Volume I – Technical Proposal

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Project Title: Development, Integration, and Demonstration of An Ultra-Low Emission Dedicated Natural Gas Heavy Duty 15-liter Engine

RFP Title: RFP # **P2013-22** entitled "**On-Road Heavy-Duty Development, Integration, and Demonstration of Ultra-Low Emission Natural Gas Engines**"

Submitted To: SOUTH COAST AIR QUALITY MANAGEMENT DISTRICT

Type of Business: Cummins Inc., a global power leader, is a corporation of complementary business units that design, manufacture, distribute and service engines and related technologies, including fuel systems, controls, air handling, filtration, emission solutions and electrical power generation systems.

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In conjunction with Cummins Program Partners

UCR | College of Engineering- Center for Environmental Research & Technology

Executive Summary

Problem: On-road heavy-duty diesel vehicles are currently the largest source of NOx emissions, which are precursors to ozone formation, in the South Coast Air Basin. The development and commercialization of a new generation of on-road heavy-duty engines that achieve 0.02 gr/bhp.hr NOx is a critical component for achieving the federal ambient air quality standards. This proposal is to develop near-zero emissions on-road heavy-duty natural gas engines.

Solution: Cummins Inc. (CMI) is a global leader in the design, development and sales of diesel and natural gas engines. Cummins manufactures Natural Gas in displacements form 5.9L up to 95L for on-road and stationary market segments globally. Through our Cummins Westport joint venture, we are producing and marketing state of the art on-highway ISL-G 8.9L and ISX12-G 11.9L engines in increasing numbers and are rounding out the lower end of the power range with the development of the ISB 6.7 liter product. Cummins is developing a 0.2 gr/bhp.hr NOx ISX15-G 15L engine for launch in 2016. Nearly all on-highway HD natural gas engines today are derived from diesel engines and typically exhibit fuel efficiencies in the range of 85-90% of comparable diesel engines. In response to SCAQMD RFP #P2013-22, the subject of this proposal is:

- Advanced engine and after treatment architecture and technology development to achieve and demonstrate a commercially viable near-zero NOx emissions capability.
- Advanced dedicated natural gas engine design optimization, including combustion system, air handling, ignition, and advanced controls to achieve and demonstrate fuel economy comparable to 2010 EPA and CARB certified diesel engines.
- Vehicle integration, detailed emissions characterization, and demonstration in revenue service with a drayage fleet operating in the South Coast Air Basin.

The proposed program will deliver maximum value by focusing on the HHD class of trucks that is responsible for 80% of all truck and bus NOx emissions according to SCAQMD's AQMP.

Proposal: An overall three year program is proposed. The first two years will be dedicated to the development and prototyping of an advanced 15L HDD natural gas engine. Contributions of various technical strategies will be evaluated for NOx reduction and efficiency improvements. A prototype engine meeting the program targets on the heavy-duty engine Federal Test Procedure will be a deliverable at the end of this phase. The third and final year of the proposed program entails three additional phases: the production of four prototype engines and their integration into Peterbilt HD truck chassis, a comprehensive series of chassis dynamometer testing at the UC Riverside test facility, and finally a six month in use demonstration of the vehicles in the California Cartage Company fleet in Southern California.

Partnership: A strong team has been assembled by Cummins to achieve the program goals. Cummins' program partners include Johnson Matthey, Peterbilt, California Cartage Company, and the University of California, Riverside. The teaming arrangement brings together industry leaders in engine development and manufacturing, catalyst technology, research and development, HD truck manufacturing and marketing, and fleet operations. Cummins partners have not only committed in-kind contributions, but also support in the technology screening process as well as consulting and guidance in their respective fields of expertise. Cummins will leverage its partners' unique capabilities throughout the scope of work.

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A.0 Summary - Technical Narrative

A.0.1 Program Focus

The goal of SCAQMD RFP P2013-22 is to fund projects that demonstrate reduction of NOx by 90% from production-intent natural gas engines integrated into an on-road heavy-duty vehicle chassis suitable for refuse haulers, goods movement and drayage trucks; and transit and school buses. The motor vehicles will be developed to the point of delivering adequate transient performance and drivability.

This proposal focuses on heavy, heavy-duty (HHD) gas trucks rather than buses. This is because these HHD trucks are anticipated to generate about 80% of truck/bus emissions in 2014 and about 70% in 2023 (Table 1). Focusing on the vehicle category with the greatest emissions contribution to the inventory provides the SCAQMD with the most likely path to achieving its goal of 90% reduction in NOx.

Code	Source Category	**2014**		**2023**
736	Heavy Heavy Duty Gas Trucks ((HHD)	1.02		0.96
746	Heavy Heavy Duty Diesel Trucks (HHD)	76.43		32.63
760	Diesel Urban Bus (UB)	13.4		11.03
762	Gas Urban Bus (UB)	0.76		0.70
772	Diesel School Buses (SB)	2.15		1.81
777	Gas Other Buses (OB)	0.86		0.53
	Total	94.62		47.66

Table 1 Data from the SCAQMD's 2012 AQMP (tons/day)

A.0.2 Approach

The engine developed in the proposed program will be based on a 2016 production ISX15-G. This engine is currently in production development and will be similar in architecture, emissions level and engine efficiency to currently available ISL-G and ISX12-G engines. The ISL-G, ISX12-G and 2016 production ISX15-G are all derived from diesel versions and as such are subject to design trade-offs that lead to performance and efficiency limitations. The ISX15-G production engine will be certified to 2013 EPA emissions requirements, and be 85-90% as efficient as a comparable diesel engine. The work proposed here will focus on significant redesign of the base engine and combustion system, and Air Handling , Fuel, After treatment, and ignition sub-systems to deliver a near-zero NOx engine with efficiency similar to a diesel engine. Table 2 list the various options that will be evaluated, analyzed and tested for each of the Engine System categories.

Sub-System	Base Engine Design	Combustion System	Air Handling	Fuel System	After Treatment	Ignition Systems
Technology Options	Variable Valve Actuation Port Flow redesign Big Intake Small Exhaust Valves Ring Pack Optimization	Compression ratio Variable Compression ratio Tumble vs Swirl Peak Cylinder Pressure limit Piston Bowl design	Low Pressure Loop EGR High Pressure Loop EGR Dedicated EGR Waste Gate Turbo Variable Geometry Turbo Two Stage Charging Miller Cycle Water Injection	Port Fuel Injection Synchronized Port Fuel Injection	Advanced TWC formulations Close Coupled Catalyst Designs Thermal Management	Induction Discharge Capacitive Discharge High Energy Ignition Dual Offset Coil Multiple Spark Ignition

Table 2: Technology Options to be Evaluated in the Proposed Program

Many of the technology options listed in Table 2 have never been applied in a production intent HHD natural gas engine. The result of this program will be the most advanced, production intent and commercially viable HHD natural gas engine. Section A.0 lays out the current state of technology, which motivates the approach that we summarized above and describe in detail in Sections A1 through A4.

A.0.3 Technology Status

The ecosystem of advanced Natural Gas engines includes both conversion of existing gasoline and diesel engines, upgrades of existing engines, and the possibility of new architectures that revise and extend their capabilities.

The market potential for Natural Gas suggests that a fundamental assessment of architecture options should be incorporated relative to Heavy Duty applications to establish the roadmap that puts the industry on a path to the highest possible efficiency combined with a cost structure that provides for a high level of market penetration. There are at the moment two classes of natural gas engines in the market. The first are those that are derived from gasoline light-duty applications. These engines were originally designed with gasoline in mind so all the primary design decisions were from that perspective, including charge motion, compression ratio and combustion system design, bore/stroke ratio, cooling system layout, fuel introduction methods, valve train design and flexibility, and peak cylinder pressure. The second natural gas engine type available includes engines derived from diesel engines which similarly carry the design characteristics from their diesel origin.

The gasoline engine conversions consist of throttled stoichiometric designs that employ automotive style three-way catalysis to meet tailpipe emission standards. These engines range in displacement from 5.4L to 6.8L and largely represent older base engine configurations that have been adapted for natural gas usage. Many have been available for years through 3rd party conversion houses; while more recently factory equipped natural gas versions have become available. However, the technologies applied and therefore system efficiencies are very similar across the range of available offerings.

Diesel engine conversions span the range from 7L to 12L with some higher displacement versions announced for production, primarily based upon stoichiometric combustion and 3-way catalysis. In the case of the highly successful ISL-G offering from Cummins-Westport, cooled exhaust gas recirculation (EGR) is also applied as a measure to improve efficiency.

Drawing on information available in the MY2013 ISL-G and ISL-D engine GHG certificates and using nominal fuel properties, we can readily calculate a Test Cycle BTE (brake thermal efficiency, or efficiency of converting fuel energy to useful work). From this we find that the ISL-G BTE runs at 0.87x – 0.90x that of the ISL-D, with the vocational-like FTP BTE being at the low end, and the Line Haul-like Ramped-Modal BTE being at the high end. The diminished BTE seen in the ISL-G relative to the ISL-D is not particularly a surprise, given the architectural factors contributing to increased energy losses in a throttled, stoichiometric engine. It must be pointed out that even with the diminished relative BTE that the ISL-G exhibits, the Tailpipe CO2 emission profile is still 10-15% lower than its Diesel counterpart, due to the nearly 25% lower CO2 production per unit of Lower Heating Value that Natural Gas enjoys over Diesel. Similar efficiency differences exist between the ISX12-G and ISX12D and are projected for the ISX15-G and D products. One of the principal objectives of this program will be to substantially reduce the BTE handicap that SEGR Natural Gas products now carry (relative to Diesel), and therefore more fully reap the GHG reduction potential that Natural Gas fuel can provide.

A.0.4 Fuel Selection

The SCAQMD RFP P2013-22 requires an a priori selection of LNG or CNG as the method of carrying the fuel on the vehicle and integration with the engine. It should be noted that all Cummins natural gas engines are able to operate on either CNG or LNG. Our fleet demonstration partner California Cartage Company operates more than 350 natural gas trucks in the Long Beach and Los Angeles ports and all these trucks are LNG fueled. California Cartage Company owns and operates a LNG fueling station. For the purpose of this program, all demonstration vehicles will be LNG fueled.

A.0.5 Approach

The subject of this proposal entails the development of an advanced 15L natural gas engine that will demonstrate tailpipe emissions of 0.02 gr/bhp.hr. NOx, 0.01 gr/bhp.hr. PM, 0.14 gr/bhp.hr. NMHC, 15.5 gr/bhp.hr. CO and less than 10 ppm NH3. In addition, the engine will be 10% more efficient compared to current Stoichiometric, cooled EGR (SEGR) natural gas engines. This will substantially address the secondary objective of the SCAQMD RFP: namely to show minimal or zero fuel economy penalty compared to 2010 EPA and CARB certified diesel engines. Further improvements are aimed at performance, durability, and reliability attributes to be substantially similar to Cummins' class leading diesel products. The near zero NOx demonstration engine for this program will be an evolution of the planned ISX15-G that is currently scheduled for launch in 2016. Adopting the base engine design of the planned ISX15-G will ensure the most advanced and reliable platform on which to base the necessary innovations to meet both the program goals as well as deliver a viable solution for a next generation product. As mentioned previously, this leads us to selecting the Stoichiometric, cooled EGR (SEGR) architecture as a basis to build on. Innovations will be pursued in various the engine sub-systems and controls to determine the best overall architecture and integrated system design. Sub-systems under consideration include:

- Combustion System
- Cylinder Head and Valve Train
- Fuel System
- Air Handling including Turbo Charging and EGR
- After Treatment System
- Control System
- Ignition System

The powertrain is an integrated system that must deliver a range of customer requirements to successfully penetrate the marketplace, and it is appropriate to discuss the optimum architecture options by focusing on some of the more critical aspects of engine layout as fundamental drivers for cost, performance, emissions, durability, reliability, and efficiency for HHD natural gas engines.

A.0.6 Natural Gas Engine Technology Status

Virtually all on-road Spark Ignited (SI) engines today operate under homogeneous charge conditions. Emissions regulations have long forced homogeneous charge SI engines to operate at stoichiometry to allow for efficient three-way catalyst operation. To maintain stoichiometric operation under all load conditions, SI engines are throttled to ensure the appropriate amount of air enters the cylinder for the amount of fuel injected. Homogeneous charge engines are sensitive to engine knock. As the flame propagates through the cylinder mixture after ignition, the unburned, or end gases, are compressed. Under high pressure and temperature conditions this end gas will spontaneously ignite. This spontaneous combustion of the end gases results in a rapid and extreme pressure rise, causing an audible "knocking" sound.

Several important loss mechanisms result in a reduced efficiency for current natural gas engines compared to diesel engines:

1. Compression Ratio limitations due to engine knock
2. Engine Throttling
3. Cylinder charge composition

Engine thermal efficiency is a strong function of compression ratio. Because diesel engines are not susceptible to knock, they can operate at much higher compression ratio than a natural gas engine. Typically, a diesel engine operates at a compression ratio of 18 or higher, while a natural gas engine is limited to a compression ratio of around 12.

Since diesel engines can operate with any level of excess air, they do not have a throttle. Natural gas engines must operate at stoichiometry under all conditions therefore must be throttled. Turbocharging of a natural gas engines limits throttling to light load conditions, but still results in greater pumping losses compared to diesel engines.

Cylinder charge composition also affects efficiency. Specifically, a larger ratio of specific heats, or γ, leads to greater efficiency. Dilution of the Stoichiometric mixture with either air or EGR will increase efficiency. Air is the preferred diluent for highest efficiency, but to maintain stoichiometry an inert diluent like EGR is the only option. Additional benefits of EGR dilution is the reduction in flame temperatures and resulting lower NOx emissions from the engine. However, EGR dilution has its limits as well: EGR temperatures are significantly higher than ambient temperature and will thus raise the cylinder charge temperature leading to both higher NOx emissions and increased propensity for engine knock. For this reason current natural gas engines employ cooled EGR. Peak EGR rates for natural gas engines are typically limited to 20-25%.

The above loss mechanisms in combination result in the current state where typical natural gas engines are approximate 15-20% less efficient compared to diesel engines. Secondary contributions, which are not insubstantial, lie in the fact that current natural gas engines are derived from diesel engines and as a result have embodied design decisions that are not optimal for natural gas.

4.0.7 Dilution Strategy

While lean burn technologies can operate with high catalyst reduction efficiencies which allow them to achieve a 0.20 g/hp-hr NO_x emission level, they add significant cost and complexity to the powertrain. It is also unclear whether this technology can successfully and cost effectively be applied to robustly achieve a NO_x emission level of 0.02 g/hp-hr in production. This is the primary reason to eliminate a lean burn architecture from consideration for this program. The choice therefore is to employ EGR to drive both the requisite NOx reductions as well as efficiency improvements.

A number of EGR architecture options can achieve efficiency benefits so it is appropriate to discuss those technologies before proposing a path of investigation.

4.0.5.1 High Pressure Loop (HPL) Cooled EGR

Engine pressure differential is normally adverse at lower loads where an intake throttle is used to lower the air flow rate. This means the intake pressure is lower than the exhaust pressure and the engine is moving the intake charge from this lower pressure state to a higher pressure state. This is the basic problem of a "pumping loss." At high loads, especially with turbocharged engines it is possible to create a "favorable" pressure difference with a good turbocharger match, where the intake manifold pressure is higher than exhaust manifold pressure. However, it is then no longer possible to use a conventional EGR system which connects the exhaust manifold to the intake manifold, known as a "high pressure" EGR system; the pressure difference doesn't support EGR flow. This is the conventional EGR system approached used in the vast majority of diesel engines today. A schematic of the high pressure loop EGR approach is shown in the figure to the right.

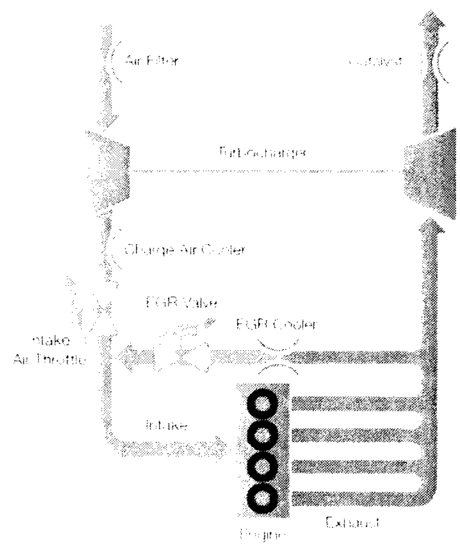


Figure 1: High Pressure Loop EGR Layout

In this case, turbocharger designs which produce higher exhaust manifold pressures than intake manifold pressure are used in order to flow EGR at high torques and low speeds. On a diesel engine, this can be a good compromise of emissions and fuel economy; however, on a spark ignited engine, sensitive to combustion knock, this high exhaust manifold pressure leads to a new problem known as high "internal residual." High internal residual represents hot exhaust that was not fully expelled from the cylinder and results in high in-cylinder temperatures contributing to combustion knock. This issue of applying cooled EGR in the "high pressure" method tends to also limit the engine designer's ability to consider "engine downsizing." Downsizing involves using a smaller engine displacement for a given application, and generally requires the engine to produce higher torque per liter of engine displacement in order to meet the original vehicle functionality. However, applying HPL cooled EGR makes increasing torque per liter from the engine more difficult due to the natural tendency to trap this hot exhaust gas.

Designs which allow for the application of cooled EGR in the absence of adverse engine pressure gradients have the opportunity to run more optimum combustion processes with higher efficiency and should be considered for natural gas applications.

4.0.5.2 Low Pressure Loop (LPL) Cooled EGR

An alternative to a HPL EGR engine system that offers breathing improvement potential is the "Low pressure" loop EGR system. This type of EGR configuration removes exhaust gas after a turbocharger and introduces it up-stream of the compressor thereby breaking the link between intake and exhaust manifold pressure differential and EGR flow. It is possible to flow substantial EGR fractions on such a system and still maintain a favorable pressure gradient on the engine over a broad range of engine operating conditions including low speed peak torque. Such systems have found their way into diesel applications for both passenger car and also HHD engines in the past 10 years, and are now also options for advanced natural gas systems. The benefits such a system provides include lower pumping work combined with more favorable internal residuals at high load. However, significant obstacles remain unresolved for natural gas applications.

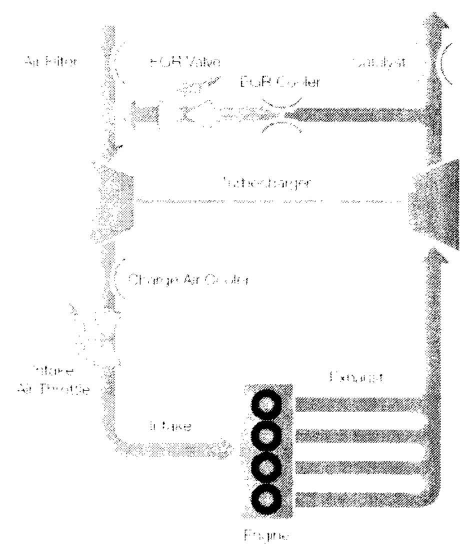


Figure 2: Low Pressure Loop EGR Layout

One of the most problematic issues in applying an LPL EGR system would be the propensity of water vapor, unburned hydrocarbons, and acid forming exhaust gas species to condense in the intake system as the exhaust gases are cooled and further mixed with the cool intake air. This can cause myriad mechanical issues associated with erosion and/or corrosion of various intake system components including the turbo compressor, charge air coolers, sensors, fuel introduction systems, and valves. This is particularly a concern for stoichiometric natural gas engines which have relatively high water concentrations compared to lean burn engines. The issues with intake system condensation must be considered as a trade-off against the potential efficiency gains that can be achieved by applying such a system.
These condensed components can also find their way into the combustion chamber where several issues arise. The exhaust condensate, primarily water, can enter the engine's cylinders in liquid form under certain conditions. The presence of the water can interfere with the ignition process by interacting with the spark plug or other ignition devices, and water can also impede the stable propagation of flames which is critical for low cyclic variability by interfering with cylinder turbulence and fuel/air mixing. Low pressure EGR systems can also exhibit difficulties with transient performance if the EGR quantity is desired to be changed quickly. These systems tend to have large volumes between the EGR valve and the location where the intake charge actually enters the engine. This large volume serves as a delay mechanism regarding certain transient engine maneuvers.

It would be excellent if an EGR alternative was available that reduced the EGR pumping difficulties of the high pressure EGR circuit design and also eliminated the drawbacks of a low pressure loop design. One possibility that must be considered is the approach known as "Dedicated EGR."

4.0.5.3 Dedicated EGR

Recently, another option for EGR has emerged from the powertrain development community. Termed "Dedicated EGR" it involves running one (or more) cylinders rich of stoichiometric and routing 100% of those cylinder's exhaust directly into the intake manifold – establishing a dedicated source of EGR that is augmented with significant amounts of Carbon Monoxide (CO) and molecular hydrogen (H2). Multi-cylinder data published on gasoline showed very good results compared to non-EGR or even conventional cooled EGR (HPL or LPL), but limited information was obtained with natural gas.

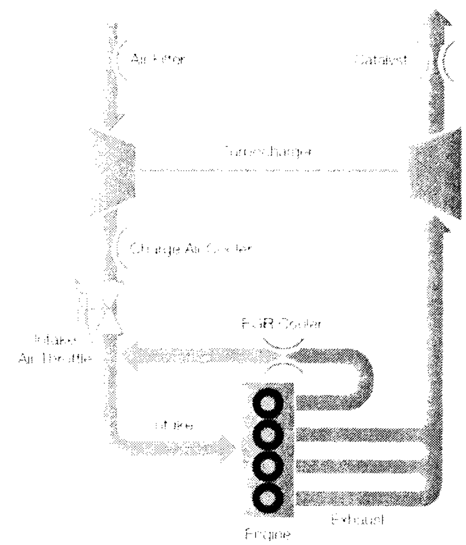


Figure 3: Dedicated EGR Layout

The benefit of this approach is associated with the different quality of EGR compared to conventional EGR. The presence of CO and H2 produces effects that are desirable for spark ignited engine performance. Many published references point to the benefits of hydrogen addition on gasoline and natural gas combustion, but practicality of hydrogen availability and storage have been significant barriers to the application of hydrogen enriched combustion. With Dedicated EGR the hydrogen is produced "on-board" via the method described. The published data indicate that shorter burn durations and improved ignition are possible based upon the presence of very small fractions of hydrogen in the intake gas. As previously discussed, methane is nominally a slower burning fuel than conventional gasoline, so the shorter burn duration from the addition of hydrogen results in a potentially higher efficiency. Furthermore, this different EGR quality may allow higher EGR fraction tolerance through decreased ignition delay.

Figure 4 shows the results of a simulation study of a SI natural gas combustion process with running two of six cylinders dedicated to EGR (fixed EGR rate of 33%). Under the conditions given, the EGR rate can be extended significantly from approximately 25% to over 40%. This concept therefore has the potential to reduce heat and pumping losses compared to stoichiometric combustion through the tolerance of higher EGR fractions. It can also eliminate many issues associated with low pressure loop EGR since the

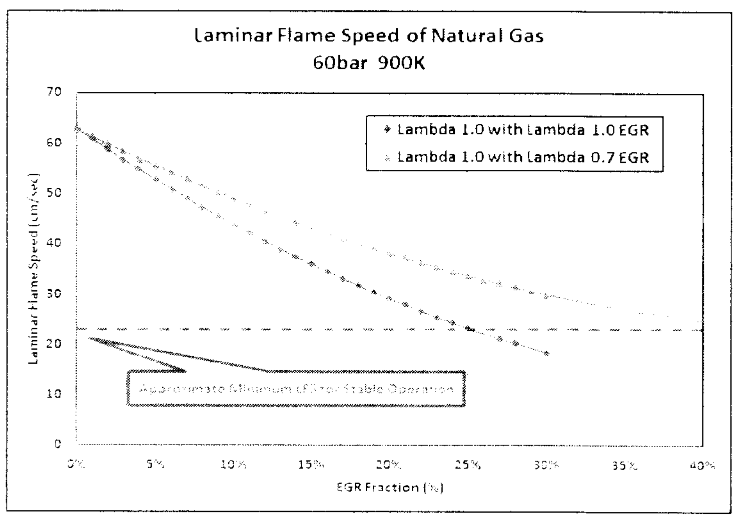


Figure 4: EGR Tolerance with Rich Dedicated EGR

Dedicated EGR configuration is effectively a high pressure EGR configuration. Engine out emissions of NOx can also be reduced significantly employing this EGR strategy, reducing the need for extreme NOx conversion rates in the after treatment system.

4.0.8 Air Handling Architecture Summary

For the purposes of this program, primary interest is to develop better understanding of the LPL and Dedicated EGR options, as the HPL EGR option is in production on both the ISL-G and ISX12-C engines. However, HPL EGR options may also be considered in combination with advanced solutions for another major component of the air handling system, namely the turbo charger. While each of the turbocharged EGR options offers improvements in torque capability and engine efficiency, given the relative scoring in Table 2 Dedicated EGR provides the most benefit. However, because the technology is unproven for natural gas application and has not been applied to a commercially produced engine, there are substantial technical risks associated with its development. The Dedicated EGR configuration requires additional research and development to prove the concept's viability utilizing natural gas for commercial release.

Primary Air Handling Configuration	Torque Capability	Efficiency	Cost	Control and OBD Complexity	Tailpipe NOx	Technical Risk	Total
Turbocharged - HPL EGR Systems	O	O	O	O	O	O	O
Turbocharged - LPL EGR Systems	O	O	O	O	O	-	-
Turbocharged - Dedicated EGR	O	+	+	+	O	- -	+

Table 2: Relative Capability of Air Handling Configurations

For the turbocharger options we will evaluate the use of an asymmetric turbine to allow EGR to be driven with reduced pumping losses. We will also investigate the use of pulse capturing devices, along with a split exhaust manifold, to aid in driving EGR. The use of an ejector to aid EGR flow shall be investigated. More experimental means of efficiently driving EGR will also be investigated.

The turbine used will likely be a wastegated unit, capable of withstanding high turbine inlet temperatures typically associated with Stoichiometric natural gas engine operation. The benefit of using a VGT will be evaluated using modeling and there will be a small amount of experimental work with a VGT to validate the modeling results. An evaluation shall be made of the capability of the VGT to withstand the expected turbine inlet temperatures.

