.00	5.00
4043	0.00	5.00
4044	0.00	5.00
4045	0.00	5.00
4046	0.00	5.00
4047	0.00	5.00
4048	12.29	18.64
4049	59.98	15.33
4050	81.06	23.70
4051	109.48	25.09
4052	108.71	39.15
4053	106.77	60.65
4054	108.81	53.31
4055	110.24	30.37
4056	109.69	34.94
4057	109.48	36.93
4058	109.83	34.73
4059	110.58	26.61

Time	Speed	Torque
4060	110.15	25.54
4061	108.55	43.19
4062	107.42	56.66
4063	106.76	69.30
4064	108.09	58.90
4065	106.98	64.89
4066	106.99	67.23
4067	105.69	78.24
4068	105.71	84.11
4069	105.96	80.36
4070	104.86	89.10
4071	100.79	97.87
4072	96.59	100.00
4073	90.92	100.00
4074	89.98	100.00
4075	98.56	100.00
4076	100.80	100.00
4077	100.86	100.00
4078	98.33	100.00
4079	97.00	100.00
4080	95.94	100.00
4081	96.21	100.00
4082	95.92	100.00
4083	94.75	100.00
4084	97.50	100.00
4085	88.09	100.00
4086	88.75	100.00
4087	93.38	100.00
4088	107.19	75.07
4089	109.88	39.39
4090	107.78	55.24
4091	107.39	60.87
4092	108.66	54.23
4093	110.48	33.77
4094	110.25	28.64
4095	110.18	28.40
4096	109.74	31.74
4097	103.64	30.43
4098	99.61	53.74
4099	111.20	30.32
4100	100.83	49.39

Time	Speed	Torque
4101	109.80	44.92
4102	109.86	40.11
4103	110.45	30.15
4104	106.65	29.56
4105	105.59	68.76
4106	110.87	36.91
4107	110.04	33.18
4108	110.04	32.01
4109	109.82	34.66
4110	102.19	51.83
4111	110.89	48.72
4112	108.80	40.40
4113	110.34	32.45
4114	109.73	34.40
4115	102.68	54.27
4116	110.79	66.11
4117	109.93	30.86
4118	110.09	32.59
4119	108.71	27.44
4120	106.35	46.31
4121	110.40	32.97
4122	109.84	33.42
4123	109.97	33.10
4124	109.85	33.36
4125	108.70	34.45
4126	99.75	37.16
4127	104.96	66.90
4128	110.88	33.34
4129	106.89	38.36
4130	100.88	84.52
4131	108.45	63.91
4132	109.28	43.17
4133	108.51	49.10
4134	108.56	49.42
4135	108.80	48.42
4136	108.74	48.48
4137	109.00	46.74
4138	108.88	46.26
4139	108.49	47.81
4140	109.06	44.44
4141	109.25	40.54

Time	Speed	Torque
4142	108.65	45.80
4143	108.76	46.81
4144	109.25	43.87
4145	108.89	44.59
4146	108.86	45.53
4147	108.72	47.35
4148	109.03	44.12
4149	109.10	44.54
4150	108.59	47.09
4151	107.44	57.38
4152	108.68	51.59
4153	108.53	51.43
4154	109.39	44.70
4155	108.09	51.03
4156	108.71	51.54
4157	108.90	44.90
4158	108.62	49.57
4159	109.05	43.04
4160	109.05	45.96
4161	108.75	44.86
4162	108.76	45.29
4163	108.43	48.69
4164	104.49	42.34
4165	80.36	5.00
4166	72.65	35.48
4167	72.34	42.77
4168	74.34	36.22
4169	72.25	41.51
4170	73.55	40.63
4171	73.81	33.50
4172	73.48	35.13
4173	74.22	32.21
4174	75.45	34.51
4175	88.60	10.15
4176	74.07	12.25
4177	72.72	38.14
4178	71.86	46.39
4179	61.19	25.95
4180	62.98	35.64
4181	60.91	18.86
4182	53.83	40.70