Excellent mixing of the air and EGR is required for this project. Different mixer designs will be evaluated using transient CFD modeling.

4.0.9 Advanced Control Systems

"Controls" are the software that integrates engine hardware components with feedback from sensors to ensure that the overall system is functioning as intended. In order to ensure robust behavior of the Natural Gas engine system in terms of maintaining system efficiency and emissions over its life under various environmental factors as different components begin to age and show variation, the control system has to be developed to utilize the sensory feedback in the optimal manner to ensure best system performance.

To meet the highly challenging requirements that modern natural gas engines have to meet, the control system should be able to control the air-handling system (including turbo-charging systems) to ensure the proper amount of charge and EGR composition, the port fueling and spark systems have to be actively coordinated to ensure efficient combustion and, the TWC catalyst has to be accurately controlled to ensure the highest performance.

With the introduction of advanced air-handling architectures (e.g., dedicated EGR, low-pressure loop EGR), better control of these systems in transients leads to improved transient emission performance.

The proper design of the control system will ensure that:

- System level performance requirements are robustly met over a wide range of operating conditions and environmental conditions
- Proper tradeoffs are made with respect to the sensing and actuation systems to ensure that the system can meet the market pressures of cost and reliability
- Improved collaboration and co-ordination between the various sub-systems is enhanced with advanced control concepts like real-time system optimization working to optimize the cost function of bsfc to help ensure that the degradation in one system is compensated for by active control of other components
- We evaluate the diagnosability of the system architecture so that the systems can meet the stringent EPA/CARB regulations. This ensures that one of the major challenges in the introduction of high efficiency natural gas engines into the market place is well understood from the initial design stage onwards and we proactively address the challenges.

Some of the key pieces of work that will be undertaken as a part of this project include:
In order to significantly improve the performance of the TWC, a full time/high accuracy lambda control using high performance wide-band O2 sensing with dynamic range augmented response model will be developed. In combination with a move to Synchronized Port Fuel Injection (SPFI), this will lead to improvements in transients Lambda control. The objective is to achieve the improved NOx emissions transiently so higher overall engine performance can be achieved.

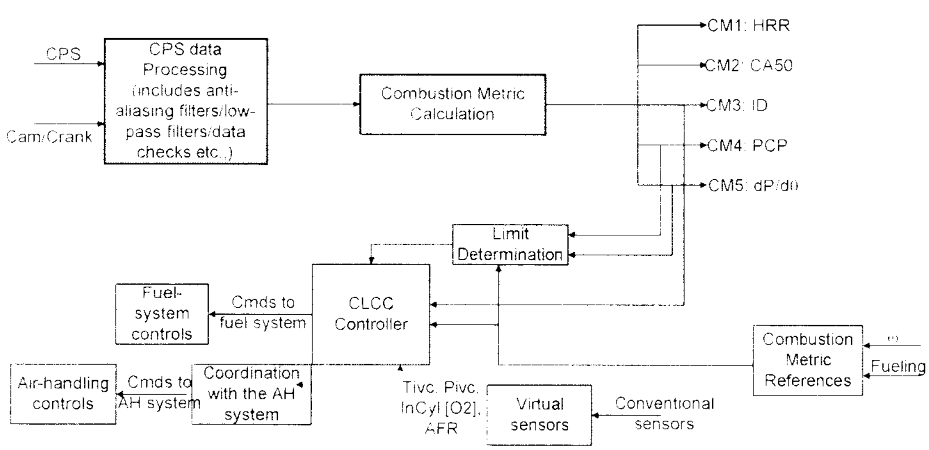


Figure 5: Controller architecture for the control of the natural gas engine with cylinder pressure sensors.

Cummins has a significant expertise on the closed-loop control of the combustion process using cylinder pressure sensors. Through various programs Cummins has developed combustion control algorithms to attenuate the impact of uncertainty (e.g., flow uniformity in the intake manifold) to ensure reduced system variation. An example of an implementation of a combustion controls architecture using cylinder pressure sensor is shown in Figure 5.

Various low-cost cylinder pressure measurement systems based on either piezo-resistive or piezo-capacitive mechanisms are available commercially. But, these sensors have been developed to meet the LD application specifications. Hence, low-cost cylinder pressure sensors meeting the durability targets of the HD applications will be developed as a part of this program.

In this program, the CPS will be utilized to control the combustion process to ensure that the centroid of combustion is robustly controlled while being as close as possible to optimum efficiency. The discrepancy in the dynamics of the port-fuel injected system and the air-handling dynamics to deliver EGR have traditionally led to transient NOx spikes which could be mitigated using the combustion control algorithm resulting to improved transient performance.

In addition, the combustion control process can be utilized to compensate for cylinder to cylinder imbalance and adjust for flow uniformity variations and determine and respond to incipient knock.

Various knock algorithms published in the controls literature (e.g., the stochastic knock detection algorithm) have been shown to improve the system efficiency. These algorithms will be developed in this program to further improved engine efficiency.

For improved fuel control, the controller will be developed to provide engine synchronized port fuel injection. The software development for this project will be based on the Core II OS and existing application code with modifications necessary to incorporate the new algorithms that will be developed as a part of this program. Core II OS is the flagship operating system and software standards that Cummins utilizes in all of its worldwide products.

The ECU is TBD but CM2380 is a potential baseline controller. We can add an additional controller as required to provide additional I/O or computational resources. The controller(s) will be implemented on product like intent hardware that is suitable for deployment on customer vehicles.

One of the key features of the controls development process at Cummins is the extensive use of simulations to ensure that the behavior of the delivered closed-loop system meets the requirements. Hence, Monte-Carlo simulations are utilized to understand the system behavior when presented with variation. These results are utilized to help modify the design of the controller as needed.

4.0.10 Ignition systems

The ignition system serves as a critical subsystem for high efficiency natural gas engines. The ignition systems in wide spread use today include conventional inductive systems, capacitive discharge systems, and hybrids of each. Inductive systems are well developed, inexpensive and reliable. Capacitive discharge systems offer slightly more ignition energy at a substantial cost premium. However the research literature is clear, charge dilution is a path toward higher efficiency; however, dilute engines whether they are based upon lean non-EGR systems or cooled EGR systems are fundamentally limited by the ignition energy available to tolerate dilution (air or EGR). An example of the improvements that can be made with high energy systems is shown in Figure 6 taken from the work of Alger et. al. (SAE 2011-01-0661).

The figure demonstrates the increase in EGR tolerance that can be obtained when increasing the energy level of the spark ignition system. COV of IMEP is a measure of cycle-to-cycle combustion variation which is commonly used to assess engine stability. Clearly, the increasing energy level associated with the multi-strike and Dual Coil Offset (DCO) ignition systems depicted shift equivalent levels of combustion variation to higher EGR fraction levels. This is described as increased tolerance of EGR which comes with a commensurate increase in engine efficiency.

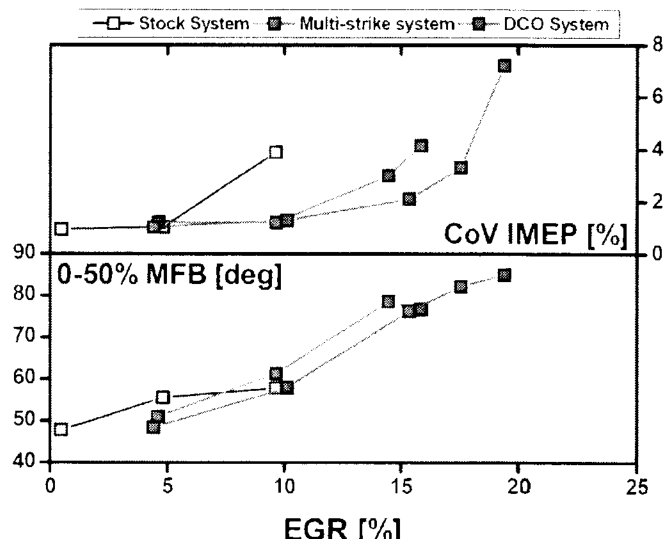


Figure 6: Stability and burn rate results for 2000 rpm / 2 bar BMEP condition

The need to increase ignition energy as a means to improve engine efficiency is driving significant innovation in ignition technology development. However, high energy ignition systems require improved control functionality to optimize their application. High levels of ignition energy are not required under all operating conditions. If not required, high levels of ignition energy results in faster ignition system deterioration without performance benefit. Further, if the ignition system has deteriorated, through spark plug wear for example, a flexible ignition system may represent a tool for maintaining efficiency. This type of flexibility in ignition system control requires system development to optimize the interaction between combustion system design, ignition system capability, and the resulting system performance. Any serious consideration of advanced natural gas engine development must include a review assessment and application of the appropriate high energy ignition system.

A.0.11 After Treatment System

While TWC catalytic converters are often described as "passive" and "maintenance free", in reality this is an oversimplification of the fact that the exhaust gas constituents and temperature must be controlled precisely in order to allow the TWC perform its intended function. The engine system and controls strategies necessary to enable near zero NOx emissions have been described in previous Sections. Additional challenges will be to meet the CH4 limits and to ensure tailpipe exhaust concentrations of ammonia remain below 10ppm. Solutions for CH4 reductions will be sought in both catalyst formulations as well as after treatment system design. One option under consideration is the development and integration of an advanced Methane oxidation catalyst mounted close to the exhaust manifold. Ammonia control will be achieved through catalyst formulations in combination with advanced air fuel ratio control strategies.

Cummins will work closely with Johnson Matthey, a longtime partner to Cummins Emissions Solutions (CES). The Cummins Catalyst Technology and Emission Chemistry Laboratories include facilities for comprehensive, in-depth characterization and diagnostics of aftertreatment systems. The Catalyst Technology lab features a number of sophisticated, in-house developed bench reactor systems, providing unique insights into performance and degradation of catalysts and exhaust gas sensors, including transient conditions. The information developed serves as a basis for mathematical models development and validation, aftertreatment architecture selection, system design, as well as for catalyst diagnostics and postmortem analysis.

For this project, Johnson Matthey will leverage its knowledge of three-way catalysts from mobile applications, as well as its vast experience from supplying catalysts to stationary rich-burn CNG applications, globally. Johnson Matthey will utilize its development resources such as reactors and modeling tools, to provide catalyst recommendations for this program. Additionally, Johnson Matthey will coat catalysts as requested throughout this program, as well as provide support for post-mortem analysis of catalysts evaluated within this program.

A.0.12 Base Engine Design

Current heavy-duty natural gas engines are all derivatives of diesel engines. Unfortunately, this practice produces compromises that limit the potential of natural gas engines in this application. These limitations include performance, reliability, durability and cost. We propose to address these limitations with gas-engine specific designs for critical components. A brief discussion of some of the key opportunities is outlined below.

Cylinder Head: To achieve optimum performance and durability, it is critical that the cylinder head is designed for gas-only operation. A key difference between gas and diesel operation comes from delivering the fuel premixed with the charge air. This differences alone demands significant changes to the port flow/charge motion, valve selection as well as cooling, structural limitations, crevice volume and sensor locations. Using a non-purpose designed component leads to considerable reduction in the ability to meet key customer and regulatory requirements.

Valve Train: Manipulating the intake and exhaust events is another area where optimized gas engine performance and reliability can be achieved. With a very low sensitivity to variations in charge flow, diesel engines have valve trains with limited flexibility. In contrast, gas engines manipulate power by changing the trapped mass of pre-mixed fuel and air. Flexibility in the valve events can yield improvements in efficiency, transient response, diagnostics and safety to name but a few. It is essential that design consideration be made for these systems from the very start to ensure an optimum cost/benefit tradeoff.

Fuel System: The differences in delivering a high pressure gaseous fuel and liquid fuel are considerable. A well integrated and purpose built gaseous fuel system is required to meet performance and safety considerations. Even something as basic as pressure regulation becomes a non-trivial issue on mobile applications that experience extremes in temperature and vibration. Fuel injection is an area where considerable industry work is underway to define and develop high performance and compact designs allowing better integration into the engine.

Crankcase Ventilation: And not to be lost is that gaseous fueled engines operate at a considerable manifold vacuum at light load conditions leading to challenges in oil carryover in the gasses that are ventilated from the crankcase. Diesel engines do not see an intake manifold vacuum and so technology for oil separation under these conditions does not readily exist. Light duty experience is not appropriate either as they do not operate under the same longevity and performance requirements as heavy duty engines.

A.0.13 Team Selection

The Cummins team will be led by Dr. Rudy Smaling (Principle Investigator), who currently serves as Executive Director Systems Engineering in the Cummins Research and Technology organization. Dr. Smaling has 25 years experience in automotive and industrial engine and components R&D, including after treatment, controls, combustion, hybrids, natural gas engines, and biodiesel combustion. Dr. Smaling has over 50 publications and presentations, co-authored a book on Advanced Hybrid Powertrains for Commercial Vehicles and holds 11 patents in the area of emissions control and fuel reforming.

The Peterbilt team will be led by Mr. Bill Kahn. He is the Manager of Advanced Concepts for Peterbilt Motors. An engineering graduate of Texas A&M University, he has over 25 years experience in the trucking and aerospace industry. His last 9 years while at Peterbilt have been dedicated to evaluating emerging technologies, and developing timelines for their viability within the Peterbilt product. His primary focus of late has been in environmental sustainability programs that seek to reduce emissions while improving fuel efficiency, and reducing operating cost.

The UC Riverside team will be led by Dr. Kent Johnson (Principal Investigator), who is currently an Assistant Researcher Faculty at the University of California, Riverside's (UCR) Center for Environmental Research and Technology (CE-CERT). He has over 15 years in-use heavy-duty emissions experience, several years of experience with advanced heavy duty vehicles such as natural gas vehicles, propane vehicles, hybrids, and all electric vehicles, and is one of the lead researchers in the area of in-use PEMS development. Dr. Wayne Miller will act as a project advisor and Drs Mark (Tom) Durbin and Georgios Karavalakis will act as Co-PI's. Wayne Miller is the Associate Director of UCR and has over 40 years of industrial experience in technology planning and new product development/commercialization.

The Johnson Matthey team will be led by Dr. Howard Hess. Dr. Hess has twenty three years' experience in the field of automotive emissions, nineteen of those while at Johnson Matthey. Dr Hess was one of the recipients of the American Chemical Society's Team Innovation Award in 2009. Dr. Hess has over 40 publications and presentations and 2 patents in the field of emission control.

The California Cartage Company team will be led by Mr. Robert Lively. Mr. Lively currently serves as Vice President, Corporate Strategy.

A.1 Fuel specifications

A.1.1 Fuel Selection

All Cummins natural gas engines are able to operate on either CNG or LNG. Our fleet demonstration partner California Cartage Company operates more than 300 natural gas trucks in the Long Beach and Los Angeles ports and all these trucks are LNG fueled. California Cartage Company owns and operates a LNG fueling station. For the purpose of this program, all demonstration vehicles will be LNG fueled.

A.1.2 Gas Analysis

A1.2.1 Engine dynamometer testing

At its natural gas test sites, Cummins employs an Online Natural Gas Analyzer, essentially an automated gas chromatograph, which measures and stores the following constituents every 45 minutes: O2 (%), N2 (%), CH4 (%), CO2 (%), C2H6 (%), H2S (%), C3H8 (%), iC4H10 (%)' nC4H10 (%), iC5H12 (%), nC5H12 (%), C6H14 (%), C7H16 (%), C8H18 (%), and C9H20 (%). BTU value and Wobbe index are readily computed from the above constituent analysis. Water content, H2, and CO are currently not measured in this near-continuous process. We plan to perform periodic sampling via bag to evaluate water, H2 and CO in Cummins' Chemlab.

The term "contaminants" can be interpreted very broadly. Currently, Cummins only measures H2S as a contaminant. If SCAQMD has specific contaminants in mind, we can certainly include those into the proposed periodic sampling and Chemlab analysis. Summary charts of all gas analysis during engine dynamometer testing will be reported.

A1.2.2 In-use chassis testing

UCR will utilize natural gas fuel from a local refueling source. At the time of refueling and as needed, grab samples will be analyzed prior to emissions testing in order to have at least two samples a week. Analysis will, at a minimum, include water content, BTU value, percent methane, ethane, propane, butane, CO, carbon dioxide (CO2), hydrogen, oxygen, nitrogen, C3+, and C6+, contaminants, and Wobbe index.

A.2 Engine development

The objective of this task is to develop production-intent or production natural gas heavy-duty engines appropriate for on-road heavy-duty vehicle applications such as buses, refuse, goods movement, and drayage trucks. The production-intent or production engines and associated exhaust after-treatment technologies must be commercially-viable and capable of:

- Achieving emissions targets of 0.02 g/bhp-hr NOx, 0.01 g/bhp-hr PM, 0.14 g/bhp-hr NMHC, and 15.5 g/bhp-hr CO or lower as determined by the heavy-duty engine FTP;
- Keeping exhaust NH_3 emissions as low as achievable. Proposals that address methods to maintain NH_3 emission at 10 ppm or lower will score higher;
- Being thermally and fuel efficient. Proposals that address methods to achieve minimal, or zero, fuel economy penalties relative to 2010 EPA and CARB certified diesel engines in similar duty cycle will score higher; and
- Capable of being certified by the U.S. EPA and CARB.

A.2.1 Work Plan

At the foundation of Cummins' world class products stands a world class technology and product development organization. Cummins technology and product development processes and workflows span the range from exploratory research to advanced manufacturing practices. These processes have been proven, especially over the past decade, when Cummins has distinguished itself through technology leadership and delivering value to our customers around the world. The proposed work plan for Task A.2 follows these well established and proven workflow and technology and product development processes. Figure 7 shows the GANTT chart for the program work plan. A brief description of each of the work elements identified in the work plan specific to Task A.2 follows:

2.01: System Model Development. This work covers a variety of model development activities: the control system model, combustion model, power cylinder model, CFD models, after treatment system models, etc. These models and simulation activities are critical in developing a better understanding of the behavior of the various sub-systems and engine system as a whole and are a critical contributor to developing system and sub-system requirements.

2.02: Simulations to develop sub-system specification and operating ranges. Understanding the interaction between sub-systems is important in developing so-called interface agreements. These agreements between the development teams of the various subsystems specify acceptable operating ranges for the sub-systems so that overall system performance is not compromised.

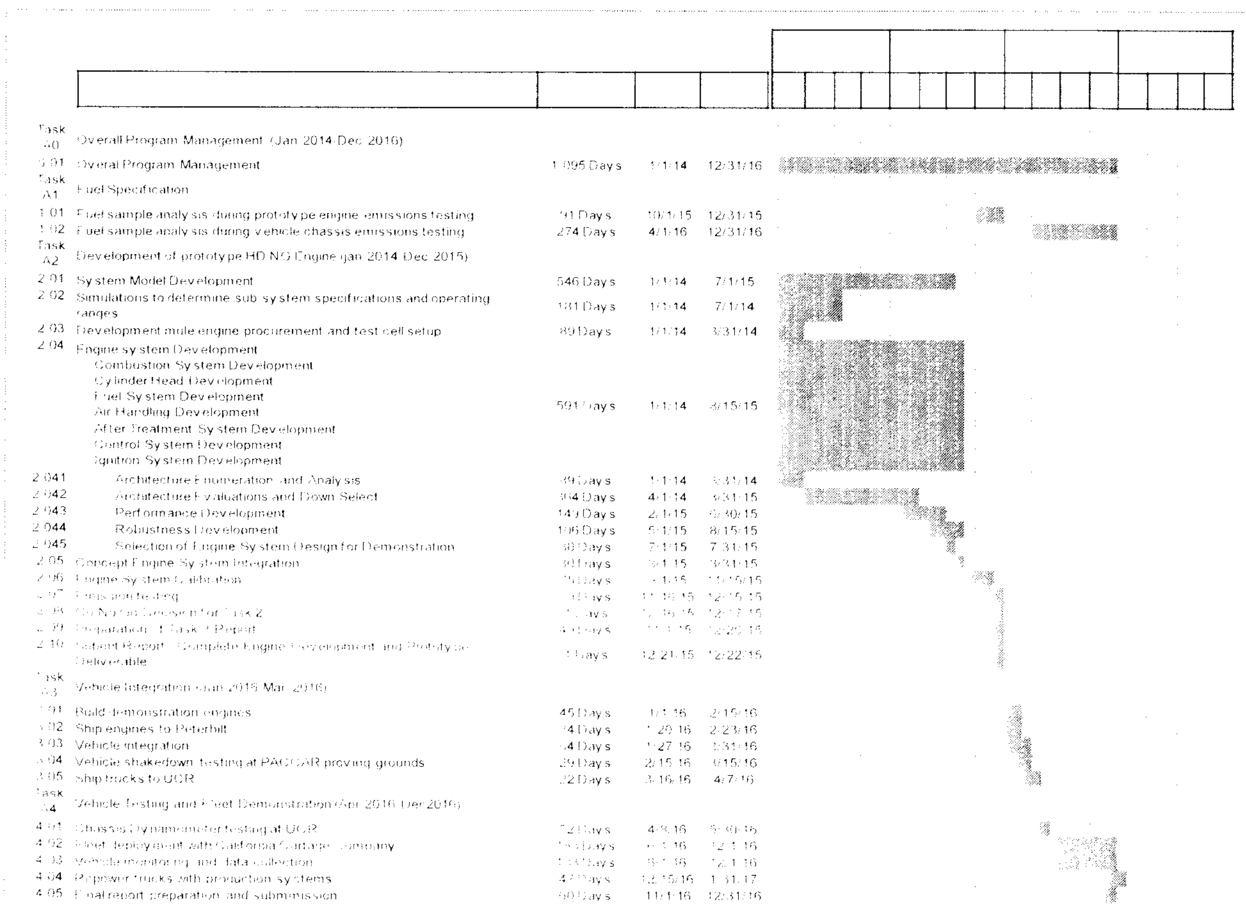


Figure 7: Program and Engine Development Work Plan Gantt Chart

2.03: Development mule engine procurement and setup: This work element simply assures that an appropriate test engine is acquired and set up in the test cell to allow for prototype component and sub-system testing when needed. Much of this testing is required to validate assumptions and models.

2.04: Engine System Development: This is the largest work element in the entire program and covers the evaluation, analysis, and development of a range of sub-systems and eventual integration into preferred system design solution to meet the overall program goals. Combustion System, Cylinder Head, Fuel System, Air Handling, After Treatment System, Controls System, and Ignition System development and overall engine system integration activities will occur in parallel during this phase. All of these parallel activities will flow through the following 5 phases:

2.041 Architecture Enumeration and Analysis: This sub-phase is the "brainstorming" phase. All possible options are considered and evaluated for contributions to the system goals as well as challenges and risks they may present in isolation or in their interaction with other sub-systems or components.

2.042 Architecture Downselect: Based on the broader evaluations in the previous sub-phase, a handful of "most likely to succeed" architectures are selected for further evaluation and testing. Whereas sub-phase 2.041 analyses are primarily based on modeling, simulations and data from prior experience or literature, in sub-phase 2.042 hardware will be built and tested to validate models and assumptions.

2.043 Performance Development: In this sub-phase, the program is typically down to a leading and sometimes alternate architecture. The focus here is optimizing the entire system through trade-off and capability analyses to deliver to program goals from a performance perspective, which includes emissions performance.

2.044 Robustness Development: In this sub-phase the focus is on developing robustness of the system through sensitivity analysis and systems response testing to noise factors. This is a process tailored to deliver engine systems that are robust enough to stand up to the rigors of field demonstrations. Once these systems are selected for commercialization, a more rigorous robustness development process is followed as part of Cummins Value Package Introduction (VPI) process in collaboration with all major OEM's using Cummins engines.

2.045 Architecture and System Design Selection: The final step in the Engine System Development phase is the System Design Selection. This is essentially the "design freeze" for the demonstration engines.

2.05: Concept Engine System Integration: At this time the concept engine, based on the ISX15-G pre-production base engine block and fitted with selected sub-system components, will be integrated and assembled adhering to all specifications and requirements including packaging constraints provided by Peterbilt.

2.06: Engine System Calibration: This effort includes all the work necessary to ensure the engine system requirements including emissions, performance, efficiency, NVH, and other functional requirements are met.

2.07: Emissions Testing: Emissions testing will be performed by the Heavy Duty Engine Federal Test Procedure at Cummins Columbus Technical Center. These facilities are utilized for a variety of test requirements including fuel economy assessments, emissions research, engine development, EPA certification, field engine surveillance, and production engine transient emissions audits.

2.08: Go/No Go Decision: At this stage a go/no go decision is called for to decide whether Task A.2 was successfully completed and whether to proceed to Task A.3.

2.09: Preparation of Task A.2 report. Relevant data and test results will be incorporated into a Task A.2 report.

2.10: Submit Report: During the entire 2 year engine system development phase (Task A.2) quarterly updates will be held between the program participants and SCAQMD personnel. Meeting locations are proposed to alternate between Southern California and Columbus, IN. Upon completion of Task A.2 a detailed report out will be provided along with submission of a written report.

During the entire engine development phase (Task A.2), Cummins will apply a range of tools and sub-processes to ensure we develop an engine system that not only meets the objectives of the program, but leads to a robust and viable solution for a next generation HHD natural gas engine.

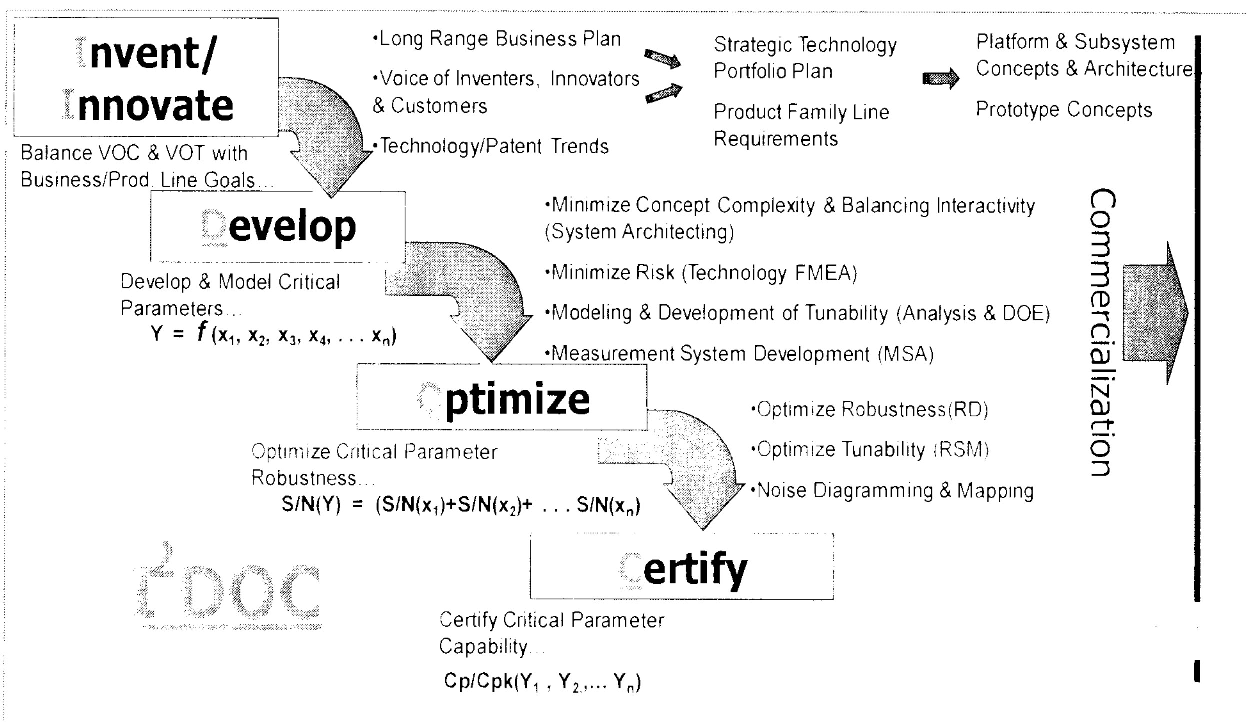


Figure 8: Cummins I²DOC Technology Development Framework

Figure 8 highlights Cummins I^2DOC Technology Development Framework. This process starts with stakeholder needs driving the development of requirements for the product and identifying critical parameters. Using an array of Technology Design for Six Sigma (TDFSS, Figure 9) tools ensures:

- Comprehensive concept generation and selection
- Risk management through FMEA's, Fault Tree Analyses, and risk matrices
- Critical Parameter Management (CPM)
- Robust capability development

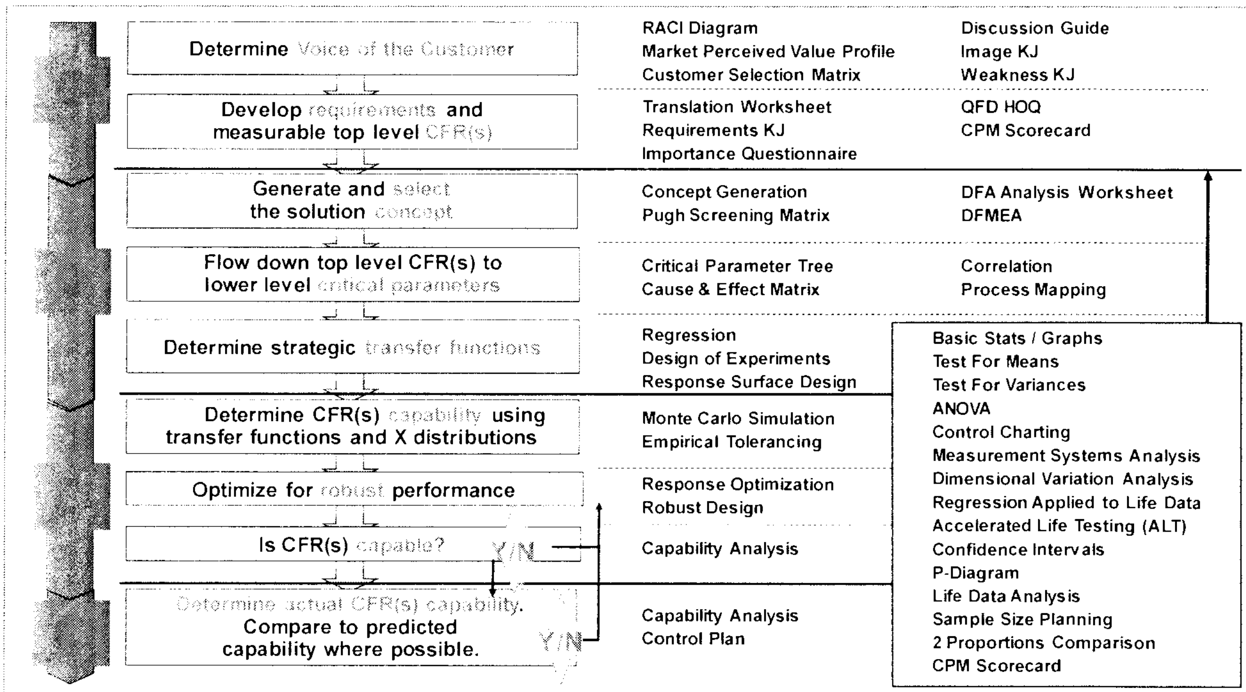


Figure 9: Cummins Technology Design For Six Sigma (TDFSS) Workflow and Tools

4.2.2 Specifications and Conceptual Design Strategy

Engine specifications Near-Zero NOx, High Efficiency ISX15-G

Displacement:	15L
Max Rating:	450 Hp/1750 Lb-ft
Emissions:	0.02/0.01/0.14/15.5 gr/bhp.hr NOx/PM/NMHC/CO and < 10ppm NH3
Fuel Economy:	98-102% of 2010 EPA and CARB certified comparable diesel engines
Fuel Capability:	Operate reliably on fuel as defined in AEB 79.02
Service Intervals:	Same as diesel on common items
	Spark Plug Interval: 60,000 miles
Transient Response:	No driver perceptible difference to ISX15 diesel
Braking power:	60% of maximum rating

The Conceptual Design Process is a well-established regiment within Cummins. The Design Team takes the lead and the responsibility for the process and follows the steps outlined below:

Define the technical requirements: Starting with the Value Package Profile requirements (customer requirements, often stated in general terms) the team translates these requirements into a set of very explicit technical requirements. This is in the form of a **Technical Profile**. The

Technical Profile lists all the critical items along with a quantified value to be assessed at delivery. A Technical Profile will be developed and is a deliverable for Task A.2.

Propose design alternatives: Against these requirements, the Design team forms multiple design options (both at the hardware and system level as required) for further evaluation. Techniques such as TRIZ, and Six Sigma tools are used to feed and formalize the concept generation process.

Analysis Led Design: Powerful analytical models (e.g. finite element analysis, computational fluid dynamics, kinematic/dynamic modeling, combustion simulation, engine performance simulation software, etc.) are used to evaluate the different design proposals against the Technical Profile requirements.

Rank the design alternatives: Using Six Sigma tools, such as a weighted Pugh matrix, the different design alternatives are ranked on a weighted basis using the program requirements. The evaluation criteria will extend beyond just those in the Technical Profile to also include program, logistic and manufacturing criteria as appropriate.

Design Refinement: With the top alternative(s) selected, further refinement based on form, fit and function are performed. This entails creating/refining detailed 3D parametric models of the parts to include realistic accounting of the expected manufacturing method (casting, fabrication, machine from stock, etc.) thus ensuring the most accurate assessment of performance. The cycle of Analysis Led Design and Design Refinement is continued until confidence in the performance is sufficient to go to hardware.

Prototype Hardware Procurement: With detailed models of the preferred hardware defined, suppliers (both in out of house) are engaged to produce prototype hardware to allow evaluation testing to begin. Often provisions will be made in the prototype hardware to allow for critical measurements to be obtained during operation to validate the analytical modeling performed earlier. This is another feedback loop that is executed to ensure robust design. A wide range of prototype suppliers have been identified that support the short durations and small volumes inherent in this phase of the work, often using the detailed 3D models to go directly to machine instructions. Innovative manufacturing techniques including direct laser sintering of metal to form parts are employed. Upon receipt, form and material property measurements are made to ensure the parts meet the defined specifications.

Prototype Hardware Evaluation: Early in this phase, rig and single cylinder engine tests are often performed to validate the analytical models as referred to previously (Task 6) as well as obtain performance related information. These test platforms offer a high degree of operating condition and instrumentation flexibility that is often not available with multi-cylinder engines. Following this phase, multi-cylinder engines run in the test cell are used to evaluate the design concepts under more realistic conditions. Here, effects such as transient response and cylinder to cylinder variation (to name but a few) can be evaluated. This phase of the testing is

Documentation: Design specifications, models and test results are documented for future use and learning.

A.2.3 Development Strategies

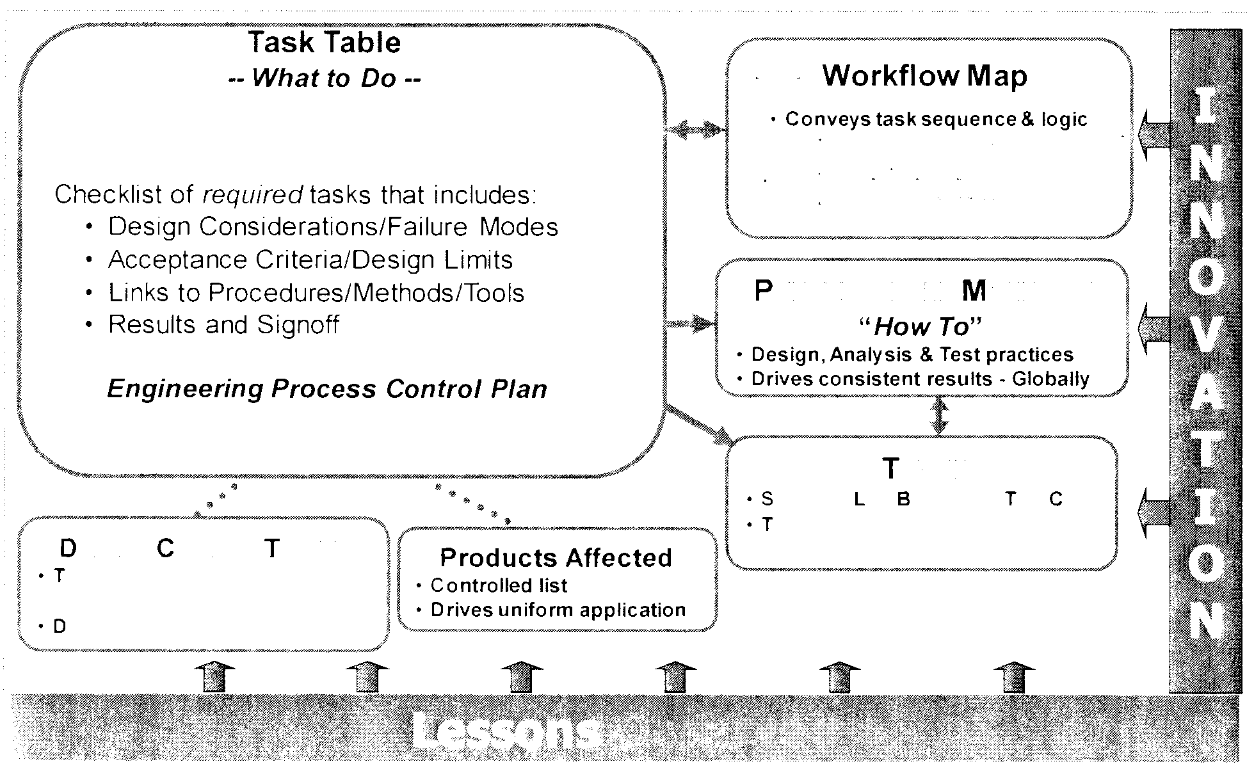
The conceptual design process outlined in Section A.2.2 applies to the development strategies for the engine mechanical components, engine control system, and requirements. In addition, Cummins employs "Engineering standard Work" (ESW) to substantially drive all engineering activities from advanced engineering through manufacturing. Figure 10 shows the ESW framework. This framework applies to all Cummins Business Units around the world, ensuring consistent practices and results globally. A typical ESW document contains:

Task Table: a checklist of required tasks that includes design considerations, failure modes, acceptance criteria, design limits, links to procedures/methods/tools, results, and signoff.

Workflow: Conveys task sequence and logic.

Procedures & Methods: Design, analysis & test practices.

Tools: Software, Laboratory, Bench top, Rig test setup, test cell, field test, hardware in the loop



C E E S

In this and following sections, we will identify the specific ESW items we will perform to address the specific Task under consideration.

ESW Number	Description	ESW Number	Description
95059	Exhaust Gas Recirculation Cooler	95043	Front-End Accessory Drive
95000	Engine Piston	95044	BRACKET, SUPPORT AND MOUNTING BRACE
95003	Cam System	95047	FLYWHEEL HOUSING
95015	Exhaust Cast & Air Cooled Manifold	95053	WIRING HARNESS
95020	Compression Piston Ring	95064	Exhaust Gas Recirculation Valve
95022	Oil Piston Ring	95070	FRONT ENGINE SUPPORT
95024	Power Cylinder System	95073	Turbocharger
95030	Flywheel and Damper Bolted Joint	95097	Fuel Economy Performance
95031	General Fastened Joints	95113	Variable Valve Actuation or Timing
95037	IGNITION COIL & DRIVER SYSTEM	95115	Aftertreatment Integration
95039	Cylinder Head	95121	Air Handling Systems Integration

Table 3: Task A.2.3 Engineering Standard Work to be Completed

Table 3 above summarizes the ESW tasks that are applicable to Task A.2.3 and will be performed as part of this program. Each of these ESW tasks reflects a series of task, processes, procedures, methods, and tools that have been developed and updated over many decades of experience in designing, developing, testing and manufacturing market leading diesel and natural gas engines.

A.2.4 After Treatment System Development

As discussed in Section A.0, meeting the challenge of near zero NOx emissions is not simply a challenge of developing a suitable after treatment system. In a Stoichiometric cooled EGR architecture (SEGR), TWC performance is largely a function of how the engine performs and the exhaust gas constituents, temperature, and flow rate passed through the TWC. Cummins will rely on system modeling and simulation to determine and achieve the best possible conditions for both high engine efficiency and high TWC conversion rates for NOx and other criteria pollutants. Cummins will collaborate closely with longtime partner Johnson Matthey to develop the best possible match of engine system, controls, and after treatment system. Johnson Matthey will leverage its knowledge of three-way catalysts from mobile applications, as well as its vast experience from supplying catalysts to stationary rich-burn CNG applications, globally. Johnson Matthey will utilize its development resources such as reactors and modeling tools, to provide catalyst recommendations for this program. Additionally, Johnson Matthey will coat catalysts as requested throughout this program, as well as provide support for post-mortem analysis of catalysts evaluated within this program.

NOx reduction: Target - 0.02 g/hp-hr

The primary aftertreatment (A/T) catalytic component for the proposed system will be a threeway catalyst (TWC). Achieving the required emissions reduction will necessitate nearly 100% NOx conversion over much of the test cycle and conversion will need to be as high as possible as early as possible in the cycle. Other catalytic components including a close coupled TWC, a NOx storage and release catalyst, and/or a ammonia cleanup catalyst may also be used as needed to affect early light off, NOx catch and release at low temperatures, and mitigate ammonia formation under rich operation respectively. Catalyst sizing, location, and formulation will be significant A/T system considerations.

Dynamic aftertreatment system modeling will be used to investigate alternative topologies and catalytic components for the A/T to achieve early catalyst light off and high conversions. In addition, A/T modeling will be used to evaluate performance of system alternatives as a function of alternative control strategies. Model development and validation will be a key activity in the proposed A/T system development. Catalyst model validation will accomplish using laboratory measurements of appropriate catalyst formulations and engine testing.

Sensors will play a pivotal role in managing, diagnosing, and controlling the A/T system. The A/T controls will rely heavily on lambda sensors. Interpretation of lambda sensors where methane is a significant reductant in the exhaust gases, but not lit off on the TWC catalyst, will present significant challenges. A second key activity will be the placement and calibration of the lambda sensors and their interaction with A/T controls.

Non-methane hydrocarbon reduction: Target - 0.14 g/hp-hr
As with NOx conversion, the primary A/T catalytic component for the proposed system will be a TWC. Achieving the requisite reduction will depend on engine-out hydrocarbon (HC) speciation. Light, saturated HCs will present a challenge especially at low temperatures. This challenge will be addressed primarily by minimizing unburned fuel components engine-out and by optimizing catalyst formulation in combination with rapid catalyst warn up strategies.

Particulate matter reduction: Target - 0.01 g/hp-hr
Particulate emissions will be addressed through engine-out emissions levels below the target.

Ammonia mitigation: Target - <10 ppm v/v cycle average.
Ammonia emissions will be minimized through a combination appropriate catalyst selection, controls optimization and, if necessary, ammonia cleanup catalyst.

System validation: The selected A/T system will be validated on engine in a test cell with developed controls and appropriate emissions measurements of the above pollutants.

ESW Number	Description	ESW Number	Description
95059	Exhaust Gas Recirculation Cooler	95097	Fuel Economy Performance
95064	Exhaust Gas Recirculation Valve	95113	Variable Valve Actuation or Timing
95073	Turbocharger	95115	Aftertreatment Integration, DOC and DPF
95076	Emissions Pre-Certification Process	95121	Air Handling Systems Integration
95085	EXHAUST GAS RECIRCULATION SYSTEM	95126	Steady State Calibration Development

Table 4: Task A.2.4 Engineering Standard Work to be Completed

A.2.5 System Validation

As described in Section A.2.1, Cummins employs a proven Technology Development phase gated process by which technology development proceeds from Invention/Innovation through Development, Optimization and Certification (robustness). This process ensures the sub-systems will sufficiently durable for field demonstration. These sub-systems and components, as described in section A.0, will be integrated with a pre-production ISX15-G base engine. The pre-production base engine will have gone through rigorous validation testing to meet high market expectations in the HHD truck segment. A Validation Matrix and DVP&R (Design Validation

Plan & Report) will be developed as part of this task after System Requirements and System Design tasks have been completed. The Validation Matrix and DVP&R are deliverables of this task.

As a further measure of ensuring a reliable vehicle will be delivered to the demonstration fleet, the first of the proposed four demonstration vehicles will go through extensive testing at the PACCAR proving ground in Washington State. This will give us a degree of confidence that any infant mortality issue will be caught before the remainder of the trucks are built and sent into the field.

ESW Number	Description	ESW Number	Description
95059	Exhaust Gas Recirculation Cooler	95043	Front-End Accessory Drive
95000	Engine Piston	95044	BRACKET, SUPPORT AND MOUNTING BRACE
95003	Cam System	95047	FLYWHEEL HOUSING
95015	Exhaust Cast & Air Cooled Manifold	95053	WIRING HARNESS
95020	Compression Piston Ring	95064	Exhaust Gas Recirculation Valve
95022	Oil Piston Ring	95070	FRONT ENGINE SUPPORT
95024	Power Cylinder System	95073	Turbocharger
95030	Flywheel and Damper Bolted Joint	95097	Fuel Economy Performance
95031	General Fastened Joints	95113	Variable Valve Actuation or Timing
95037	IGNITION COIL & DRIVER SYSTEM	95115	Aftertreatment Integration
95039	Cylinder Head	95121	Air Handling Systems Integration

Table 5: Task A.2.5 Engineering Standard Work to be Completed

A.2.6 Durability Testing Procedures

As part of the performance and robustness development phases of the engine system development task, the concept engine and its components and sub-systems will operate well beyond the 250 hours mentioned as a minimum durability test time in the SCAQMD RFP. The engine will go through rigorous durability testing protocol in an engine durability test cell. Component systems such as turbochargers, fuel systems, sensors, EGR valves, and catalysts will go through component durability testing at Cummins or program partner or supplier facilities. Complete engine system durability testing will be performed in a Cummins durability test cell to standards set relative to the planned vehicle demonstration program.

As a further measure of ensuring a reliable vehicle will be delivered to the demonstration fleet, the first of the proposed four demonstration vehicles will go through extensive testing at the PACCAR proving ground in Washington State. This will give us a degree of confidence that any infant mortality issues will be caught before the remainder of the trucks are built and sent into the field.

A.2.7 Transient Engine Dynamometer Testing

The Cummins Columbus Technical Center has 88 test cells that cover all aspects of diesel engine and alternative fueled engine applications. The emissions test facility includes eight CVS cells (five dilution tunnels) with two cells equipped for alternative fuel engines. Four additional CVS cells capable of measuring to the 2010 emissions requirements have been added. All cells utilize humidity and temperature controlled combustion air and are computer controlled. The gaseous emissions analyzers are microcomputer controlled and provide instantaneous measurement of unburned hydrocarbons, oxides of nitrogen, carbon monoxide and carbon dioxide. Additional emissions measurement equipment allows for measurement of a wide range of exhaust gas species, including NH_3, N_2O, NO_2, CO_2 and ultra fine particles. The technical center is certified to run EPA and CARB certification tests. Once the concept engine is deemed to be ready for emissions testing, tests will be scheduled in the appropriate test cells at the Technical Center to performed the Heavy Duty Engine Dynamometer FTP test as well as any specific duty cycles developed in collaboration with the University of California, Riverside.

UCR riverside will develop a low power engine test cycle from the California Drayage Port Truck Cycles recently performed for an SCAQMD funded in-use testing program. The new engine test cycles will be used to investigate the engines performance over low temperature operation as typically found during some drayage operation.

A.2.8 Independent party testing

Cummins' Columbus Technical Center (CTC) has state of the art engine testing facilities. Rather than go through the expense and effort of setting up a prototype engine at an independent facility that at best might match Cummins' capabilities, we propose that SCAQMD personnel, or their chosen representatives, witness performance and emissions testing at CTC in Columbus, IN.

Cummins will work with SCAQMD to make the engine available for third party testing, if SCAQMD so chooses.

A.2.9 Path to Obtaining US EPA and CARB emissions certification and commercialization

As part of Cummins normal business, we certify a broad range of products to US EPA and CARB standards. A key goal for Cummins in this program is to meet not only the objectives of the program but to develop a commercially viable solution for our next generation Natural Gas engine products.

Cummins and Peterbilt have a long history of product development with Long Term Agreements and a proven ability and commitment to bring new and innovative technologies to market. Commercialization of the technology developed requires sound economics based on acceptable payback periods for the customer, acceptable capital investments, and acceptable return-on investment.

To insure technology research and development remains focused on commercial implementation, both Cummins and Peterbilt will apply mature six-sigma product development processes and business case development. The six-sigma process is a disciplined Phase-Gate process by which technology development proceeds from Invention/Innovation through Development, Optimization and Certification (robustness). The technologies developed under this agreement will subsequently transition into the Cummins and Peterbilt product development groups for product consideration in the 2020 to 2025 timeframe. This is a cross-functional and corporate-wide process to productionize and commercialize new products.

Cummins and Peterbilt will also seek input from expert fleet customers like California Cartage Company, Walmart, US Xpress, and others. The customer view will include practicality, maintenance, liability, operation and total cost of ownership data. Cummins and Peterbilt will focus on making the near zero NOx and high efficiency demonstrator technology a value proposition with an acceptable customer payback.

The trucking industry operates on small margins (<3%). Fuel cost is a significant fraction of the cost of ownership. Lower fuel cost and efficient engines and trucks will represent an easier business case.

ESW 95076 Emissions Pre-Certification Process will be completed as part of the proposed program. ESW 95084 is the process Cummins performs when certifying a production engine for emissions.

A.3 Chassis Integration

A.3.1 Work Plan

The overall program work plan is shown in Figure 6. Peterbilt will apply mature six-sigma product development processes and business case development. The six-sigma process is a disciplined Phase-Gate process by which technology development proceeds from Invention/Innovation through Development, Optimization and Certification (robustness).

Cummins and Peterbilt have a long history of product development and well established processes to ensure effective and efficient engine/vehicle integration. Peterbilt will provide packaging requirements and constraints for the various vehicles and chassis under consideration for the 15L demonstration natural gas engine.

Upon completion of Task A.2, Cummins will procure al required components to build 4 demonstration engines. The first engine will be built and shipped ahead of the other three engines and shipped before the end of January 2016. This will allow for integration into the vehicle and a series of vehicle tests at the PACCAR proving grounds in Bellevue, WA.

The first vehicle is planned for fleet deployment by the end of March 2016. The remaining three demonstration vehicles will not be placed into revenue service until the end of June 2016. This time delay allows for discovery of any infant mortality issues during operation of the first truck.

A.3.2 Specifications and Conceptual Design Strategy

Cummins today provides a range of engines integrated into Peterbilt trucks. Both Cummins diesel and Cummins-Westport natural gas engines are available in several Peterbilt models aimed at refuse, good movement, drayage, and school bus markets.

The ISX15-G near zero NOx demonstrator engine will be integrated into a Peterbilt model 384 truck (Figure 11). Today, this truck is already available with ISL-G and ISX12G engines in addition to several Cummins diesel products. The demonstrator engine will be compatible with all currently offered transmission models.

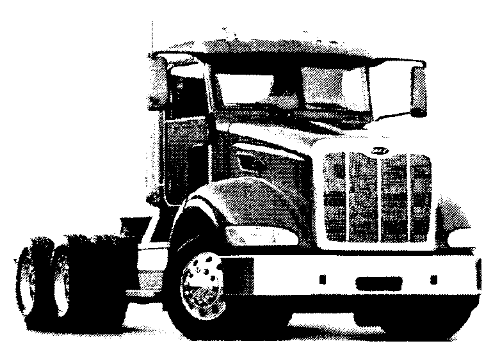


Figure 11: Peterbilt 384 DayCab Truck

A.3.3 Vehicle Integration Strategy

The engine and vehicle integration strategy will follow well established processes. A range of Cummins diesel engines and Cummins-Westport Natural Gas engines are currently available in Peterbilt trucks. Apart from the established production engine and vehicle integration processes, Cummins and Peterbilt have a long history in collaboration on advanced technology demonstration projects. A recent example is the US Department of energy sponsored Supertruck program. The Cummins-Peterbilt developed demonstration vehicle exceeded program objectives, delivering a 54% fuel economy improvement.

A.3.4 Independent Party Testing

The University of California, Riverside will perform and extensive set of vehicle testing at their CE-CERT facility in Riverside, California. UCR has earned a strong reputation for independent vehicle emissions measurement and reporting.