Time	Speed	Torque
4183	60.76	60.42
4184	83.50	85.87
4185	107.31	72.03
4186	116.96	43.40
4187	108.78	43.12
4188	108.20	55.65
4189	110.23	36.72
4190	109.73	36.07
4191	109.88	34.46
4192	109.89	33.66
4193	127.42	31.55
4194	113.91	20.04
4195	109.23	38.51
4196	109.63	35.57
4197	109.66	36.25
4198	109.83	35.02
4199	109.17	40.09
4200	109.44	40.57
4201	108.51	45.08
4202	107.06	61.13
4203	107.10	65.39
4204	108.59	54.53
4205	109.30	44.12
4206	108.40	45.81
4207	107.26	61.58
4208	105.71	71.12
4209	104.75	91.01
4210	108.43	65.50
4211	106.80	64.32
4212	108.26	61.20
4213	107.99	52.01
4214	107.17	63.95
4215	108.69	56.12
4216	109.25	44.23
4217	108.68	46.68
4218	108.08	53.46
4219	108.44	52.89
4220	108.48	51.13
4221	109.35	45.73
4222	110.26	33.49
4223	110.24	29.94

Time	Speed	Torque
4224	108.76	40.30
4225	108.93	47.28
4226	107.74	54.16
4227	108.35	56.39
4228	109.91	40.57
4229	110.20	30.40
4230	109.73	35.64
4231	110.45	30.68
4232	110.21	30.14
4233	110.98	23.73
4234	110.49	22.53
4235	109.89	31.28
4236	110.36	28.94
4237	110.24	28.94
4238	110.42	28.86
4239	107.91	23.80
4240	75.45	5.00
4241	64.93	27.26
4242	67.12	19.24
4243	64.36	30.97
4244	64.81	33.99
4245	65.39	29.02
4246	56.60	25.10
4247	53.99	32.91
4248	57.74	25.70
4249	87.78	47.87
4250	110.96	32.76
4251	102.40	40.64
4252	111.20	42.15
4253	106.22	47.45
4254	111.91	29.34
4255	110.13	29.72
4256	110.24	28.19
4257	110.67	26.14
4258	110.47	25.31
4259	103.80	45.45
4260	111.89	36.44
4261	109.69	31.88
4262	110.56	27.36
4263	107.08	35.00
4264	110.39	36.76

Time	Speed	Torque
4265	110.00	29.39
4266	101.66	29.70
4267	106.56	57.36
4268	110.32	27.86
4269	102.89	63.36
4270	110.35	41.62
4271	101.57	40.86
4272	109.16	44.62
4273	110.51	60.74
4274	103.06	98.81
4275	110.31	53.49
4276	110.02	33.17
4277	109.51	37.53
4278	109.80	35.51
4279	109.96	33.67
4280	109.95	33.84
4281	109.86	34.37
4282	109.92	33.59
4283	109.65	35.25
4284	109.34	39.40
4285	109.59	38.05
4286	109.80	35.57
4287	109.78	35.01
4288	109.71	35.13
4289	109.66	35.98
4290	109.73	35.76
4291	109.40	38.74
4292	109.66	37.15
4293	109.80	35.40
4294	109.67	36.28
4295	109.80	35.83
4296	109.66	36.55
4297	109.57	36.68
4298	109.62	37.29
4299	109.89	34.78
4300	109.69	35.48
4301	109.64	36.71
4302	109.71	36.01
4303	109.83	35.26
4304	110.06	32.55
4305	109.94	32.39

Time	Speed	Torque	Time	Speed	Torque	Time	Speed	Torque
4306	109.93	33.36						
4307	110.01	33.05						
4308	110.05	32.17						
4309	109.97	32.56						
4310	110.03	32.00						
4311	109.99	32.43						
4312	109.93	33.32						
4313	109.88	33.60						
4314	110.08	32.10						
4315	101.89	5.00						
4316	79.87	5.00						
4317	37.15	5.00						
4318	46.31	5.00						
4319	41.00	5.00						
4320	36.00	5.00						
4321	30.00	5.00						
4322	25.00	5.00						
4323	16.00	5.00						
4324	8.00	5.00						
4325	0.00	5.00						
4326	0.00	5.00						
4327	0.00	5.00						
4328	0.00	5.00						
4329	0.00	5.00						
4330	0.00	5.00						
4331	0.00	5.00						
4332	0.00	5.00						
4333	0.00	5.00						
4334	0.00	5.00						
4335	0.00	5.00						
4336	0.00	5.00						
4337	0.00	5.00						