The contractor will work with AQMD to make the vehicle available for third party testing in a way to avoid disruptions to the fleet and minimize vehicle d own time. The additional third party testing up to four weeks is available if so directed by AQMD.

A.3.5 Path to Commercialization

Cummins and Peterbilt have a long history of product development with Long Term Agreements and a proven ability and commitment to bring new and innovative technologies to market. Commercialization of the technology developed requires sound economics based on acceptable payback periods for the customer, acceptable capital investments, and acceptable return-on investment.

To insure technology research and development remains focused on commercial implementation, both Cummins and Peterbilt will apply mature six-sigma product development processes and business case development. The six-sigma process is a disciplined Phase-Gate process by which technology development proceeds from Invention/Innovation through Development, Optimization and Certification (robustness). The technologies developed under this agreement will subsequently transition into the Cummins and Peterbilt product development groups for product consideration in the 2020 to 2025 timeframe. This is a cross-functional and corporate-wide process to productionize and commercialize new products.

Cummins and Peterbilt will also seek input from expert fleet customers like California Cartage Company, Walmart, US Xpress, and others. The customer view will include practicality, maintenance, liability, operation and total cost of ownership data. Cummins and Peterbilt will focus on making the near zero NOx and high efficiency demonstrator technology a value proposition with an acceptable customer payback.

The trucking industry operates on small margins (<3%). Fuel cost is a significant fraction of the cost of ownership. Lower fuel cost and efficient engines and trucks will represent an easier business case.

A.4 Vehicle demonstration

In this task, the team will demonstrate that the pre-production vehicles built in Task 3 are drivable, safe, and meet performance and emissions expectations. The demonstration and evaluation task will require a substantial data collection effort starting with the chassis dynamometer testing for emissions and performance on expected driving schedules. After the dynamometer testing, the vehicles will enter revenue service where operational data will be collected on demonstration and control vehicles for comparison. The demonstration project data needs are identified and summarized in Table 6.

Type of Data	Frequency Recorded	Data Collected
	Vehicle Specification and Performance Expectations	
Vehicle System Descriptions	Start of data collection and changes as needed	Detailed description of installed systems; see **Appendix C Section H**
Vehicle Performance Expectations	Start of data collection and changes as needed	Criteria and testing results for performance expectations
	Vehicle Operation (See Fleet Survey Appendix D)	
Vehicle Operating Cycle	Start of data collection and changes as needed	General description of daily use of vehicles
Vehicle Usage in Service	At each time usage is measured	Odometer reading,
Fuel Consumption	Each time a vehicle is fueled	• Amount of fuel • Odometer reading
	Each time fuel price changes at a site	Price per unit
Noise Level	Start of data collection	Standardized decibel measurements taken at various load conditions
Engine Oil Consumption, Analysis and Changes	Each time oil is added	• Amount of oil; • Odometer reading; • Date
	At regular service intervals	Oil analysis
	Each time oil is changed as recommended by OEM	• Price per quart, amount and mileage • Amount of oil
Maintenance (include maintenance costs not only for lo-NOx technology, but for items like injectors, turbocharger seals, battery life, alternators, fan clutch, AC compressor, etc. that may be reduced due to the use of lo-NOx technology)	For each work order	• Type: scheduled, unscheduled, road call • Labor hours, date of repair, mileage • Number of days out of service • Parts replaced, cost, and problem • Description of repair performed • Typical data on maintenance costs for trucks w/out Lo-NOx technology
Safety Incidents	Each occurrence	Description of each accident or incident involving the test or control vehicles, including collisions and fueling incidents
	Other Information to evaluate Lo-NOx technology	
Emissions Testing	Once during the data collection period	As listed in **Task 4.1**
Driver Satisfaction	Daily and at end of demonstration	Quarterly and at end of demonstration. See Fleet Survey **Appendix D Section H**
Fleet Facility Descriptions	Daily data collection system and as needed if and when changes are made	• Refueling equipment • Maintenance area description • Vehicle storage area description • Telemetry system see **Task 4.2**

Table 6: Lo-NOx Technology Demonstration Data Collected[1]

[1] Adapted from NREL 540-32392, *General Evaluation Plan for Fleet Tests & Evaluation Projects*; July 2002

Task A.4 is broken down into three sub-tasks 1) chassis performance and emissions testing, 2) on-road fleet demonstration, and 3) vehicle accessibility.

A.4.1 In-use vehicle demonstration (chassis performance and emissions testing)

The initial in-use vehicle demonstration includes vehicle performance and emissions testing on a chassis dynamometer. The vehicle performance task is to verify the overall emissions, engine controls, fuel delivery system, and drive train are operating as expected in the integrated chassis system. The performance verifications will include, but not limited to, exhaust after treatment system, finalized controls, fuel delivery systems, transient performance, extended load performance, expected fuel economy verification, nominal emissions verification, and other system performance verifications prior to emissions testing. While optimization is expected to be completed during the engine development, some adjustments to the integrated chassis system will be available during the performance testing.

After the vehicle's performance is successfully verified, the next step is to verify the emissions are meeting the designed targets of this project. The emissions testing will demonstrate that the vehicles overall cycle averaged emissions are meeting the targets of this proposal over a variety of duty cycles. The emissions testing will include performing several standardized drive cycles unique to the SCAB. The selected test cycles will represent port drayage operation, greenhouse gas emissions inventory cycles, and cycles designed for comparisons to engine dynamometers. UCR proposes to test up to four vehicles on the chassis dynamometer two of the demonstration NG vehicles and two control vehicles from the same fleet, one fueled by diesel and the other by natural gas. This analysis will provide a direct comparison of the latest advances in vehicle technology compared to the latest advances in NG vehicle technology.

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A.4.1.1 Performance testing & preliminary emissions

The approach for the vehicle performance will utilizes UCR's heavy duty chassis dynamometer and mobile emissions laboratory. This section discusses UCR's approach for the in-use vehicle performance testing and the details of the statement of work.

Heavy-duty chassis laboratory: In 2010 UCR installed a state-of-art heavy-duty chassis dynamometer that is capable of performing all published chassis duty cycles. UCR's chassis dynamometer is an electric AC type design that can simulate inertia loads from 10,000 lb to 80,000 lb which covers a broad range of in-use medium and heavy duty vehicles, see Figure 15. The design incorporates 48" rolls, 45,000 lb base inertial plus two large AC drive for achieving a range of inertias. The dyno has the capability to absorb accelerations and decelerations up to 6 mph/sec and handle wheel loads up to 600 horse power at 70 mph. This facility was also specially geared to handle slow speed vehicles such as yard trucks where 200 hp at 15 mph is common. See Appendix B Section II for more details.

Statement of Work performance testing & preliminary emissions

Test Vehicle: Two of the demonstration vehicles will be evaluated. The demonstration vehicles are a brand new design based on the ISX-15G 15L spark ignited engine equipped with advanced three way catalyst (TWC) technology.

Vehicle Inspection: Prior to in-use chassis emissions tests, all vehicles be determined to be representative of a well maintained vehicle that meet the appropriate certification specifications.

As part of UCR's standard operating procedures, a checklist, developed with the California Highway Patrol and previous emissions testing programs, will be used to ensure a vehicle is safe to operate and will provide representative emissions of in-use operation. In appendix?

Test Fuel will be provided by local suppliers. All fuels will be analyzed as described in Task A.1.2. Only fuels meeting federal specifications will be used.

Transient performance will be quantified and evaluated on the chassis dyno following driving traces and looking at wide open throttle accelerations. Engine diagnostics systems will be compared with emissions results to ensure proper control system integration.

Exhaust catalyst verification will be quantified and evaluated on the chassis dyno. Pre and post catalyst temperatures will be monitored in addition to other ECM signals such as integrated NOx sensors, lambda sensors, reported fuel rate, engine load and other details related to the exhaust after treatment system.

In-use electronics control strategies will be evaluated on the chassis dyno by real time brake specific emissions calculations. Transient, steady state, and low power modes of operation will be investigated to verify the electronic control strategies are properly working. Measurements such as pre and post catalyst temperatures will be monitored in addition to other ECM signals such as integrated lambda sensors, reported fuel rate, engine load and other details related to the exhaust after treatment system.

One important step to be quantified with the performance testing is to understand the engines on board diagnostics for emissions performance. Sensors will be added to the control solution for performance evaluation and on-road fleet evaluation. During the performance testing, UCR will characterize and quantify the emissions diagnostic systems against its emissions laboratory. The lessons learned during chassis testing will be used in conjunction with the on-road fleet demonstration to vehicles on-road performance as described in the telemetry section of Task 4.2

Finalize electronic controls will be confirmed with the Urban Dynamometer Driving Schedule (UDDS) chassis test cycle to confirm the overall integrated emissions agree with that reported during the engine testing at Cummins Inc. See Section H for more details on the UDDS driving schedule. Additional testing may be needed to optimize the catalyst solution as integrated in the chassis where physical locations, fuel systems, and other details may affect the overall emissions. Measurements such as pre and post catalyst temperatures will be monitored in addition to other ECM signals such as integrated NOx sensors, lambda sensors, reported fuel rate, engine load and other details related to the exhaust after treatment system.

Extended load performance will be quantified and evaluated on the chassis dyno. The fuel delivery system such as fuel pressure, fuel rate, and emissions will be recorded and analyzed. Pre- and post-catalyst temperatures will monitored in addition to other ECM signals such as integrated NOx sensors, lambda sensors, and other details related to the exhaust after treatment system.

Fuel economy verification will be quantified and evaluated on the chassis dyno using which cycle?. The fuel economy will be evaluated on a steady state basis and during transient testing.

The reported value will be compared with engine testing to varying proper operation and design prior to emissions testing and on-road fleet demonstration.

Base emissions verification: Prior to the suit of emissions comparison testing a final UDDS emission test will be performed in triplicate to confirm all systems are operating in a robust and repeatable manner. Measurements such as pre and post catalyst temperatures will be monitored in addition to other ECM signals such as integrated NOx sensors, lambda sensors, reported fuel rate, engine load and other details related to the exhaust after treatment system.

4.4.1.1 Emissions testing before 6-month demonstration

The approach for the emissions testing utilizes UCR's heavy duty chassis dynamometer, mobile emissions laboratory, and extensive experience in emissions testing. This section discusses UCR's approach to the emissions testing and the specific statement of work.

The chassis dyno laboratory was described in the previous section where this section describes the approach for emission testing. This section discusses the some important aspects of the non-regulated emissions and their impact on advanced vehicle solutions. Additional discussion is provided why their measurements are considered in this study.

Emission testing includes details on measuring regulated and non-regulated emissions which include specific quantification regulated emissions including GHG emissions and non-regulated emissions such as carbonyls (including formaldehyde), ultra-fine particle size distribution, and number, and other details specific to advanced vehicle technologies. Additionally due to the ultra-low NOx emissions expected in the presence of high ambient NOx concentration scope was added to investigate the impact ambient NO_x will have on the emissions results. It is expected at these low levels ambient contribution may reach 100% of the emissions measurement and thus unique measurement methods are proposed.

UCR Mobile Emission Lab: The approach used for measuring the emissions from a vehicle is to connect UCR's heavy-duty mobile emission lab (MEL) to the total exhaust of the diesel engine. The details for sampling and measurement methods of mass emission rates from heavy-duty diesel engines are specified in Code of Federal Regulations (CFR): Protection of the Environment, Section 40, Part 1065. UCR's unique heavy-duty diesel mobile emissions laboratory (MEL) is designed and operated to meet those stringent specifications. The accuracy of MEL's measurements were /verified against ARB's[2] and Southwest Research Institute's[3,4] heavy-duty diesel laboratories. See Appendix B Section H for more details.

Greenhouse gas emissions: Heavy duty greenhouse gas (GHG) emissions are becoming an important concern for the federal and state agencies. The impact of advanced vehicles should not only be considered in terms of their regulated emissions benefit, but also their impact in terms of

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[2] Cocker III, D. R., Shah, S. D., Johnson, K. C., Zhu, X., Miller, J. W., Norbeck, J. M., Development and Application of a Mobile Laboratory for Measuring Emissions from Diesel Engines. 2. Sampling for Toxics and Particulate Matter, Environ. Sci. Technol. **2004**, 38, 6809-6816

[3] Cocker III, D. R, Shah, S. D., Johnson, K. C., Miller, J. W., Norbeck, J. M., Measurement Allowance Project – On-Road Validation. Final Report to the Measurement Allowance steering Committee.

[4] Johnson, K.C., Durbin, T.D., Cocker, III, D.R., Miller, W.J., Bishnu, D.K., Maldonado, H., Moynahan, N., Ensfield, C., Laroo, C.A. (2009) On-road comparison of a portable emission measurement system with a mobile reference laboratory for a heavy-duty diesel vehicle. Atmospheric Environment 43 (2009) 2877–2883

their GHG emissions. NG vehicle solutions are considered a comprehensive solution for meeting 2050 GHG reductions in our light duty fleet [5]. Additionally one of the key design aspects of this fully integrated solution is to optimize the thermodynamic efficiency of the combustion of NG. As such, in this proposal additional measurements were proposed to include N_20 that is expected during the cold start of the TWC to complete the GHG reporting. The vehicle will be tested on the US EPA GHG chassis test cycle to provide a quantitative comparison to other heavy duty vehicle solutions.

Non-regulated emissions: Several non-regulated emissions were considered in the RFP which include ultra-fines and ammonia. Previous research at UCR indicates that excessive ammonia emissions are accompanied with emissions formaldehyde, a known carcinogen... Given the potential for releases of NH_3 emissions, additional samples will be collected to quantify the impact of formaldehyde emissions from this advanced NG vehicle solution. Additional measures will be considered at how to minimize these emissions during chassis optimization. See Appendix B Section H for more details on NH3 measurement methods and the impact NH3 emissions can have on secondary PM formation.

Ultra-low NOx measurements: One of the main goals of this project is to reduce NOx emissions up to 90% compared to 2010 emission standards. The expected overall integration emissions are expected to be 0.02 g/hp-h or less. Figure 12 shows the NOx emissions for a diesel engine certified to 0.2 g/hp-h standards. During a cruise section the NOx emissions were close to 0.02 g/hp-h with an average concentration of 0.3 ppm (time segment from 2000 to 3600). Ambient NO_x emissions in Southern California (unlike Columbus Indiana) have been shown to range from 0.05 ppm to about 0.250 ppm depending on the season, time of day, and location[6]. It is possible during this project that ambient concentrations of NO_x emissions will represent 100% correction. Thus, it is important to investigate the contribution to ambient NO_x emissions on the NG solution to consider the impact and reality of potentially negative numbers.

[5] National Research Council "Transitions to Alternative Vehicles and Fuels" Committee on Transitions to Alternatives Vehicles and Fuels, Board of Energy and Environmental Systems, Division on Engineering and Physical Sciences.

[6] Blanchard, L. C., Envair, S. T. "Trends in Ambient NOx and Particulate Nitrate Concentrations in California, 1980 - 2000", Final Rport to CRC Project No. A-43

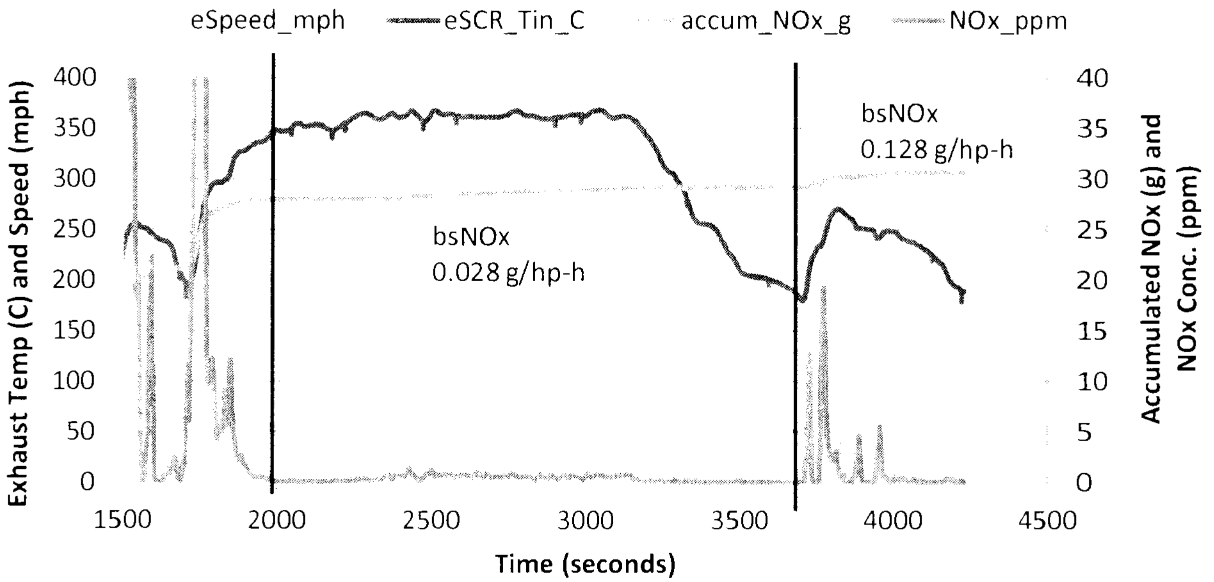


Figure 12: NO_x emissions from a 2010 compliant heavy duty diesel vehicle.

Emissions analyzers used for vehicle sampling have small sample volumes due to the need for fast time response to meet the requirements of transient emission testing (1 second response time). Typically the NO_x measurement sensitivity for vehicle testing is 0.01 ppm which is not sensitive enough to quantify ambient concentrations especially the subtraction of two very small numbers (sample and ambient). As such, UCR proposes to integrate ambient NOx instrumentation from bag samples and continuous ambient monitoring to quantify the true NOx reduction in the presences of typical Southern California ambient NOx concentrations.

The proposed approach utilizes UCR's ambient level NO_x analyzers with 0.00005 ppm resolution analyzers and 20 years of experience measuring sub ppm NO_x emissions source in their atmospheric reaction chambers. The added scope of work is necessary to provide guidance on future emission standards at such low levels and possible calculation changes to accommodate issues in report accurate emission factors at such low emission levels.

Statement of Work for emissions testing and reporting

Test Vehicles: Two demonstration vehicles and two control vehicles from the same fleet, one fueled with diesel and the other by natural gas, will be evaluated as part of the demonstration. The demonstration vehicles will be the brand new design based on the ISX-15G 15L spark ignited engine equipped with advanced three way catalyst (TWC) technology. The controlvehicles will represent the latest technology available that represents 2015 or 2016 MY vehicles.

Vehicle Inspection: Prior to in-use chassis emissions testing, all test vehicles be determined to be representative of a well maintained vehicle that meet the appropriate certification specifications. As part of UCR's standard operating procedures, a checklist, developed with the California Highway Patrol and previous emissions testing programs, will be used to ensure a vehicle is safe to operate and will provide representative emissions of in-use operation.

Test Fuel will be provided by local suppliers. All fuels will be analyzed as described in Task A.1.2. Only fuels meeting federal specifications will be used.

Test Cycles will be performed as chassis dynamometer tests with a minimum of triplicate with emissions being measured. Additional repeats may be necessary in order to quantify the ultra-low NOx emissions. The selected test cycles will represent port drayage operation, greenhouse gas emissions inventory cycles, and cycles designed for comparisons to engine dynamometers. The following test cycles are proposed for the good movement demonstration (descriptions of the test cycle are presented in Appendix A Section H):

- Drayage Port Test Cycle (DPT)
- US EPA greenhouse gas cycle (EPA-GHG)
- Urban Dynamometer Driving Schedule (UDDS)

Cold Starts will be performed primarily with the UDDS test cycle. Additional cold starts testing will be performed with the DPT cycle if time permits.

Emissions will be measured during the specified chassis dynamometer test cycles of regulated gases, toxic gases, and particulate matter (PM).

- Gases include total hydrocarbon (THC), non-methane HC, nitrogen dioxide (NO_2), nitrogen oxides (NO_x), carbon monoxide (CO), carbon dioxide (CO_2), and ammonia (NH_3)
- Particulate matter properties including mass, number, and particle size distribution, including ultrafines.
- Measurement of all carbonyls which include formaldehyde
- Additional high resolution NO_x measurements for continuous ambient and bag sample.

Test Loads are proposed to be set at 69,500 lb to represent typical drayage port operations and to be comparable to previous in-use chassis dynamometer studies conducted by SCAQMD. Additional tests may also be performed at empty weights to represent returning empty containers to the port as part of the drayage operation.

A.4.2 Fleet survey and on-road demonstration

In this task, the team will demonstrate that the four pre-production vehicles built in Task 3 are drivable, safe, and meet performance and on-road emissions expectations over at least a six month period. Beyond that time, the vehicles will be available for third party testing.

The demonstration and evaluation task will require a substantial data collection effort starting with the chassis dynamometer testing for emissions and performance on the expected driving schedules. After the dynamometer testing, the vehicles will enter revenue service where operational data will be collected. Both pre-production and existing/control vehicles in the fleet will be tested on the dynamometer and monitored in the demonstration program.

Given the large investment to demonstrate ultra-low NOx emissions during fleet operation, UCR and Cummins have agreed to develop a low cost integrated NO_x and NH_3 sensing system to be utilized on all four demonstration vehicles during the course of the program. This system will utilize the experience with OBD sensors from Cummins Inc. and the in-use testing experience from UCR to develop a small low cost integrated NO_x and NH_3 measurement system to quantify and report the actual in-use emissions during the full duration of all four NG vehicles. The details behind this design and integration are described in more detail in Task 4.2 under telemetry.

At the end of the in-use evaluation phase, all data will be assimilated, analyzed and documented in a report. Types of analyses will include a determination of actual performance, emission benefits and cost as compared with expected values. The team recognizes that values from four demonstration vehicles while quite useful only lay the foundation for understanding the actual cost and reliability with full fleet implementation. Notwithstanding, the in-use evaluation and data do provide definitive real world data, a direction for future demonstration activities and a technical basis for communication between various stakeholders.

Statement of Work for Data Collection during 6-month on-road demonstration
The RFP outlines a number of areas of importance to ensure a successful outcome to the demonstration phase and those items are covered in this section.

Vehicle Specifications: These data include vehicle system descriptions and vehicle performance expectations (see Appendix C Section H for specific information). While the vehicle systems are described at the beginning of the data collection; changes may be required if major systems are altered. For these evaluations, the descriptions consist of specification information for the advanced technology vehicle and control vehicles. The specifications are intended to describe the main systems of the vehicle propulsion system as well as accessory equipment. This information documents equipment similarity of the evaluation vehicles and describes specific equipment that may affect the performance of the vehicles' fuel economy and overall reliability.

Site selection: With resources limited, site selection is a critical element for any in-use demonstration program so the team suggested a framework and criteria for site and fleet selection as outlined below.

- Fleets must consist of company-owned trucks or a group of independent owner-operators.
- Fleet must show strong interest in participating
- Fleet should have experience with demonstration of new technologies.
- Fleet must be interested in and able to provide help in the required data collection.
- Fleet must be committed to operating, maintaining, and supporting lo-NOx reduction equipment.
- Fleet should have vehicles with similar use (duty cycle) to serve as controls.

California Cartage Company was selected as the fleet/site partner. California Cartage has been in business since 1944 and operates the largest cross-dock transload network on the west coast, along with the largest fleet of specialized equipment in the country. They own and operate six drayage firms and three warehouse company brands. Nationwide we have a drayage fleet of 1,500 tractor units and 4.5 million square feet of warehouse space – so we can handle all of your import/export warehousing, trucking, transloading, deconsolidation and distribution needs.

California Cartage maintains partnerships with shippers, and beneficial cargo owners, as well ocean carriers, intermodal companies and customs house brokers. Fastening the full-circle supply chain, they stand shoulder to shoulder with giants in the retail, hardware, apparel, footwear and toy industries. They have participated in many in-use demonstration programs of low emission technologies and have a strong interest in participating in this project. CalCartage meets all of the selection criteria shown above.

Vehicle deployment/Route Selection: Vehicle deployment and route selection is a key to a successful evaluation. A previous study of trucks operating in South Coast District showed that the emissions from trucks fall into two categories. First, those trucks moving cargo a short distance tend to have colder exhaust temperatures and higher emissions. Second, trucks that move cargo from the ports to the Inland County distribution centers tend to have higher exhaust temperature and lower emissions. Accordingly, we decided to test four trucks with two of them operating over short distances (<10miles) and two of them going long distances (~50 miles, one-way). We expect the selection of two routes will provide a more robust evaluation of the technology.

Data Collection: With the site and routes identified, the next challenge will to collect the data listed in Table 1. Vehicle operation data items include the vehicle operating cycle, vehicle usage in service, fuel consumption, engine oil consumption, maintenance, and safety incidents. For this project the vehicle operating cycle will be described in text format for the general expected usage of the test vehicles. Data collection includes expected route descriptions, average speeds, typical operating hours, number of days per week the vehicle is operated, and the amount of fuel and range in miles during a given work day and between fueling.

The vehicle in service usage includes an analysis for each vehicle of how many miles it is used in service per day and per month. For both the control and advanced vehicles detailed information will be provided on the vehicle usage or duty cycle as described by the average speed, route assignments, terrain information, and possibly, global positioning system tracking information to understand speed and acceleration in service. The control and lo-NOx vehicles will have electronic monitors for some of the information needed to describe the in-service duty cycle. In those cases, we plan to download the onboard data. The specifics of how the in-use data are actually recorded and collected will be finalized after discussion with the fleet representative and the drivers involved. Whenever possible, telemetry will be used to record data from the installed ECM or monitors added specifically for this test program, like NOx sensors.

Telemetry system: The vehicle and engine will be instrumented with telemetry system. The telemetry system will record engine and chassis related items on a second by second basis with a real time cellular or wireless feed to servers for real time investigation of the vehicles on-road performance. The real time measurements will include, but not limited to the following data:

- Engine load (% load, friction torque, actual torque, and reference torque)
- Fuel rate (calculated from fuel injection and engine dyno measurements)
- Calculated exhaust flow from EGR rate, speed density method, and lambda
- Intake air temperature and pressure
- Engine speed and vehicle speed
- Emissions diagnostics such as oxygen, lambda, and other integrated ECM calculated values.
- Catalyst temperatures pre and post catalyst

- Additional information as requested by AQMD

Online NO_x and NH_3: UCR and Cummins will design and install four integrated NO_x and NH_3 sensors in each demonstration vehicle. The sensors will be commercially available OBD type sensors but installed in an environment for stable measurements. Experience shows that in-situ exhaust sensors under slightly rich conditions do not perform well. In this design, a small amount of sample will be drawn from the exhaust into a sub-system where diluted exhaust will be measured by the sensors. The signals form these sensors will be recorded with the data logging telemetry system as part of the overall telemetry task of this project.

From the concentration measurement, dilution ratio, calculated exhaust flow, and engine load a quick check on brake specific emissions can be calculated and recorded in real time during the full 6 months of demonstration. The NO_x and NH_3 system will be designed during the engine testing where it will be evaluated. It will also be evaluated during the chassis testing at UCR and maintained by UCR during the demonstration phase.

The other in-use data needed include: data collection at each fuel fill (amount of fuel, odometer reading, and date) and fuel prices (each fuel, each time the fuel price changes – price and date). Data collection also includes engine oil consumption and engine oil changes. Information is recorded from each engine oil addition (amount of oil, odometer reading, and date) and oil changes (amount of oil, odometer reading, and date as part of a maintenance action). Engine oil prices are also to be collected (the oil price and date each time it changes).

In the data collection, an odometer reading is usually replaced with a hubodometer reading. A hubodometer is a device placed on the wheel hub (usually the rear wheel facing the fueling side of the vehicle) that measures the revolutions of the wheel and converts those revolutions into miles traveled. The hubodometer reading is usually the only measurement of vehicle usage in miles-traveled used by the site.

Maintenance data include each repair action such as preventive maintenance, unscheduled maintenance, and road calls (date of repair, labor hours, number of days out of service, odometer reading, parts replaced, parts cost, and descriptions of problem reported and repair performed). Engine oil changes are included as part of preventive maintenance. The maintenance data are used to estimate operating costs (along with fuel and engine oil consumption costs) and for reliability and durability calculations.

Any safety incidents occurring with the vehicles, the fueling station, or the maintenance facilities are described, including the nature of the incident and the vehicles or facilities involved. Also, any changes in procedures or hardware changes required to ensure that the incident is not repeated must be described.

During the data acquisition phase, the team will periodically check on the data collection to ensure that: 1) the data being collected; and 2) the data match expected values. Based on these interim reviews, mid-course corrections may be made after consultation with the AQMD project manager:

Reporting: An enormous amount of valuable data will be collected based on the various parameters listed in Table 1. The results of the evaluation should quantify cost, reliability, and any in-use barriers identified in the initial assessment as well as identify other possible issues. The evaluation will determine, document, and present the actual costs and benefits associated with lo-NOx technology for the demonstration and as projected for fleet applications. The evaluation report should examine the expected benefits for reduction of NOx and NH_3 emissions and energy savings due to improved NG combustion efficiency, even for trucks that are traveling for short distances. Regardless of the outcome of the evaluation, all results will be published, and these results will determine the next steps for the plan.

A.4.3 Third party vehicle availability

The contractor will work with AQMD to make the vehicle available for third party testing in a way to avoid disruptions to the fleet and minimize vehicle d own time. The additional third party testing up to four weeks is available if so directed by AQMD.

B. Program Schedule

An overall 3 year program is envisioned. The first two years will be dedicated to the development and prototyping of an advanced 15L natural gas engine, based on the ISX15-G engine currently in production development. Contributions of various technical strategies will be evaluated for NOx reduction and performance and efficiency improvements. These include, but are not limited to: knock sensitivities, evaluations of compression ratio and charge motion, cylinder head and valvetrain design options, various EGR options, EGR fraction, air fuel ratio management, variable geometry turbocharger, advanced ignition systems, and advanced controls strategies. Prototype sub-systems will be designed, procured, integrated and validated on a concept engine. The concept engine including after treatment hardware will be optimized for emissions, efficiency, and performance. Engine tests will also be used to calibrate simulation models. A prototype engine meeting the above stated emissions targets on the heavy-duty engine Federal Test Procedure will be a deliverable at the end of this phase.

The third and final year of the proposed program entails 3 additional phases: the production of three prototype engines and their integration into Peterbilt HD truck chassis, a comprehensive series of chassis dynamometer testing at the UC Riverside test facility, and finally a 6 month in use demonstration of the vehicles in the California Cartage Company fleet in Southern California.

Proposed Program Milestones are as follows:

Milestone	Date
Program Kickoff	1/1/2014
Quarterly Review	4/1/2014
Quarterly Review	7/1/2014
Quarterly Review	10/1/2014
Quarterly Review	1/1/2015
Quarterly Review	4/1/2015
Select Demonstration System Architecture	4/15/2015
Quarterly Review	7/1/2015
Complete BOM for Concept Engine build	8/1/2015
Quarterly Review	10/1/2015
Complete Engine Dyno Emissions Testing	12/15/2016
Submit (Task A.2) Interim Report	12/22/2016
Quarterly Review	1/1/2016
First vehicle build complete	2/15/2016
Quarterly Review	4/1/2016
First vehicle deployed with Fleet	4/1/2016
Quarterly Review	7/1/2016
All Vehicles deployed with Fleet	7/1/2016
Quarterly Review	10/1/2016
Demonstration Period Completed	1/1/2017
Program Wrapup meeting	1/15/2017
Submit Program Final Report	1/31/2017

C. Project Organization

The program team consists of the following partners:

Cummins	Engine OEM, After Treatment System Integrator - overall program lead.
Peterbilt	Truck OEM and Chassis Integrator
Johnson Matthey	After-Treatment Manufacturer
California Cartage	LNG HDD vehicle Fleet operating in SCAB
UC Riverside	Center for Environmental Research & Technology

The governance structure of the program will be based on a clear understanding of the deliverables from each of the team members to the program.
Representatives of the team members shall engage in meeting, technical exchanges, and other forms of collaboration at appropriate intervals to ensure the program will meet its schedule and objectives on time and within the allocated budget.
Furthermore the program team proposes quarterly program updates for SCAQMD personnel. The location for these meetings is proposed to alternate between the SCAQMD offices in Diamond Bar, CA and Cummins facilities in Columbus, IN.

Commitment letters from each of the participating partners are provided in Volume II.

Information about each of the team members is provided throughout this Volume, with specific qualifications and assigned personnel in Sections D, E, and F.

In summary, contributions from each of the team members are as follows:

Cummins: Overall program leadership and engine system design, development, testing, and production.
Peterbilt: Vehicle Integration and testing.
Johnson Matthey: Catalyst design, development, testing, and production.
UC Riverside: Vehicle chassis dyno testing, fleet data gathering, and duty cycle development.
California Cartage Company: Fleet demonstration, monitoring, and operational feedback.

D. Qualifications

Cummins

Cummins has a solid history of partnerships, collaborative R&D relationships, and successful technical delivery of challenging programs with the U.S. Department of Energy (DOE), Department of Defense (DOD), many of the National Laboratories, and numerous non-federal entities, such as Gas Technology Institute, California Energy Commission, South Coast AQMD, and others. These programs, which have leveraged entity funding with considerable Cummins internal cost share funding have led to both evolutionary and breakthrough technologies and analytical approaches, speeding up the time for commercialization of vehicles and power systems based on advanced combustion engines and emission control technologies. In the last 5 years, major projects either completed, or still active, including the agency reference's name, title and telephone number:

1. **ARES** (Advanced Reciprocating Engine System) is a DOE sponsored large stationary natural gas engine program that has led the way on developing advanced fuel efficiency and low emission technologies for the stationary distributed power generation market. With its completion slated for Q3-2013, it is on track to demonstrate its final objective of 50% Brake Thermal Efficiency.
2. **CHP**, a joint Cummins Power Generation / Engine Business program also sponsored by DOE, is delivering a packaged natural gas based Combined Heat and Power system for commercial and light industrial applications achieving more than 80% combined efficiency.
3. **ISX-12G** is a program executed through the Cummins-Westport Inc. joint venture, with sponsorship involving several entities, including GTI and NREL with pooled funding from CEC and AQMD. This product has now launched and is beginning to fill a critical need and growing demand for heavy duty, on-highway natural gas products, with good criteria pollutant / GHG emissions and very competitive operating costs operating on a domestically abundant fuel source.
4. **SuperTruck** is a DOE sponsored heavy duty, class 8 truck system integration program, teaming Cummins with Peterbilt Motors and other major component makers developing and demonstrating advanced technologies for transformational freight transportation efficiency improvements. Cummins leads the first, and so far only one, of 4 competitor teams to achieve and exceed its 1st objective, which was 50% diesel engine brake thermal efficiency. Its 2nd objective of a 50% improvement in long haul drive cycle freight efficiency (ton-miles / gallon) was achieved in 2012, and the team is currently on track to exceed its 3rd objective of 68% improvement in freight efficiency over a 24 hour cycle including overnight on-board power consumption in Q4 2013. Significant progress in technology scoping, modeling, and single cylinder concept evaluation has been made versus the 4^{th} objective of 55% engine

brake thermal efficiency. Concept integration toward multi-cylinder demonstration is underway. This 4 year program completes in April 2014

5. **ATLAS** is a DOE sponsored light duty (1/2 ton) pickup system integration program developing 40% fuel economy benefits (vs. gasoline baseline), ultra-low NOx emission technology (Tier 2 / Bin2 or 0.02 g/mile), and advanced lightweighting technology for the light duty truck market, with potential scalability to other vehicle classes or fuel types. This 4 year program is fully on track, with completion of all program deliverable in Q3 2014
6. **CEC, or Ultra-Low Carbon Powertrain**, is a California Energy Commission sponsored program which shares the advanced ATLAS platform and supports Cummins development of a downsized medium duty engine / powertrain optimized for E85 targeting 50% GHG emissions reduction compared to the diesel powered baseline vehicle.
7. **CRADAS** – Cummins also maintains a strong portfolio of CRADAS (Cooperative Research And Development Agreements), which team world class researchers at the DOE's system of National Laboratories with their counterparts at Cummins, jointly working on technologies and problem areas of mutually recognized criticality. These run the gamut from research into Combustion / Fuel Nozzle flow modeling, High Strength / Lightweight / High Temperature Materials, Combustion Uniformity Diagnostics, Catalysis and Aftertreatment Component Reaction Performance and Materials Fundamentals, Biofuels, and Vehicle Thermal and Aerodynamic Analysis and Accessory Hybridization. These programs contribute significantly to the quality, depth, and breadth of current and future system integration programs and product technology.

These varied programs over the last 5 years are just the most recent in a long history of successful R&D programs that Cummins has led in living one of its most valued mission statements ... "demanding that everything we do leads to a cleaner, healthier, and safer environment". References (name, title, phone number), per program, are provided below. References for the CRADA's are available upon the request.

ARES and CHP Programs	Robert Gemmer, Technology Development Manager	DOE / EERE / Advanced Manufacturing Office	202-586-5885
ISX-12G Program (NREL RCI-0-40455)	George Mitchell, Advanced Vehicle Deployment	National Renewable Energy Laboratory	303-384-7989
SuperTruck and ATLAS Programs	Roland Gravel, Technology Development Manager	DOE / EERE / Vehicle Technologies Office	202-586-9263
CEC Ultra-Low Carbon Powertrain (ARV-10-044)	Eric VanWinkle, Energy Analyst	California Energy Commission, Emerging Fuels & Technology Office	916-651-1235

Cummins possesses one of the largest diesel technology, performance, and emissions test facilities in the world. These facilities are utilized for a variety of test requirements including fuel economy assessments, emissions research, engine development, EPA certification, field engine surveillance, and production engine transient emissions audits.

The Cummins Technical Center located in Columbus, IN consists of a multi-building complex with 98,700 sq ft of office and 378,500 sq ft of laboratory space. The technical center has 88 test cells that cover all aspects of diesel engine and alternative fueled engine applications. The emissions test facility includes eight CVS cells (five dilution tunnels) with two cells equipped for alternative fuel engines. Four additional CVS cells capable of measuring to the 2010 emissions requirements have been added and will be available for this program. All cells utilize humidity and temperature controlled combustion air and are computer controlled. The gaseous emissions analyzers are microcomputer controlled and provide instantaneous measurement of unburned hydrocarbons, oxides of nitrogen, carbon monoxide and carbon dioxide.

Cummins CyberCell is a specialized engine test cell that implements a vehicle dynamic system model to run the engine in real world vehicle drive cycles. By removing variability associated with vehicle testing, CyberCell can reliably identify changes in fuel economy on drive cycles that would be nearly impossible to resolve in actual vehicle tests. Controlling variability allows evaluation of "noise" factors that affect real world fuel economy. The CyberCell also allows many more vehicle configurations to be evaluated than is possible with real trucks.

The Cummins Catalyst Technology and Emission Chemistry Laboratories include facilities for comprehensive, in-depth characterization and diagnostics of aftertreatment systems. The Catalyst Technology lab features a number of sophisticated, in-house developed bench reactor systems, providing unique insights into performance and degradation of catalysts and exhaust gas sensors, including transient conditions. The information developed serves as a basis for mathematical models development and validation, aftertreatment architecture selection, system design, as well as for catalyst diagnostics and postmortem analysis.

Peterbilt

Peterbilt will develop, build and test the HDD LNG demonstration daycab tractor at the Denton, Texas site. The truck manufacturing facility has 455,000 sq ft and is capable of producing 10 heavy duty trucks per hour. The world class manufacturing plant is certified to ISO 19001 standards and further certified as a "zero waste to landfill" manufacturing plant. The site has the 29,500 sq ft Engineering Development Lab to model, prototype, test, and validate products. Engineering is done on-site from a 126,200 sq ft office facility. Vehicle testing is done either on-site or through PACCAR's Technical Center located in Mt. Vernon, Washington, which includes a dedicated test track, engine test cells, environmental test facilities, materials and electrical labs, NVH test facilities and accelerated life testing. Analysis computing resources are located at Peterbilt and PACCAR's Technical Center, plus arrangements are in place for use of extensive computational fluid dynamics computing resources through Exa Corporation.
Peterbilt's Development Lab has four 20' x 55' truck bays with a 10-ton crane and a full machine shop. The Lab includes a full Clay development studio and surface data collection is done with Capture 3D photogrammetry inspection and Faro contact based inspection.

University of California, Riverside

UC Riverside qualifications are embedded throughout Task 4 and individual expertise is stated in key personnel CVs in Appendix E and in Letters of Support from subcontractors in Volume III. A brief summary is also provided here.

CE-CERT is well position to be a strong team player with experience derived from 20 years of collaboration with California agencies focused on the environment and reducing emissions. CE-CERT is uniquely skilled in understanding the driving schedules for California applications and is currently measuring the after treatment temperatures of trucks operating within California. Furthermore, CE-CERT is uniquely qualified to measure NOx at very low levels with: 1) its mobile lab for on-road vehicles and 2) having just completed a project for the ARB and Energy Commission in measuring NOx from power plants at the 0.1ppm levels.

Recently UCR completed a comprehensive study where twenty-five on-road heavy-duty vehicles (test vehicles) used in the transit, refuse, and goods movement vocations and powered by engines fueled with natural gas, propane, diesel, and a combination of diesel and natural gas fuels were tested for in-use emissions. The engines are categorized into eight groups including natural gas engines with three-way catalysts, high pressure direct injection (HPDI) engines with EGR and DPF with or without SCR technology, propane and diesel school buses, propane engines certified at or below 0.2 g NOx, diesel engines certified at 1.2 g NOx, diesel engines certified above 0.2 g NOx without SCR technology, and diesel engines certified at or below 0.2g NOx with SCR technology. The work was split between two testing laboratories where sixteen of the vehicles were evaluated at UC Riverside. The test vehicles were tested over different transient cycles on a chassis dynamometer to characterize the in-use emissions of total hydrocarbon (HC), nitrogen dioxide (NO2), nitrous oxide (N2O), nitric oxide (NO), NOx, carbon monoxide (CO), carbon dioxide, (CO2), PM (mass, composition, and fine particle size distribution), ammonia (NH3), formaldehyde, and other toxic air contaminants.

The UC Riverside research team will be led by Dr. Kent Johnson (Principal Investigator), who is currently an Assistant Researcher Faculty at the University of California, Riverside's (UCR) Center for Environmental Research and Technology (CE-CERT). He has over 15 years in-use heavy-duty emissions experience, several years of experience with advanced heavy duty vehicles such as natural gas vehicles, propane vehicles, hybrids, and all electric vehicles, and is one of the lead researchers in the area of in-use PEMS development. Dr. Wayne Miller will act as a project advisor and Drs. Mark (Tom) Durbin and Georgios Karavalakis will act as Co-PI's. Wayne Miller is the Associate Director of UCR and has over 40 years of industrial experience in technology planning and new product development/commercialization. He also has recently performed several large scale deployment projects for marine hybrid demonstrations in California. Tom Durbin holds a Research Engineering position at CE-CERT and Georgios Karavalakis is an Assistant Research Engineer. Technical engineering staff will perform standard laboratory analyses, while the Graduate Student Researcher will perform specialized testing (Ammonia, PM and ultrafine analysis, and nitrous oxide emissions measurements).

The UC Riverside research team will be led by Dr. Kent Johnson (Principal Investigator), who is currently an Assistant Researcher Faculty at the University of California, Riverside's (UCR) Center for Environmental Research and Technology (CE-CERT). He has over 15 years in-use heavy-duty emissions experience, several years of experience with advanced heavy duty vehicles such as natural gas vehicles, propane vehicles, hybrids, and all electric vehicles, and is one of the lead researchers in the area of in-use PEMS development. Dr. Wayne Miller will act as a project advisor and Drs. Mark (Tom) Durbin and Georgios Karavalakis will act as Co-PI's. Wayne Miller is the Associate Director of UCR and has over 40 years of industrial experience in technology planning and new product development/commercialization. He also has recently

performed several large scale deployment projects for marine hybrid demonstrations in California. Tom Durbin holds a Research Engineering position at CE-CERT and Georgios Karavalakis is an Assistant Research Engineer. Technical engineering staff will perform standard laboratory analyses, while the Graduate Student Researcher will perform specialized testing (Ammonia, PM and ultrafine analysis, and nitrous oxide emissions measurements).

Johnson Matthey

For this program, catalyst research and development will be performed at the Johnson Matthey North American Technical Center, located in Wayne, PA. The Technical Center includes a pilot plant equipped with gasoline and diesel coating equipment, which would be utilized when producing samples for this proposed program. The analytical laboratories within the Technical Center are also available for characterization work. Analytical tools including (but not limited to) XRF, XRD, SEM, BET and TGA would potentially be utilized during the development of new catalyst formulations, as well as during the post-mortem analysis of aged samples throughout the proposed program. Further, the Technical Center has available reactors for catalyst screening and post-mortem analysis, to assist in the development and refinement of advanced catalyst formulations. The R&D center is situated adjacent to Johnson Matthey's manufacturing facility in Wayne, PA, which is the largest auto catalyst manufacturing facility in the world. The manufacturing plant opened in 1974, and has shipped over 300 million automobile catalysts to date. The facility is used for the manufacture of gasoline as well as diesel catalysts.

E. Assigned Personnel

Cummins

Rudy Smaling has as B.S. in Mechanical Engineering from the Technical University of Delft, The Netherlands, M.S. in Mechanical Engineering from Michigan Technological University in Houghton, MI, a dual M.S. in System Design and Management from the Massachusetts Institute of Technology, and a PhD in Engineering Systems from Massachusetts Institute of Technology. Rudy currently serves as Executive Director Systems Engineering in the Cummins Research and Technology organization. Dr. Smaling has 25 years experience in automotive and industrial engine and components R&D, including after treatment, controls, combustion, hybrids, natural gas engines, and biodiesel combustion. Dr. Smaling has over 50 publications and presentations, co-authored a book on Advanced Hybrid Powertrains for Commercial Vehicles and holds 11 patents in the area of emissions control and fuel reforming.

Patrick Pierz graduated with a BS in Mechanical Engineering from University of Illinois at Champaign-Urbana in 1982. Pat is currently Director of Advanced Systems Design, with responsibility for leading design and analysis of components and systems for future engine and generator set applications. He has served in a variety of roles at Cummins including mechanical and performance development of various engine platforms, manufacturing and assembly engineering support, advanced alternate fuels research and concept development, and fundamental combustion research on pre-mixed combustion techniques. He was also heavily involved in definition and development of aftertreatment technology to comply with U.S. and European emission regulations and has served as both author and trainer of internal engine and aftertreatment courses. Pat served as VP and Director of Engineering at Ricardo's Chicago Technical Center from 1995-97 and is a guest lecturer at IUPUI Engineering School. He holds 11 U.S. patents and is a Licensed Professional Engineer.

Gary Salemme graduated with a BS in Mechanical Engineering from Cornell University in 1990 and a MS in Aerospace Engineering from University of Cincinnati in 1993. Gary is currently the Director of Advanced Engine Systems Integration since early 2012, leads research for next generation engine system technology for 2016-2020 products, development of technology roadmaps for future engines and systems, and is a core member of the GHG Phase 2 regulation development team. Having joined Cummins in late 1994, his more than 18 years of experience at Cummins have developed an extensive background in diesel engine performance, vehicle, engine, and aftertreatment system integration and modeling. He previously held the role of Corporate lead on engine modeling and simulation software tool development. Earlier in his career, he was responsible for High Horsepower engine combustion/performance/emissions development including Marine, rail, and industrial applications and field testing. Prior to joining Cummins, he served 4 years performing aircraft engine system development at GE Aircraft Engines. Gary is a registered Professional Engineer and has 4 patents in the areas of engine control and engine aftertreatment system design.

John Wright graduated with a BS and MS in Mechanical Engineering from University of Illinois in May 1992 / August 1996, respectively. He's been actively leading turbocharger and airhandling system architecture activities for the past 6 years. John was the CPE (combustion, performance, emissions) leader for the product preceding technology program that spawned the highly successful ISL-9G Stoichiometric / TWC Natural Gas engine. Model development and application has been a common and important theme throughout his career, ranging from early work at Argonne National Laboratory as a research assistant doing surface chemical reaction modeling to GT Power models, criteria emission models, combustion models for autoignition, ignition delay, and heat release rate, Methane number prediction, HCCI combustion models, and numerous embedded engine performance models. John teaches classes in Fundamentals of IC Engine Performance and Application of Turbomachinery to Reciprocating Engines at Cummins and has co-chaired the Compression Ignition Combustion Processes session at the SAE Congress for more than five years. He holds 14 US patents.

Aleksey Yezerets graduated from the Mendeleev University of Chemical Technology (Russia), with an M.S. in Chemical Engineering and a Ph.D. in Physical Chemistry, and received additional training at the Milan State University (Italy) and Northwestern University (USA). As the Director of Catalyst Technology with Cummins Inc., Dr. Yezerets leads a corporate R&T team responsible for guidance and support to emission control products at all stages of their lifecycle, from conceptual development to post-field diagnostics. He coordinates an extensive portfolio of in-house and collaborative research projects, with several National Labs, universities and industrial partners. Having joined Cummins in 2000, he enjoyed being part of the team which laid the foundation for Cummins' success in emission control, first by developing and operating various experimental tools, and later by supervising and expanding the Catalyst Technology and Emission Chemistry Department. Dr. Yezerets has 9 patents and has co-authored nearly 50 peer-reviewed articles, published in premier academic and industrial journals. Dr. Yezerets is very active in the professional community as an organizer of emission control sessions, with the SAE World Congress, North American Catalysis Society, etc. He serves on the Editorial Board of the Journal of Applied Catalysis B: Environmental and has acted as a guest editor for three issues of the Catalysis Today Journal. He has contributed to training of many of graduate students in the USA, Sweden, and Denmark as a member of Ph.D. defense committees or formal opponent; he also has a special appointment to the graduate faculty of Purdue University. His recent recognitions include the Herman Pines Award in Catalysis, R&D 100

Award, and the National Award for Team Innovation from the American Chemical Society. He was recently elected an SAE Fellow.

Neal Currier received his B.A. in Chemistry and Mathematics from St. Olaf College in 1974 and is currently the senior scientist in the Catalyst Technology and Integration group of Research and Technology at Cummins Inc. He has three decades of industrial research experience in various industries. For the past twenty years he has worked in diesel exhaust emissions and aftertreatment, and currently leads the Analysis Led Design and Modeling team. He has twenty publications in peer-reviewed journals, numerous oral presentations, eleven issued and several pending patents in the area of exhaust aftertreatment and emissions. Mr. Currier has been responsible for developing and executing Cummins' research portfolio in the area of Lean NOx Trap technology specifically and exhaust emissions reduction catalysis in general, including initiating and leading several academic collaborations and two Cooperative Research and Development Agreement (CRADA) collaborations with national laboratories.

Edmund Hodzen graduated with a BS in Engineering from University of Hartford in 1984 and an MS in Engineering from Rensselaer Polytechnic Institute at Hartford in 1988. Ed is currently the Director of Advanced Engineering Control Systems in the Research & Technology organization of Cummins Inc. With more than 25 years of total experience in engineering engine control systems, he has worked on gas turbine controls for Pratt & Whitney and transmission controls for Allison Transmission. Since joining Cummins in 1992, he has specialized in embedded engine and aftertreatment controls. He currently leads a staff of 47 supporting all of Cummins advanced engineering and product preceding controls technology.

Paul Miller graduated with a B.S. and M.S. in Mechanical Engineering from Michigan Technological University in 1982, completing research on the effect of emerging diesel aftertreatment component technology on the physical, chemical, and biological character of diesel particulate emissions as part of a multi-disciplinary team led by his thesis advisor, Dr. John H. Johnson and funded by the U.S. Environmental Protection Agency. As the Director of External Relations for Cummins Research & Technology organization since early 2012, he leads interactions and program development activity between Cummins and its external collaborative R&D partners, including Government agencies that provide R&D funding as well as those it partners with in the National Labs, Universities, and Industry. Having joined Cummins in 1982, he was active in many aspects of combustion, aftertreatment and advanced controls research leading up to the large scale emission reductions of the early 2000's. From 2000-11, he was active in the launch of EGR across the entire on-highway product line, product preceding technology development preparing for major 2007 programs, and a variety of individual contributor and leadership roles in the Dodge Ram pickup family of engines that brought EGR, Diesel Particulate Filters and NOx adsorber technology to that market. His most recent prior role was System Performance Integration leader for the MY2013 Dodge Ram pickup, leading the combustion, performance, aftertreatment integration, controls, and OBD integration teams bringing SCR technology to the product line. He holds 24 patents in the fields of combustion and aftertreatment technologies and electronic controls of combustion, airhandling, and aftertreatment processes. He was honored by Cummins in 2008 with the Dr. Julius Perr Innovation Award for embodying the innovative spirit of the late Dr. Julius Perr, a longtime technological leader at Cummins, and whose inventions significantly benefit the Company, the industry or the environment.

Johnson Matthey

Sougato Chatterjee has a B.S. in Chemical Engineering from Jadavpur University, Calcutta India and M.S. and Ph.D. in Chemical Engineering from the University of Akron, Akron, OH. Sougato joined Johnson Matthey in 1994 and has worked extensively in designing, developing and implementing emission control systems for diesel engines. Some of his work involved the development, introduction and commercialization of Johnson Matthey's successful CRT® particulate filter system in North America, the development of PCRT™ Level II partial filter system for retrofit and the successful development of retrofit NOx and PM control systems such as SCRT® and EGRT®. Currently, Sougato is responsible for developing and supporting emission control technologies for US 2013 and beyond on-road regulations which will require both advanced NOx and PM reductions from new engines. The advanced technologies include Urea based SCR (Selective Catalytic Reduction) systems, advanced Lean NOx Trap systems, actively regenerated DPF systems, etc. Sougato is an active member of Society of Automotive Engineers (SAE), AIChE – American Institute of Chemical Engineers and ACS – American Chemical Society. Sougato has 42 publications and presentations and 2 patents in the field of emission control.

Haiying Chen (BS Chemistry, Fudan University, 1989), PhD (Chemistry, Surface Chemistry and Catalysis, Fudan University, 1994) is currently the Product Development Manager at Johnson Matthey, where he leads a team of scientists to develop advanced emission control catalysts for mobile-source and stationary-source applications. His research group focuses on the development of three-way catalysts, diesel oxidation catalysts, NOx adsorber catalysts, NH3/urea SCR catalysts, catalyzed soot filters, NH3 slip catalysts and VOC oxidation catalysts. Prior to joining Johnson Matthey in 2000, Dr Chen was a post-doctoral fellow in the Center for Catalysis and Surface Science at Northwestern University, where he focused on investigating the nature of active sites of Fe/ZSM-5 SCR catalysts, proposing their catalytic reaction mechanisms. At Johnson Matthey, Dr Chen has also furthered efforts in SCR catalysis, developing a thermally durable and highly active Cu-SCR catalyst, which has become one of the leading technologies for diesel engines to meet the US EPA 2010 NOx emission regulations. Dr Chen was awarded for Science and Technology Achievements in Shanghai in 1993. Additionally, he has received the Top Cited Article Award by Catalysis Today for articles published in 1998. Further, Dr Chen was also a recipient of the American Chemical Society Award for Team Innovation in 2009, for his key contributions to the development and the first commercial introduction of NOx adsorbers, for the Cummins-powered Dodge Ram truck.

Howard S Hess III (BS (Chemical Engineering, Penn State, 1990), M.Eng (Environmental Engineering, Penn State, 1995), PhD (Fuel Science / Energy and Geo-Environmental Engineering, Penn State, 2002) has twenty three years' experience in the field of automotive emissions, nineteen of those while at Johnson Matthey. In the past thirteen years, Dr Hess has focused on the introduction of new catalyst technologies for light-duty and heavy-duty diesel vehicles, as well as for CNG applications. In particular, he has worked closely with Cummins on the introduction of NOx adsorbers for the 2007 Dodge Ram pickup, which resulted in achieving the EPA's strict 2010 emissions requirements a full three years ahead of legislative requirements. As a result of his efforts on this program, Dr Hess was one of the recipients of the American Chemical Society's Team Innovation Award in 2009. Howard has over 40 publications and presentations and 2 patents in the field of emission control.

Phil Ross (BSME) has 13 years' experience in the application of performance and emissions of Diesel engines. Phil's initial work included OEM rating development on several tier 1 DI off-road engine platforms ranging from 14 to 27 liters. Later, he continued similar efforts with 14.6L on-highway engines including work to meet the EPA's 1998 consent decree. In 2002, Phil joined Johnson Matthey and participated in the initial efforts on a Cummins LDD engine for the light truck automotive market. This work later and currently culminated with participation in the development of the first NOx absorber based production HD automotive truck engine. Phil's specific work on this program included identification of non-regulated emissions, component durability and aged performance of close coupled catalysts, NOx absorbers and coated diesel particulate filters.

Balaji Sukumar (Post-Doc (Process Systems Engineering, Carnegie Mellon University, 2009), PhD (Process Systems Engineering, National University of Singapore, 2007), B. Tech (Chemical Engineering, India, 2003)) has ten years of experience in exhaust emission control focusing on computational modeling and simulation of after-treatment systems. Dr Sukumar has an extensive experience in kinetics, multi-scale modeling and computational fluid dynamic modeling with 1 patent and 12 internationally recognized journal publications. He is one of the recipients of "Computers and Chemical Engineering best paper award" and "Chemical Engineering Congress best paper award". Currently, Dr Sukumar leads the modeling team at Johnson Matthey to develop models and analyze the characteristics of different catalysts for light and heavy duty diesel, gasoline and natural gas applications.

Peterbilt

Bill Kahn is the Manager of Advanced Concepts for Peterbilt Motors. An engineering graduate of Texas A&M University, he has over 25 years experience in the trucking and aerospace industry. His last 9 years while at Peterbilt have been dedicated to evaluating emerging technologies, and developing timelines for their viability within the Peterbilt product. His primary focus of late has been in environmental sustainability programs that seek to reduce emissions while improving fuel efficiency, and reducing operating cost. Bill is a member of both the Society of Automotive Engineers and American Society of Mechanical Engineers, and is a technical contributor to the 21st Century Truck Partnership, EPA SmartWay and Blue Skyways programs. Bill's responsibility will be program manager and lead mechanical design engineer on the program, at up to 300 hours / year.

Bryan Knight is currently a Senior Design Engineer at Peterbilt. He has BS and MS in Mechanical Engineering from Texas A&M University. His Master's work there focused on controls development of biodiesel engines based on blending percentages. In his present role, Bryan is responsible for design, fabrication, controls development and integration of advanced vehicular systems in the area of hybrids, alternative fuels, fuel cells, and component electrification. Bryan will handle mechanical design support, electrical coordination, and controls integration at up to 700 hours / year.

University of California, Riverside

Kent Johnson has a Ph.D. in Chemical and Environmental Engineering from the University of California, Riverside a M.S. in Electrical Engineering from California Polytechnic Pomona, and a B.S. in Mechanical Engineering from the California Polytechnic, San Luis Obispo. Over 15 years of research specifically related to the characterization and performance of diesel engines. Primary responsibility include emission related programs with annual budgets >$1,000,000.

Main responsibilities include development, execution, and design of testing projects; the analysis and interpretation of test results; and the preparation of project specific data for reports and scientific articles. Projects include characterization of heavy duty Natural Gas vehicles with lean burn and three way catalysts systems; characterization and impact of 2010 compliant heavy-duty diesel vehicles and their impact on regional emissions; evaluation and characterization of heavy-duty hybrid evaluations and heavy duty electric vehicle evaluations.

Wayne Miller has a Ph.D. in Chemical Engineering from the California Institute of Technology He joined UCR in December 2000 after a distinguished industrial career of more than 30 years of experience in technology planning, new product commercialization, business development and multi-national relationships. He was one of six oil members on the landmark Auto/Oil Research Program and the DOE's National Petroleum Council review of the U.S. refining industry. Dr. Miller led the largest proprietary research program on the relationship between gasoline properties and tailpipe emissions, resulting in a patent on reformulated gasoline. For the past twelve years at UCR, his research has concentrated on the physical and chemical nature and impact of emissions from mobile and stationary sources with an emphasis on sources related to goods movement. His research is funded by: California Air Resources Board, California Energy Commission, U.S. Environmental Protective Agency, Health Effects Institute, Department of Defense, Coordinating Research Council (auto/oil industries), U.S. Maritime Administration, Ports of Los Angeles and Long Beach, Airline Transport Association, Cummins Inc., SoCal Gas and many private companies. Dr. Miller as PI/co-PI has received over $10 million for research since 2001. Since 2001, research findings of Dr Miller and his students were included as part of the technical support for one federal and six California regulations aimed at cleaner air.

Tom Durbin has a Ph.D. in Physics from the University of California, Riverside. He is a principal investigator for a variety of mobile source related programs with annual budgets of approximately >$1,000,000. Responsibilities include research and program development and management, proposals, project budgeting, the establishment and execution of project plans and schedules, daily oversight of project testing, the analysis and interpretation of test results, and the preparation of project reports and scientific articles.

George Karavalkis has a Ph.D. in Chemical Engineering from the National Technical University of Athens, Athens, Greece. He is a principal investigator for a variety of mobile source and air quality related programs. My research is focusing on the use of biomass-derived fuels and on the air quality impacts of vehicle emissions. I am particularly interested in studying the particle emissions and gaseous toxic pollutants from iso-butanol blends in gasoline direct injection vehicles. I am also investigating the emissions from biodiesel and renewable diesel fuels from LD and HD vehicles and their potential health effects. My research includes studies on NGVs/engines, black carbon emissions from vehicles, PM toxicity, and PM hydroscopicity. Responsibilities include daily oversight of project testing, the analysis and interpretation of test results, and the preparation of project reports and scientific articles.

California Cartage Company

Robert A. Lively is the Vice President of Strategic Planning for California Cartage Company in Long Beach, CA. He has committed Cal Cartage to partner with the team in providing highly relevant Port of Los Angeles and Port of Long Beach drayage duty of varying types for the demonstration vehicles of this program.

F. Subcontractors

The research group has identified one subcontractor:

1) The University of California, Riverside's (UCR) Center for Environmental Research and Technology (CE-CERT) will provide emissions testing, data analysis, and reporting during the demonstration part of the project. See Volume III for letter of support.
   - Kent Johnson, PhD, Assistant Research Faculty: Principal Investigator
   - Wayne Miller, PhD, Associate Director of CE-CERT: Advisor
   - Mark T. Durbin, PhD, Associate Research Engineer: Co-PI
   - Georgios Karavalakis, PhD, Assistant Research Engineer: Co-PI

UCR Labor Hours by Task

Personnel	Calendar Months	Overall	Labor Hours*				
			Task 2.2.6	Task 4.1	Task 4.1.1	Task 4.1.2	Task 4.2
Kent Johnson	5.4	870	122	122	292	292	42
J. Wayne Miller	1.9	306	17	17	125	125	21
Mark T. Durbin	0.75	122	9	9	42	42	21
Georgios Karavalakis	0.75	122	9	9	42	42	21

*Labor hours are approximate and will not be used in invoicing or reporting; the university charges for labor by percent effort based on a full-time monthly salary

** Graduate student will also be assigned this project for 1 full year and about 1,700 hr

G. Conflict of Interest

None of the parties supporting this proposal have identified a Conflict of Interest.

H. Additional Data

Appendix A Description of Chassis Test Cycles

Port drayage truck cycle (PDT)

The port cycle was developed by TIAX, the Port of Long Beach and the Port of Los Angeles for the purpose of characterizing the impact of drayage operation in the South Coast air basin. Over 1,000 Class 8 drayage trucks at these ports were data logged for trips over a four-week period in 2010. Five modes were identified on the basis of several driving behaviors average speed, maximum speed, energy per mile, distance, and number of stops. These behaviors are associated with different driving conditions such as queuing or on-dock movement, near-dock, local or regional movement, and highway movements. The data was compiled and analyzed to generate a best fit trip. The best-fit trip data was then additionally filtered (eliminating accelerations over 6 mph/s) to allow operation on a chassis dynamometer.

The final recommended port cycle was then compared to other chassis cycles. It was found the cruise section of the port cycle was similar to the CARB HDDT cruise cycle thus the CARB HDDT was used as the cruise part of the cycle for consistence. Also the long periods of idle were reduced to facilitate performing the chassis testing in a reasonable time frame. It is expected that the shorter idle times may bias the results because the catalyst would be warmer over a shortened idle times. As such, the final recommended drayage port cycles is based on the above analysis and recommendations.

The final driving schedule is called the drayage port tuck (DPT) cycle and is represented by three modes where each mode has three phases to best represent Near Dock (short drayage), Local (medium drayage), and Regional (long drayage) driving as shown in Table 7 and Figure 13. Figure 14 shows the preconditioning cycles that will be performed for the first test of the day. The precondition cycles are 20 minutes long representing the end of each mode. Preconditioning will be performed after warming up the vehicle and chassis dyno.

Each test cycle (Near Dock, Local, and Regional) have the same first two phases where the change is with Phase 3. For the Near Dock cycle the final phase includes the short high speed transient mode, for the Local the final phase is the long high speed mode, and for the Regional the final phase is the high speed cruise. These different phases represent short, medium and long drayage operations. The Near-Dock cycle is 5.6 miles long with a maximum speed of 40 mph, the Local is 8.7 miles long with a maximum of 46 mph, and the Regional is 27 miles long with a maximum of 59 mph. With a chassis setting of 60,000 lb GVW, the average power for the Near-Dock, Local, and Regional were approximately 25, 50, and 100 hp respectively.

Description	Distance mi	Ave Speed mph	Max Speed mph	Phase 1	Phase 2	Phase 3
Near-dock	5.61	6.6	40.6	Creep	Low Speed Transient	Short High Speed Transient
Local	8.71	9.3	46.4	Creep	Low Speed Transient	Long High Speed Transient
Regional	27.3	23.2	59.3	Creep	Low Speed Transient	High Speed Cruise

Table 7: Drayage Truck Port cycle by mode and phases

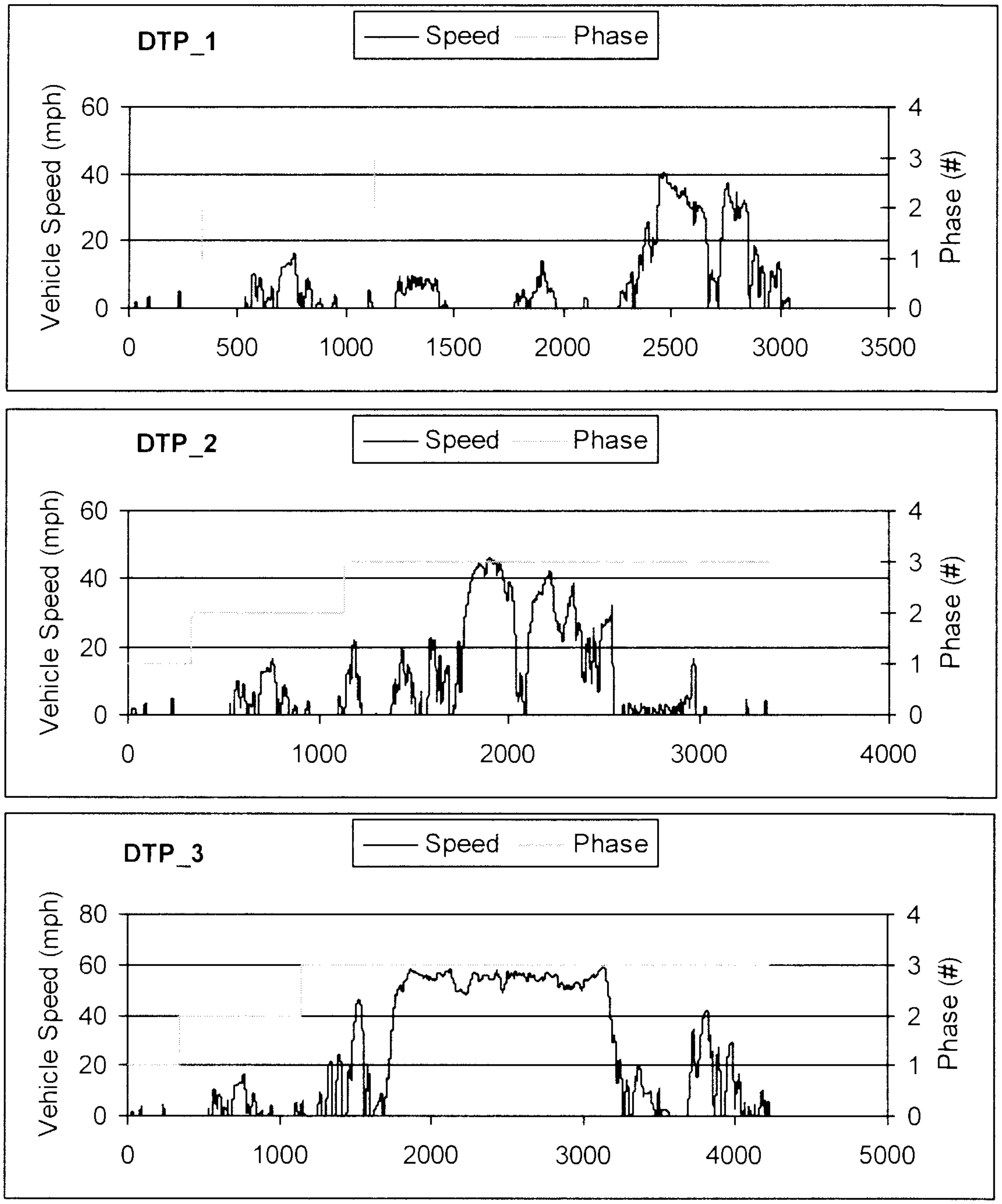


Figure 13: Port cycle near dock (DTP_1), local (DTP_2), and regional (DTP_3)

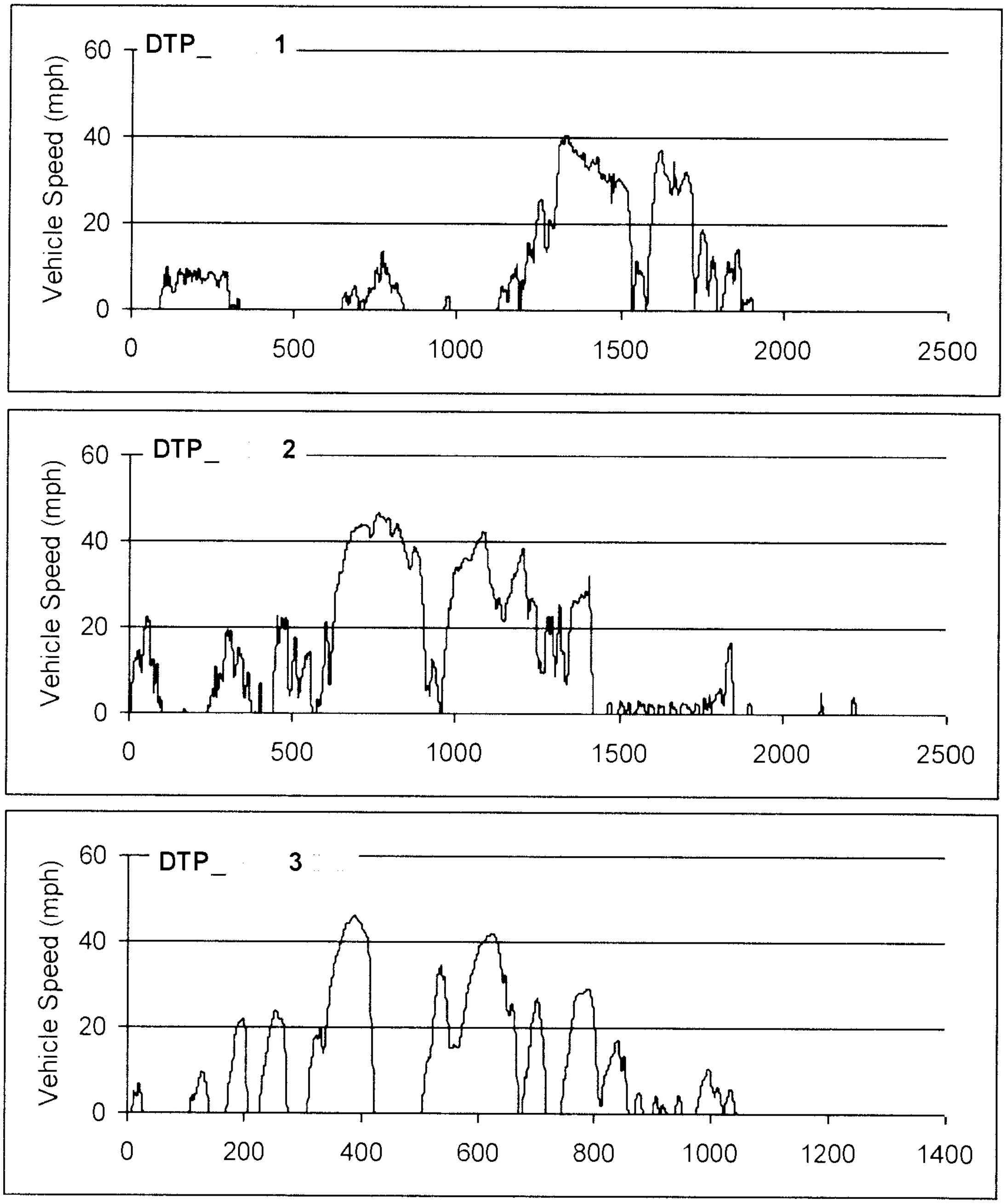


Figure 14: Drayage truck port cycle conditioning segments consisting of phase 3 parts

Greenhouse gas emissions cycle (EPA_GHG)

The US EPA adopted heavy and medium duty vehicle standards for greenhouse gases (GHG) in 2011. The basis of the GHG standard is focused on in-vehicle chassis testing for CO_2, N_20, and CH_4. As such an EPA chassis GHG cycle was developed. Figure 15 shows the full cycle which includes a transient phase and two steady state phases. The cycle phases is weighted according to each heavy duty application where Day Cabs show a 19% weighting factor for the transient section and the remaining for the high speed cruise sections. This table was designed to represent the nominal expected operation for each application.

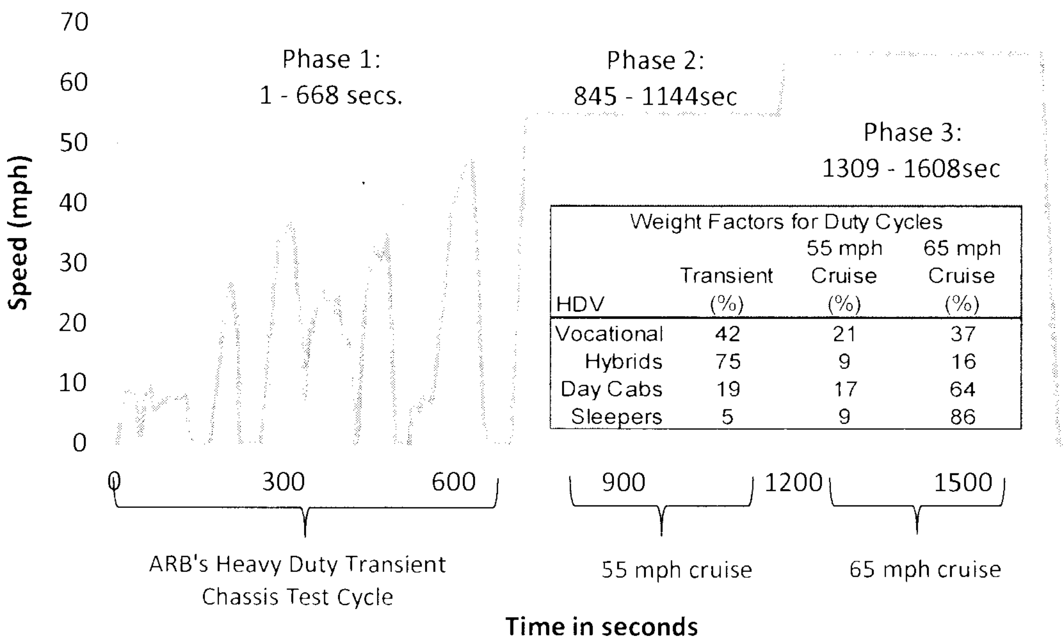
This cycle covers a total distance of 12.8 miles with an average speed of 15.3 mph for the transient phase and a total sample time of 1286 seconds, and maximum speed of 45.7 mph for the transient phase. This cycle will be performed as a double EPA-GHG (2x EPA-GHG) to collect sufficient sample for the batched media (exg. Gravimetric PM filters) where the total sample time will be 2122 seconds. The 1x speed/time trace for the EPA-GHG is provided below in Figures 15.

HDV	Transient (%)	55 mph Cruise (%)	65 mph Cruise (%)
Vocational	42	21	37
Hybrids	75	9	16
Day Cabs	19	17	64
Sleepers	5	9	86

Table 8: EPA-GHG cycle weighting factors for different heavy duty vehicle vocations

Phase	Ave Speed (mph)	Distance (mi)	Max Speed (mph)	Duration (sec)
HDDT	15.3	2.8	47.5	668
55 mph	55.0	4.6	55.0	300
65 mph	65.0	5.4	65.0	300

Table 9: EPA-GHG cycle statistics for each phase



Weight Factors for Duty Cycles			
HDV	Transient (%)	55 mph Cruise (%)	65 mph Cruise (%)
Vocational	42	21	37
Hybrids	75	9	16
Day Cabs	19	17	64
Sleepers	5	9	86

Figure 15: EPA's GHG cycle for heavy duty chassis vehicle testing

Engine Dyno Comparison Cycle (UDDS)

The Federal heavy-duty vehicle Urban Dynamometer Driving Schedule (UDDS) is a cycle commonly used to collect emissions data on engines already in heavy, heavy-duty diesel (HHD) trucks. This cycle covers a distance of 5.55 miles with an average speed of 18.8 mph, sample time of 1061 seconds, and maximum speed of 58 mph. This cycle will be performed as a double UDDS (2xUDDS) to collect sufficient sample for the batched media (exg. Gravimetric PM filters) where the total sample time will be 2122 seconds. The 1x speed/time trace for the UDDS is provided below in Figure 16.

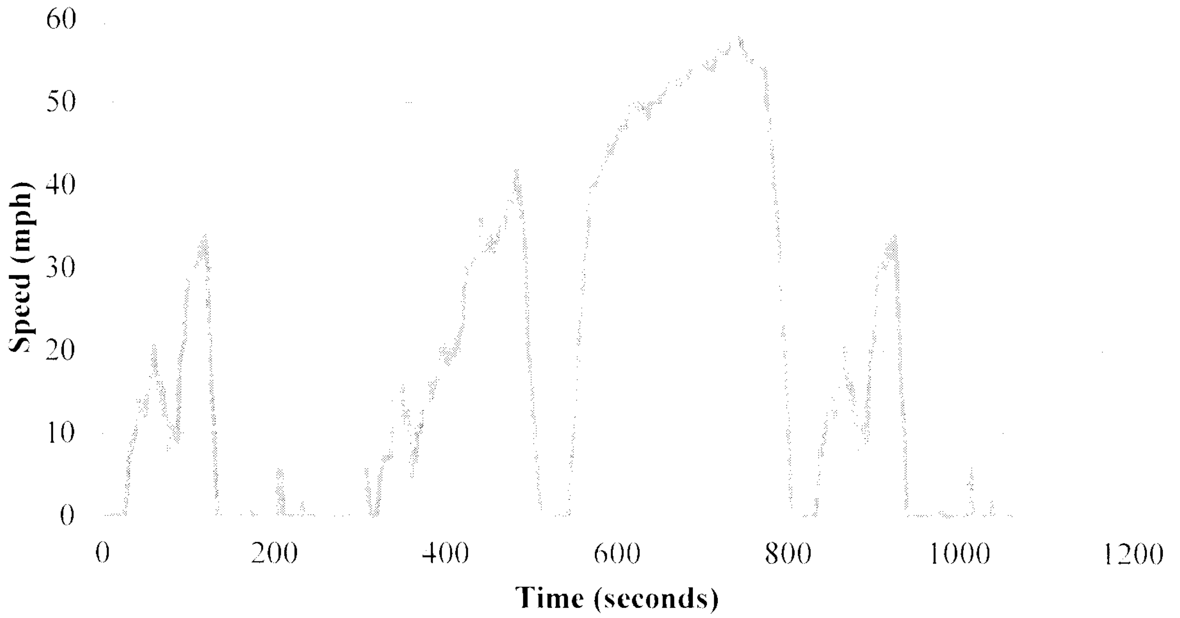


Figure 16. Speed/Time Trace for UDDS cycle for the chassis dynamometer.

Appendix B Description of UCR's Chassis, Emissions, and Analytical Measurements

Heavy-duty chassis laboratory

In 2010 UCR installed a state-of-art heavy-duty chassis dynamometer that is capable of performing all published chassis duty cycles. UCR's chassis dynamometer is an electric AC type design that can simulate inertia loads from 10,000 lb to 80,000 lb which covers a broad range of in-use medium and heavy duty vehicles, see Figure 17. The design incorporates 48" rolls, 45,000 lb base inertial plus two large AC drive for achieving a range of inertias. The dyno has the capability to absorb accelerations and decelerations up to 6 mph/sec and handle wheel loads up to 600 horse power at 70 mph. This facility was also specially geared to handle slow speed vehicles such as yard trucks where 200 hp at 15 mph is common.

The chassis dynamometer was designed to accurately perform all published duty cycles for any speed vs time trace that do not exceed the acceleration and deceleration rates of typical dynamometers. The load measurement uses state of the art sensing and is accurate to 0.05% FS and has a response time of less than 100 ms which is necessary for repeatable and accurate transient testing. The speed accuracy of the rolls is ± 0.01 mph and has acceleration accuracy of ± 0.02 mph/sec which are both measured digitally and thus easy to maintain their accuracy. The torque transducer is calibrated as per CFR 1065 and is a standard method used for determining accurate and reliable wheel loads.

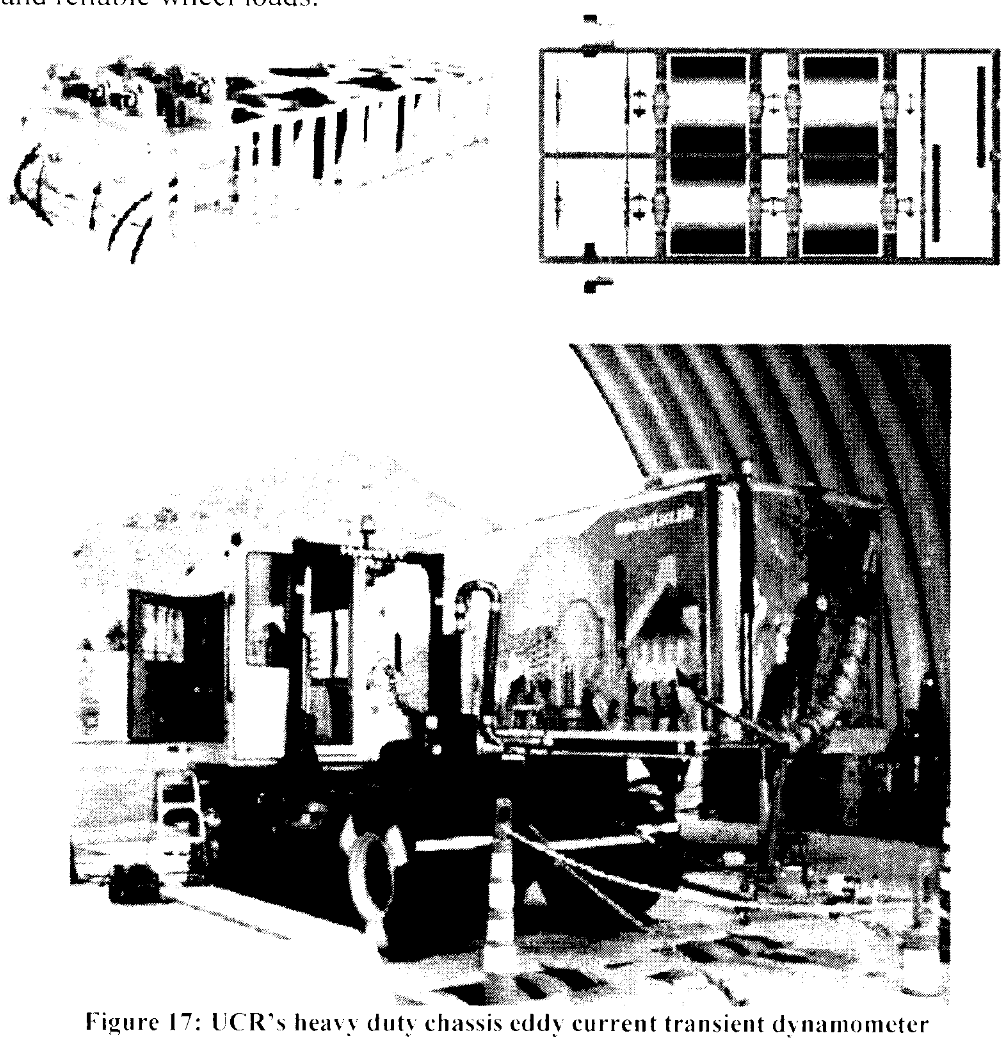


Figure 17: UCR's heavy duty chassis eddy current transient dynamometer

UCR Mobile Emission Lab

The approach used for measuring the emissions from a vehicle is to connect UCR's heavy-duty mobile emission lab (MEL) to the total exhaust of the diesel engine. The details for sampling and measurement methods of mass emission rates from heavy-duty diesel engines are specified in Code of Federal Regulations (CFR): Protection of the Environment, Section 40, Part 1065. UCR's unique heavy-duty diesel mobile emissions laboratory (MEL) is designed and operated to meet those stringent specifications. MEL is a complex laboratory and a schematic of the major operating subsystems for MEL are shown in Figure 18. The accuracy of MEL's measurements have been checked/verified against ARB's[7] and Southwest Research Institute's[8,9] heavy-duty diesel laboratories. MEL routinely measures Total Hydrocarbons (THC), Methane, Carbon Monoxide, Carbon Dioxide, Nitrogen Oxides, and Particulate Matter (PM) emissions from diesel engines. Design capabilities and details of MEL are described in Cocker et al[1,10]. Samples can be collected for more detailed analyses such as hydrocarbon speciation, carbonyl emissions, polynuclear aromatic hydrocarbons, etc.

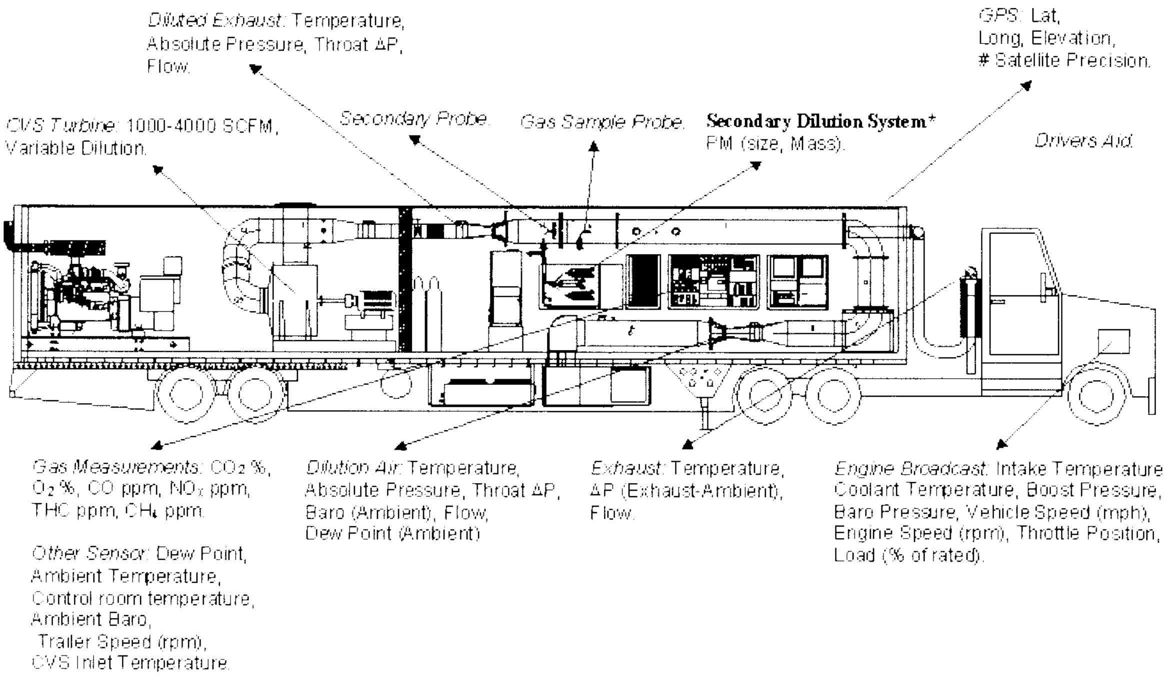


Figure 18: UCR's Mobile Emission Lab (MEL)

Emission Measurements: Regulated and non-regulated emissions.

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[7] Cocker III, D. R., Shah, S. D., Johnson, K. C., Zhu, X., Miller, J. W., Norbeck, J. M., Development and Application of a Mobile Laboratory for Measuring Emissions from Diesel Engines. 2. Sampling for Toxics and Particulate Matter. Environ. Sci. Technol. **2004**, 38, 6809-6816

[8] Cocker III, D. R, Shah, S. D., Johnson, K. C., Miller, J. W., Norbeck, J. M., Measurement Allowance Project On-Road Validation. Final Report to the Measurement Allowance steering Committee.

[9] Johnson, K.C., Durbin, T.D., Cocker, III, D.R., Miller, W.J., Bishnu, D.K., Maldonado, H., Moynahan, N., Ensfield, C., Laroo, C.A. (2009) On-road comparison of a portable emission measurement system with a mobile reference laboratory for a heavy-duty diesel vehicle, Atmospheric Environment 43 (2009) 2877-2883

[10] Cocker III, D. R, Shah, S. D., Johnson, K. C., Miller, J. W., Norbeck, J. M., *Development and Application of a Mobile Laboratory for Measuring Emissions From Diesel Engines I. Regulated Gaseous Emissions*, Environmental Science and Technology, **2004**, 38, 2182-2189

Testing results will provide continuous emissions of NO_X (NO and NO_2), CO, CO_2, NMHC, and $PM_{2.5}$ with one-second resolution from the MEL, as described in the previous section. Several real-time PM analyzers (AVL soot sensor and DMM-230) will measure PM mass, and PM samples will be collected on Teflo® filters to determine mass following the 1065 protocol. Ultrafines will be monitored using UCR's SMPS analyzer[11], which is specifically designed for ultrafines and a particle number counter.

Ammonia from Heavy-Duty Diesel Vehicles. While recent studies have shown reduced NOx and PM emissions from most trucks, other studies show a potential increase in exhaust emissions. In particular, the University of Denver showed high levels of ammonia emissions from trucks fueled with liquefied natural gas (LNG). In another study by The Netherland Organization (TNO), NOx emissions from heavy-duty diesel vehicles with SCRs exceeded certification levels. Since the number of such engines and controls is rapidly increasing, additional studies are now prudent to avoid another 'surprise' such as that encountered in the 1990's, and to ensure that planned progress towards achieving clean air is maintained.

Recently, researchers[12] from the University of Colorado used cross plume measurement instruments and detected up to 1,500 ppm of ammonia (NH_3) emissions from over 1,000 Sterling LNG heavy-duty trucks with TWC at the Port of Los Angeles (POLA). Simultaneously, they recorded carbon monoxide emissions up to 5,000 ppm. By today's standards with TWC, both the NH_3 and CO values are excessive. In the same study, heavy-duty diesel trucks operating on diesel fuel did not show any ammonia emissions.

It was also found during the same study that the lean burn NG techniques did not show any measurable NH_3 emissions, but did show high NOx emissions that were similar to 2007 diesel engines certified to 1.25 g/hp-h. Although their NH3 emissions were low, the NOx emissions were not meeting their design objectives of 0.2 g/hp-h NO_X emissions.

This research study shows two very important points that need to be addressed in this proposal, 1) controlling NO_X emissions to very low levels needs to designed with controls for NH_3 emissions and 2) reliability and robustness of the NG solution needs to be implemented where the ultra-low emissions are maintained in-use throughout the life of the product. Designing for robustness will be uniquely addressed in this proposal approach as this will be the first fully integrated from the ground up design for a NG engine solution from the an OEM supplier who represents more than 80% of the NG engine's in the marketplace.

AQMD Significance of High Ammonia Levels. As stated earlier, AQMD is a non-attainment region and their Air Quality Management Plan requires both ozone and PM precursors to be reduced. Yet, if NO_X is reduced while ammonia is increased, then ozone may drop, but PM will increase as the ammonia forms ammonium nitrate particulate matter ($PM_{2.5}$) in the atmosphere. Thus, the objective of this proposal is to find ways to reduce both NO_X and PM, as well as their precursors, using new technology that has proven successful in gasoline TWC controlled vehicles.

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[11] S.D. Shah, D.R. Cocker*, "*A Fast Scanning Mobility Particle Spectrometer for Monitoring Particle Size Distributions From Vehicles*," Aerosol Science and Technology, 39, 519-526, 2005.

[12] Bishop, U Denver, CRC presentation (2010)

Emission Measurements: Ammonia (NH_3) Emissions. Data in Figure 19 show the very rapid release of NH_3 on acceleration and *the* quick response of the TDL sensor used in UCR's earlier research. Like before, UCR will measure NH_3 with a tunable diode laser (TDL) system that is capable of quantifying NH_3 levels down to 1 ppmv, even during transient conditions. Other measurement methods, such as the dilute FTIR or a chemiluminescent analyzer, do not give the needed response and accuracy during transient operation, as seen in other research[13]. TDL advantages are clearly seen in the Figure 17.

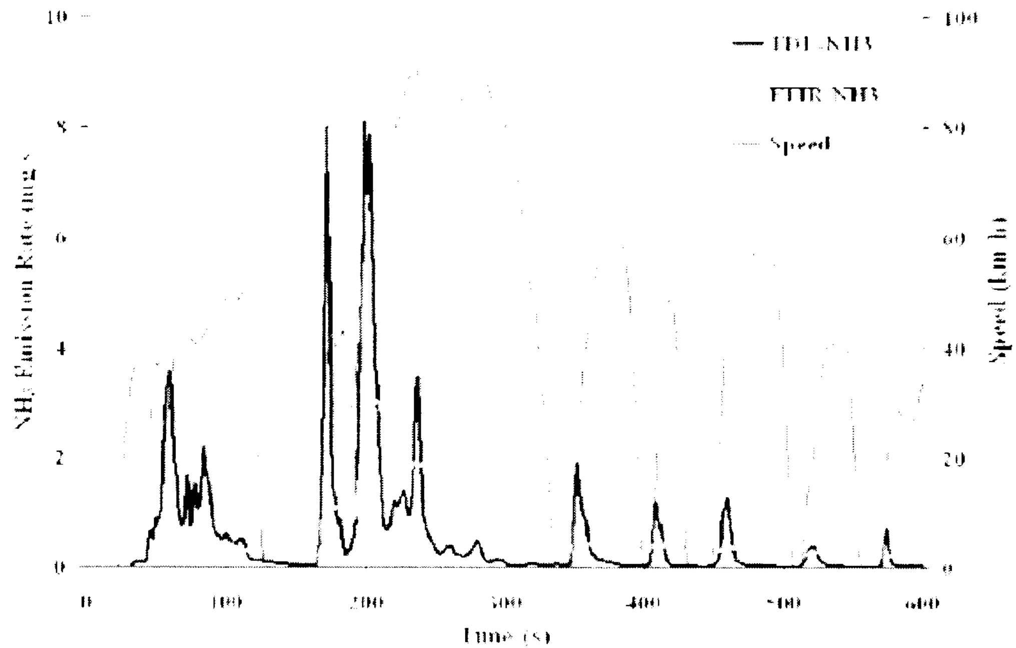

Figure 19: Comparison of FTIR (dilute) & TDL (raw) for Measuring Ammonia

Emission Measurements: Carbonyls Emissions. Carbonyls are collected on 2,4-dinitrophenylhydrazine (DNPH) coated silica cartridges (Waters Corp., Milford, MA) after a Teflon filter. A critical flow orifice controls the flow to 1.0 LPM through the cartridge and the sample time is adjusted to draw a known volume of exhaust sample through the DNPH cartridge so that the amount of formaldehyde on the cartridge is at the mass level recommended by Waters. Sampled cartridges are extracted using 5 mL of acetonitrile and injected into an Agilent 1100 series high performance liquid chromatograph (HPLC) equipped with a diode array detector. The column is a 5μm Deltabond AK resolution (200cm x 4.6mm ID) with upstream guard column. The HPLC sample injection and operating conditions are set up according to the specifications of the SAE 930142HP protocol. Samples from the dilution air are collected for background correction.

[13] Huai, T., T.D. Durbin, J.W. Miller, J.T. Pisano, C.G. Sauer, S.H. Rhee, and J.M. Norbeck. **2003**. *Investigation of NH_3 Emissions from New Technology Vehicles as a Function of Vehicle Operating Condition*. Environ. Sci. & Technol., vol. 37, 4841-4847.

Appendix C NREL's Advanced Vehicle Technology Inspection Form

Operating Company	
Vehicle Number	
Vehicle Manufacturer	
Model	
Vehicle Identification Number (VIN)	
Date of Purchase	
Accumulated Mileage at Start of Operation	

Vehicle Dimensions	
Length, ft	
Width, in.	
Height, in.	
Ground clearance, in.	
Wheel Base	
Front overhang (axle to vehicle front), in.	
Number of axles	
Number of driven axles	
Gross Vehicle Weight Rating, lb.	
Front Axle	
Rear Axle	
Total	
Curb Weight, lb.	
Front Axle	
Rear Axle	
Total	
Seated Load Weight	
Front Axle	
Rear Axle	
Total	

Passenger Seats	
Number of Passenger Seats with no Wheelchairs on Board	
Number of Wheelchair Positions	
Number of Passenger Seats with all Wheelchair Positions Occupied	
Maximum Number of Standees	
Fuel	
Type(s)	
Necessary Additives	
Hybrid Configuration	
Series or Parallel?	
Charge Sustaining or Charge Depleting?	
Multiple operating modes? (Yes/No)	
Number of operating modes	
Driver controlled or automatic?	
Regenerative Braking?	
Power Plant	
OEM or Retrofit?	
Power Plant Type (engine, turbine, fuel cell)	
Manufacturer	
Model Number	
Year of Manufacture	
2 Cycle or 4 Cycle?	
Compression Ratio	
Ignition Aids Used? (Yes/No)	
Type of Ignition Aid (Spark Plug, Glow Plug, Pilot Ignition, Other)	
EPA Certified? (Yes/No)	
CARB Certified? (Yes/No)	
Power Rating	
Max. bhp	
RPM of Max. bhp	

Max. Torque (ft.-lbs.)	
RPM of Max. Torque	
Displacement (L)	
Engine Oil	
Type(s) Used	
Necessary Additives	
Oil Capacity (qts.)	
Blower? (Yes/No)	
Turbocharger? (Yes/No)	
Liquid Fuel Delivery Systems	
Mechanical or Electronic Fuel Injectors?	
Injector Manufacturer	
Injector Model Number	
Number of Fuel Filters	
Fuel Filter Manufacturer	
Fuel Filter Model	
Gaseous Fuel Delivery Systems	
Direct Injection or Fumigation?	
Throttle for Intake Air? (Yes/No)	
OEM or Retrofit?	
Power Plant Accessories	
Mechanical or Electric Drive Accessories?	
Generator	
Output at Normal Idle	
Maximum Rating	
Starter Type (Electrical/Air)?	
Manufacturer	
Model	
Hydraulic Pump	
Manufacturer	
Model	
Output (gpm @ psi)	

Heating	
Heating System Type	
Capacity, BTU/hr	
Air Conditioning	
Manufacturer	
Model	
Capacity, BTU/hr	
Air Compressor	
Manufacturer	
Model Number	
Capacity, Cubic Ft./Min.	
Drivetrain	
Transmission/Gearbox	
Manufacturer	
Model Number	
Model Year	
Manual or Automatic?	
Number of forward speeds	
Gear Ratios	
Torque conversion ratio	
Additional features	
Retarder	
Manufacturer	
Model Number	
Drive Axle	
Manufacturer	
Model Number	
Axle ratio(s)	
Tires	
Manufacturer	
Model Number	
Size	

Appendix D Sample Vehicle Demonstration Vehicle Survey

Cal Cartage has agreed to utilize a fleet survey during daily operation of the demonstration vehicles. The following is an example of the fleet survey.

Put an "X" in the column that agrees with your answer as it compares to a similar diesel equivalent vehicle

Description	Better	Same	Worse
Cold morning starting			
Warm morning starting			
Crank duration			
Fuel odor			
Power comparison			
Hill climbing			
Warm up			
Re-starting problem (warm starts)			
Idling			
Sounds			

Question	Description
What load amount are you carrying	
How much fuel did you add	
How many time did you refuel today	
Any issues during refueling	
Did you experience any driving problems	
Did you notice any problems	

Volume II – Cost Proposal

South Coast AQMD

College of Engineering- Center for Environmental Research & Technology

The proposed program involves Cummins leading the overall program, with significant participation by program partners … Johnson-Matthey, Peterbilt Motors, and UC Riverside CE-CERT … as described in the task descriptions and other detailed documents contained in the Technical Proposal. Both Johnson-Matthey and Peterbilt Motors are providing In-Kind Participation at the levels outlined below, and in their letters of support. UC Riverside is requesting funds for its Subcontractor role, as noted below, in their letter of support request, and in their detailed Cost Proposal material attached later in this document. An overview of the top level financial structure is shown in the tables below. Supporting documentation is provided in the pages that follow.

Program Financials - Funding Sources

As Proposed / Budgeted

	Total Program =	$6,027,990	Total
30.0%	Cummins Cost Share =	$1,808,397	Cummins
70.0%	Customer Cost Share =	$4,219,593	SCAQMD

Program Financials - Funding Uses

As Proposed / Budgeted

	Total Program =	$6,027,990	Total
91.7%	Cummins Led Activities =	$5,525,006	Cummins
8.3%	UCR Subcontract =	$502,984	UCR

Program Financials - Funding Sources

Reflecting Additional Partner In-Kind Participation*

100.0%	Total Program =	$6,567,990	Total
35.8%	***Total Partner*** Cost Share =	$2,348,397	All Partners
64.2%	Customer Cost Share =	$4,219,593	SCAQMD
2.3%	JMI In-Kind =	$ 150,000	JMI *
5.9%	Peterbilt In-Kind =	$ 390,000	Peterbilt *

* though not contractually in budget

Cummins Inc
Cummins Technical Center
1900 McKinley Avenue M/C
Columbus, IN 47201

Attn: Paul R. Miller M/C 50185

SCAQMD-P2013-22
On-Road Heavy-Duty Development, Intergration, and Demonstration of Ultra-Low Emission Natural Gas Engines

Proposal Summary

Rate	Topic	Cost ($)
	Exempt Wages	1,404,546
	Hourly Wages	50,494
	Total Direct Labor	1,455,040
24.90%	Exempt Fringes	349,732
57.27%	Hourly Fringes	28,918
18.22%	Exempt Profit Sharing	255,908
13.95%	Hourly Profit Sharing	7,044
134.10%	CTC Overhead	1,951,209
	Purchased Parts	1,147,100
	Subcontractors	502,984
	Specialty Testing	-
	Travel	15,800
	Total Non-Labor	1,665,884
	Subtotal Cost	5,713,735
5.50%	Corporate G&A	314,255
	Total Cost	6,027,990
	Cost of Money	-
	Proposed Profit	-
	Total Program	6,027,990
30.00%	Cummins Cost Share	1,808,397
70.00%	Customer Cost Share	4,219,593

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Project Total	**Hours**	27,887.13
	Avg Rate ($/hr)	**52.18**
	Cost	1,455,040

Labor Type

1 After Treatment Engineer	Hours	4,703.11
	Avg Rate ($/hr)	54.08
	Cost	**254,324**
2 Application and Customer Engineer	Hours	944.04
	Avg Rate ($/hr)	55.26
	Cost	**52,169**
3 Combustion Analysis Engineer	Hours	3,880.10
	Avg Rate ($/hr)	51.57
	Cost	**200,107**
4 Controls Engineer	Hours	4,656.99
	Avg Rate ($/hr)	49.13
	Cost	**228,791**
5 Design Engineer	Hours	1,676.82
	Avg Rate ($/hr)	53.62
	Cost	**89,919**
6 Performance Engineer	Hours	3,162.35
	Avg Rate ($/hr)	48.68
	Cost	**153,942**
7 Principle Investigator	Hours	2,867.41
	Avg Rate ($/hr)	84.79
	Cost	**243,117**
8 System Intgration Engineer	Hours	3,758.97
	Avg Rate ($/hr)	48.46
	Cost	**182,177**
9 Technician	Hours	2,237.35
	Avg Rate ($/hr)	22.57
	Cost	**50,494**

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SCAQMD-P2013-22

On-Road Heavy-Duty Development, Intergration, and Demonstration of Ultra-Low Emission Natural Gas Engines

	Rates	
Exempt Wages		1,404,546
Hourly Wages		50,494
Total Direct Labor Dollars		1,455,040
Exempt Fringes	24.90%	349,732
Hourly Fringes	57.27%	28,918
Exempt Profit Sharing	18.22%	255,908
Hourly Profit Sharing	13.95%	7,044
Total Fringes + Profit Sharing		641,602

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Columbus, IN 47201

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SCAQMD-P2013-22

On-Road Heavy-Duty Development, Intergration, and Demonstration of Ultra-Low Emission Natural Gas Engines

	Rate	
Exempt Wages		1,404,546
Hourly Wages		50,494
Direct Labor Dollars		1,455,040
CTC Overhead	134.10%	1,951,209

Cummins Inc
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Attn: Paul R. Miller M/C 50185

SCAQMD-P2013-22

On-Road Heavy-Duty Development, Intergration, and Demonstration of Ultra-Low Emission Natural Gas Engines

Subcontractors Total ==> $502,984.00

Description	Source	Cost	Cost Basis
UCR	University	$502,984	Engineering estimate

Cummins Inc
Cummins Technical Center
1900 McKinley Avenue M/C
Columbus, IN 47201

Attn: Paul R. Miller M/C 50185

SCAQMD-P2013-22
On-Road Heavy-Duty Development, Intergration, and Demonstration of Ultra-Low Emission Natural Gas Engines

Travel

Total ==> $15,800.00

Projected Order Date	Projected Invoice Date	Purpose	Origin	Destination	No Nights	No Persons	Round Trip Airfare per Person	Preferred Lodging per Person per Night	Meal Total per Person per day	Car Rental per trip	Total
1/1/14	1/1/14	Program kickoff	Columbus	Diamond Bar, CA	1	1	$800.00	$200.00	$50.00	$100.00	$1,150.00
4/1/14	4/1/14	Briefing to SCAQMD	Columbus	Diamond Bar, CA	1	1	$800.00	$200.00	$50.00	$100.00	$1,150.00
10/1/14	10/1/14	Briefing to SCAQMD	Columbus	Diamond Bar, CA	2	2	$800.00	$200.00	$50.00	$100.00	$2,700.00
4/1/15	4/1/15	Briefing to SCAQMD	Columbus	Diamond Bar, CA	2	2	$800.00	$200.00	$50.00	$100.00	$2,700.00
10/1/15	10/1/15	Briefing to SCAQMD	Columbus	Diamond Bar, CA	2	2	$800.00	$200.00	$50.00	$100.00	$2,700.00
4/1/16	4/1/16	Briefing to SCAQMD	Columbus	Diamond Bar, CA	2	2	$800.00	$200.00	$50.00	$100.00	$2,700.00
10/1/16	10/1/16	Briefing to SCAQMD	Columbus	UC Riverside	2	2	$800.00	$200.00	$50.00	$100.00	$2,700.00

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Columbus, IN 47201

Attn: Paul R. Miller M/C 50185

SCAQMD-P2013-22
On-Road Heavy-Duty Development, Intergration, and Demonstration of Ultra-Low Emission Natural Gas Engines

Purchased Parts **Total ==> $1,147,100.00**

Projected Order Date	Projected Invoice Date	Description	Source	Cost	Cost Basis
1/1/14	1/1/14	ISX12-G mule engine for development	Estimate	$20,000.00	engineering estimate
4/1/15	4/1/15	Early production ISX15-G test engine	Estimate	$20,000.00	engineering estimate
4/1/14	4/1/14	Cylinder head Cast Tooling	Estimate	$250,000.00	engineering estimate
4/1/14	4/1/14	Castings (10 @ $5k)	Estimate	$50,000.00	engineering estimate
4/1/14	4/1/14	Machining (10 @ $5k)	Estimate	$50,000.00	engineering estimate
4/1/14	4/1/14	Pistons ($2500/each)	Estimate	$45,000.00	engineering estimate
4/1/14	4/1/14	Ringpack ($200/each)	Estimate	$3,600.00	engineering estimate
4/1/14	4/1/14	Turbo ($5K each)	Estimate	$25,000.00	engineering estimate
4/1/14	4/1/14	Exhaust Manifold Cast Tooling	Estimate	$37,000.00	engineering estimate
4/1/14	4/1/14	Exhaust Manifold Machining ($1000/set)	Estimate	$3,000.00	engineering estimate
4/1/14	4/1/14	EGR Plumbing ($3000/set)	Estimate	$9,000.00	engineering estimate
4/1/14	4/1/14	Gas fuel valves ($500/each)	Estimate	$9,000.00	engineering estimate
4/1/14	4/1/14	High energy Ignition system ($1500/each)	Estimate	$4,500.00	engineering estimate
4/1/14	4/1/14	ECM and Advanced Sensors ($2000/engine)	Estimate	$6,000.00	engineering estimate
4/1/14	4/1/14	Advanced TWC ($7500)	Estimate	$45,000.00	engineering estimate
4/1/14	4/1/14	Misc Parts	Estimate	$50,000.00	engineering estimate
9/1/15	9/1/15	Concept Engine Build	Estimate	$110,000.00	engineering estimate
1/1/16	1/1/16	Vehicle Engine Builds	Estimate	$410,000.00	engineering estimate

Cummins Inc
Cummins Technical Center
1900 McKinley Avenue M/C
Columbus, IN 47201

Attn: Paul R. Miller M/C 50185

SCAQMD-P2013-22
On-Road Heavy-Duty Development, Intergration, and Demonstration of Ultra-Low Emission Natural Gas Engines

Subtotal - Cost Before G&A	5,713,735
G&A Rate	5.50%
Total G&A	314,255

Volume II, Cost Proposal

South Coast AQMD's RFP#P2013-22

UCR Subcontracting Costs

Cost Proposal, All UCR Tasks

A. Labor

Personell	Number of Hours	Hourly Billing Rate - Total	Average Hourly Billing Rate (Direct Labor)	Average Hourly Billing Rate (Fringe Benefits)	Hourly Billing Rate (Indirect Cost Overhead)	Hourly Billing Rate (Direct Cost - Facilities)	Hourly Billing Rate (Profit Only)
Kent Johnson, Principal Investigator	870	$ 129	$ 56	$ 29	$ 22	$ 22	$ -
Wayne Miller, Associate Director	306	$ 164	$ 73	$ 36	$ 28	$ 28	$ -
Georgios Karavalakis, Assistant	122	$ 114	$ 49	$ 26	$ 20	$ 20	$ -
Tom Durbin, Research Engineer	122	$ 133	$ 59	$ 29	$ 23	$ 23	$ -
TBD, Graduate Student	1,740	$ 48	$ 24	$ 11	$ 6	$ 6	$ -
TBD, Development Engineer	209	$ 87	$ 39	$ 18	$ 15	$ 15	$ -

The PI will oversee the project and provide a large role for overseeing the graduate student. Therefore the level of effort is high. In conjunction, the assistant researcher and research engineer will provide assistance and technical help in setting up the testing and interpreting results. The graduate will be working approximately 25% of the time on the project for 36 months. The associate director will provide needed oversight and interaction with the participating parties.

The graduate fees are included in fringe benefits
Facilities fees are a direct charge to the project. Indirect administrative fees are subject to the off-campus rate of 26%.
UCR is a not-for profit entity so the profit is 0.

B. Subcontractor
There are no subcontractors.

C. Travel
There is no travel.

D. Other Direct Costs
Facilities rental fees: as an off-campus facility, CE-CERT incurs facilities rental fees. Facilities rental fees are charged as a direct cost and cover direct, lease-based charges. Facilities rental charges are estimated at 26% of Modified Total Direct Costs (MTDC; total direct costs less equipment, graduate student tuition/fee remission, and any subcontract costs greater than $25,000) for the year 2013. This charge is included in the fully burdened total hourly billing rate detailed in item A, and in the supplies and expenses listed below.

Supplies and expenses total $15,300, $6,500 for lab supplies $4,000 for fuel, $4,800 for fuel analysis as per 1065 (8 analysis total)

Testing expenses total $121,920 are as follows:

	Count	Units	Cost Rate/Units		Total Cost
Chassis + MEL laboratories	55	2	$956	$/hr	$105,160
NH3 sampling	2	2	$250	$/wk	$1,000
N20 sampling	2	2	$100	$/wk	$400
PM fine sampling	2	2	$100	$/wk	$400
DNPH Fomaldyhyde analysis	24	2	$190	ea	$4,560
Low NOx analysis	2	2	$2,600	weeks	$10,400

Supplies and Expenses and testing are charged a direct facilities fee and indirect costs for the project.

Indirect Costs

The University's federally approved Overhead (Indirect Cost or IDC) rate for off-campus facilities is 26% of Modified Total Direct Costs (MTDC). IDC rates are predetermined through June 30, 2013 and provisional thereafter: DHHS agreement dated January 30, 2009.

Cost Proposal, Task 2.6.2

A. Labor

Personell	Number of Hours	Hourly Billing Rate-Total	Average Hourly Billing Rate (Direct Labor)	Average Hourly Billing Rate (Fringe Benefits)	Hourly Billing Rate (Indirect Cost Overhead)	Hourly Billing Rate (Direct Cost - Facilities)	Hourly Billing Rate (Profit Only)
Kent Johnson, Principal Investigator	122	$ 129	$ 56	$ 29	$ 22	$ 22	$ -
Wayne Miller, Associate Director	17	$ 164	$ 73	$ 36	$ 28	$ 28	$ -
Georgios Karavalakis, Assistant Research Engineer	9	$ 114	$ 49	$ 26	$ 20	$ 20	$ -
Tom Durbin, Research Engineer	9	$ 133	$ 59	$ 29	$ 23	$ 23	$ -
TBD, Graduate Student	87	$ 37	$ 24	$ 0	$ 6	$ 6	$ -
							$ -

The PI will oversee the project and provide a large role for overseeing the graduate student. Therefore the level of effort is high. The other personell will provide minimal support, consistent with attending meetings and coordination with other tasks. The graduate will be working 50% of the time on the project for the duration of the task, 1 month.

The graduate fees are included in fringe benefits
Facilities fees are a direct charge to the project. Indirect administrative fees are subject to the off-campus rate of 26%.
UCR is a not-for profit entity so the profit is 0.

B. Subcontractor
There are no subcontractors.

C. Travel
There is no travel.

D. Other Direct Costs
Facilities rental fees: as an off-campus facility, CE-CERT incurs facilities rental fees. Facilities rental fees are charged as a direct cost and cover direct, lease-based charges. Facilities rental charges are estimated at 26% of Modified Total Direct Costs (MTDC; total direct costs less equipment, graduate student tuition/fee remission, and any subcontract costs greater than $25,000) for the year 2013. This charge is included in the fully burdened total hourly billing rate detailed in item A.

Indirect Costs

The University's federally approved Overhead (Indirect Cost or IDC) rate for off-campus facilities is 26% of Modified Total Direct Costs (MTDC). IDC rates are predetermined through June 30, 2013 and provisional thereafter: DHHS agreement dated January 30, 2009.

Cost Proposal, Task 4.1.1

A. Labor

Personell	Number of Hours	Hourly Billing Rate- Total	Average Hourly Billing Rate (Direct Labor)	Average Hourly Billing Rate (Fringe Benefits)	Hourly Billing Rate (Indirect Cost Overhead)	Hourly Billing Rate (Direct Cost - Facilities)	Hourly Billing Rate (Profit Only)
Kent Johnson, Principal Investigator	122	$ 129	$ 56	$ 29	$ 22	$ 22	$ -
Wayne Miller, Associate Director	17	$ 164	$ 73	$ 36	$ 28	$ 28	$ -
Georgios Karavalakis, Assistant	9	$ 114	$ 49	$ 26	$ 20	$ 20	$ -
Tom Durbin, Research Engineer	9	$ 133	$ 59	$ 29	$ 23	$ 23	$ -
TBD, Graduate Student	87	$ 37	$ 24	$ 0	$ 6	$ 6	$ -
TBD, Development Engineer							$ -

The PI will oversee the project and provide a large role for overseeing the graduate student. Therefore the level of effort is high. The other personell will provide minimal support, consistent with attending meetings and coordination with other tasks. The graduate will be working 50% of the time on the project for the duration of the task, 1 month.

The graduate fees are included in fringe benefits

Facilities fees are a direct charge to the project. Indirect administrative fees are subject to the off-campus rate of 26%.

UCR is a not-for profit entity so the profit is 0.

B. Subcontractor

There are no subcontractors.

C. Travel

There is no travel.

D. Other Direct Costs

Facilities rental fees: as an off-campus facility, CE-CERT incurs facilities rental fees. Facilities rental fees are charged as a direct cost and cover direct, lease-based charges. Facilities rental charges are estimated at 26% of Modified Total Direct Costs (MTDC; total direct costs less equipment, graduate student tuition/fee remission, and any subcontract costs greater than $25,000) for the year 2013. This charge is included in the fully burdened total hourly billing rate detailed in item A, and in the supplies and expenses listed below.

Supplies and expenses total $500 for lab supplies.

Indirect Costs

The University's federally approved Overhead (Indirect Cost or IDC) rate for off-campus facilities is 26% of Modified Total Direct Costs (MTDC). IDC rates are predetermined through June 30, 2013 and provisional thereafter: DHHS agreement dated January 30, 2009.

Cost Proposal, Task 4.1.2

A. Labor

Personell	Number of Hours	Hourly Billing Rate- Total	Average Hourly Billing Rate (Direct Labor)	Average Hourly Billing Rate (Fringe Benefits)	Hourly Billing Rate (Indirect Cost Overhead)	Hourly Billing Rate (Direct Cost - Facilities)	Hourly Billing Rate (Profit Only)
Kent Johnson, Principal Investigator	292	$ 129	$ 56	$ 29	$ 22	$ 22	$ -
Wayne Miller, Associate Director	125	$ 164	$ 73	$ 36	$ 28	$ 28	$ -
Research Engineer	42	$ 114	$ 49	$ 26	$ 20	$ 20	$ -
Tom Durbin, Research Engineer	42	$ 133	$ 59	$ 29	$ 23	$ 23	$ -
TBD, Graduate Student	418	$ 49	$ 24	$ 12	$ 6	$ 6	$ -
TBD, Development Engineer	104	$ 87	$ 39	$ 18	$ 15	$ 15	$ -

The PI will oversee the project and provide a large role for overseeing the graduate student. Therefore the level of effort is high. In conjunction, the assistant researcher and research engineer will provide assistance and technical help in setting up the testing and interpreting results. The graduate will be working 20% of the time on the project. The Associate Director will provide guidance on the project and interface with the participating parties.

The graduate fees are included in fringe benefits

Facilities fees are a direct charge to the project. Indirect administrative fees are subject to the off-campus rate of 26%.

UCR is a not-for profit entity so the profit is 0.

B. Subcontractor

There are no subcontractors.

C. Travel

There is no travel.

D. Other Direct Costs

Facilities rental fees: as an off-campus facility, CE-CERT incurs facilities rental fees. Facilities rental fees are charged as a direct cost and cover direct, lease-based charges. Facilities rental charges are estimated at 26% of Modified Total Direct Costs (MTDC; total direct costs less equipment, graduate student tuition/fee remission, and any subcontract costs greater than $25,000) for the year 2013. This charge is included in the fully burdened total hourly billing rate detailed in item A. and in the supplies and expenses listed below.

Supplies and expenses total $7,400, including $3,000 for lab supplies $2,000 for fuel, $2,400 for fuel analysis as per 1065 (4 analysis total)

Testing expenses totalling $66,303 are as follows:

	Count	Units	Cost	Rate/Units	
Chassis + MEL laboratories	55	1	$956	$/hr	$52,580
NH3 sampling	2	1	$250	$/wk	$500
N20 sampling	2	1	$100	$/wk	$200
PM fine sampling	2	1	$100	$/wk	$200
DNPH Fomaldyhyde analysis	24	1	$190	ea	$4,560
Low NOx analysis	2	1	$2,600	weeks	$5,200

Supplies and Expenses and testing are charged a direct facilities fee and indirect costs for the project.

__Indirect Costs__

The University's federally approved Overhead (Indirect Cost or IDC) rate for off-campus facilities is 26% of Modified Total Direct Costs (MTDC). IDC rates are predetermined through June 30, 2013 and provisional thereafter: DHHS agreement dated January 30, 2009.

Cost Proposal, Task 4.1.3
A. Labor

Personell	Number of Hours	Hourly Billing Rate-Total	Average Hourly Billing Rate	Average Hourly Billing Rate	Hourly Billing Rate (Indirect	Hourly Billing Rate (Direct	Hourly Billing Rate (Profit
Kent Johnson, Principal Investigator	292	$ 129	$ 56	$ 29	$ 22	$ 22	$ -
Wayne Miller, Associate Director	125	$ 164	$ 73	$ 36	$ 28	$ 28	$ -
Georgios Karavalakis, Assistant Research Engineer	42	$ 114	$ 49	$ 26	$ 20	$ 20	$ -
Tom Durbin, Research Engineer	42	$ 133	$ 59	$ 29	$ 23	$ 23	$ -
TBD, Graduate Student	418	$ 49	$ 24	$ 12	$ 6	$ 6	$ -
TBD, Development Engineer	104	$ 87	$ 39	$ 18	$ 15	$ 15	$ -

The PI will oversee the project and provide a large role for overseeing the graduate student. Therefore the level of effort is high. In conjunction, the assistant researcher and research engineer will provide assistance and technical help in setting up the testing and interpreting results. The graduate will be working 20% of the time on

The graduate fees are included in fringe benefits
Facilities fees are a direct charge to the project. Indirect administrative fees are subject to the off-campus rate of 2
UCR is a not-for profit entity so the profit is 0.

B. Subcontractor
There are no subcontractors.

C. Travel
There is no travel.

D. Other Direct Costs
Facilities rental fees: as an off-campus facility, CE-CERT incurs facilities rental fees. Facilities rental fees are charged as a direct cost and cover direct, lease-based charges. Facilities rental charges are estimated at 26% of Modified Total Direct Costs (MTDC; total direct costs less equipment, graduate student tuition/fee remission, and any subcontract costs greater than $25,000) for the year 2013. This charge is included in the fully burdened total hourly billing rate detailed in item A, and in the supplies and expenses listed below.

Supplies and expenses total $7,400, including $3,000 for lab supplies $2,000 for fuel, $2,400 for fuel analysis as per 1065 (4 analysis total)

Testing expenses totalling $66,303 are as follows:

	Count	Units	Cost Rate/Units		
Chassis + MEL laboratories	55	1	$956	$/hr	$52,580
NH3 sampling	2	1	$250	$/wk	$500
N20 sampling	2	1	$100	$/wk	$200
PM fine sampling	2	1	$100	$/wk	$200
DNPH Fomaldyhyde analysis	24	1	$190	ea	$4,560
Low NOx analysis	2	1	$2,600	weeks	$5,200

Supplies and Expenses and testing are charged a direct facilities fee and indirect costs for the project.

Indirect Costs

The University's federally approved Overhead (Indirect Cost or IDC) rate for off-campus facilities is 26% of Modified Total Direct Costs (MTDC). IDC rates are predetermined through June 30, 2013 and provisional thereafter; DHHS agreement dated January 30, 2009.

Cost Proposal, Task 4.2

A. Labor

Personell	Number of Hours	Hourly Billing Rate-Total	Average Hourly Billing Rate (Direct Labor)	Average Hourly Billing Rate (Fringe Benefits)	Hourly Billing Rate (Indirect Cost Overhead)	Hourly Billing Rate (Direct Cost - Facilities)	Hourly Billing Rate (Profit Only)
Kent Johnson, Principal Investigator	42	$ 129	$ 56	$ 29	$ 22	$ 22	$ -
Wayne Miller, Associate Director	21	$ 164	$ 73	$ 36	$ 28	$ 28	$ -
Georgios Karavalakis, Assistant	21	$ 114	$ 49	$ 26	$ 20	$ 20	$ -
Tom Durbin, Research Engineer	21	$ 133	$ 59	$ 29	$ 23	$ 23	$ -
TBD, Graduate Student	731	$ 49	$ 24	$ 12	$ 6	$ 6	$ -
TBD, Development Engineer							$ -

The PI will oversee the project and provide a large role for overseeing the graduate student. Therefore the level of effort is high. In conjunction, the assistant researcher and research engineer will provide assistance and technical help in setting up the testing and interpreting results. The graduate will be working 35% of the time on the project for a 12 month period.

The graduate fees are included in fringe benefits
Facilities fees are a direct charge to the project. Indirect administrative fees are subject to the off-campus rate of 26%.
UCR is a not-for profit entity so the profit is 0.

B. Subcontractor
There are no subcontractors.

C. Travel
There is no travel.

D. Other Direct Costs

Facilities rental fees: as an off-campus facility, CE-CERT incurs facilities rental fees. Facilities rental fees are charged as a direct cost and cover direct, lease-based charges. Facilities rental charges are estimated at 26% of Modified Total Direct Costs (MTDC; total direct costs less equipment, graduate student tuition/fee remission, and any subcontract costs greater than $25,000) for the year 2013. This charge is included in the fully burdened total hourly billing rate detailed in item A.

Indirect Costs
The University's federally approved Overhead (Indirect Cost or IDC) rate for off-campus facilities is 26% of Modified Total Direct Costs (MTDC). IDC rates are predetermined through June 30, 2013 and provisional thereafter: DHHS agreement dated January 30, 2009.

JOHNSON MATTHEY, INC.
900 FORGE AVENUE, SUITE 100, AUDUBON, PA 19403-2305
T +484-320-2300 F +484-232-2306

JM Johnson Matthey
Catalysts

To: Dr. Wayne A. Eckerle
Vice President - Corporate Research & Technology
1900 McKinley Avenue, Columbus IN 47201-6414
Office: 812-377-8615
e-mail: wayne.a.eckerle@cummins.com

Date: 19-July-2013

Subj: Johnson Matthey Letter of Support, SCAQMD CNG proposal

Johnson Matthey would like to commit to providing support to Cummins, in the SCAQMD – Ultra-Low NOx CNG Engine Program. Johnson Matthey is qualified to participate in this program based upon roughly 40 years' experience in the development and manufacture of catalysts for emission control. In particular, Johnson Matthey has over 20 years' of experience in the development and manufacture of catalysts for spark ignited CNG applications, which would directly relate to this opportunity.

For the program, Johnson Matthey is willing to commit the following:

- Engineering support for the selection of catalysts (e.g., sizing, formulations, PGM loadings)
- Modelling support to assist in the optimization of system performance
- Manufacture of catalyst samples for purchase during the program
- Post-mortem analysis of catalysts evaluated during the program

We look forward to the opportunity to participate in this program, as it is an exciting area of research and development. We welcome the possibility of providing our expertise and insight for this project, in order to address the challenges associated with substantially reducing NOx emissions on stoich-burn CNG applications.

If there are any questions or comments, please let me know.

Sincerely,

Diane McKeon Bailey
VP & Business Director HDD NA
Johnson Matthey, Emission Control Technologies
900 Forge Avenue, Suite 100
Audubon, PA 19403
Office: 484-320-2234

EMISSION CONTROL TECHNOLOGIES

July 15, 2013

Dear Gentlemen:

PACCAR is a global technology leader in the design, manufacture and customer support of premium light-, medium- and heavy-duty trucks under the Kenworth, Peterbilt and DAF nameplates.

Peterbilt Motors is an industry leader in the manufacturing of Heavy Duty over-the-road trucks. This year Peterbilt will produce around 31,000 trucks, in sleeper and daycab configurations, in ratings from 26,000 to 63,000 lbs. The national market for these type trucks is 210,000.

Alternative Fuel Engines are seeing increased acceptance in the trucking industry, based on low-cost fuel price, domestic availability, and energy independence. All current natural gas engines are optimized to run on diesel, i.e. compression ratio, piston design, etc., leading to lower fuel efficiency and higher than necessary emissions.

Peterbilt is very interested in the potential that a Cummins "Purposed Built" Natural Gas Engine, with features such as optimized compression ratio, unique piston design, variable gate turbo technology, etc. would have, toward increased efficiency and lower emissions.

In support of this effort, Peterbilt is will to provide up to 1000 hours of engineering support at $125 per hour per year, and 200 hours technician support $100 per hour per year for years one and two. Peterbilt is also willing to provide $100K of testing at the PACCAR Technology Center in Mt. Vernon, WA for the Program.

Total contribution is potentially $390,000

Sincerely,

Landon Sproull
Chief Engineer
Peterbilt Motors

CALIFORNIA CARTAGE COMPANY

07/15/2013

Mr. Paul R. Miller
Director – External Relations, Corporate Research and Technology
Cummins Inc.
1900 McKinley Avenue, MC 50185
Columbus, IN 47202-3005 USA

RE: Letter of Support for SCAQMD's RFP#P2013-22

Dear Mr. Miller,

This letter is to inform you that California Cartage Company intends to partner with Cummins Inc. on the South Coast Air Quality Management District's, "On-Road Heavy-Duty Development, Integration, and Demonstration of Ultra-Low Emissions Natural Gas Engines" RFP # P2013-22.

We understand the goal is to develop, integrate, and demonstrate natural gas engines in a variety of heavy-duty vehicle applications with Ultra-Low NOx emissions at 0.02 g/bhp-hr. Cummins Inc is taking the lead in the development of a brand new design based on the ISX-15G 15L spark ignited engine equipped with advanced three way catalyst (TWC) technology. California Cartage Company will be the vehicle demonstration partner. California Cartage Company owns and operates the largest fleet of clean trucks in the South Coast with about 300 spark ignited Cummins-Westport ISL G 8.9L engines equipped with TWC and 45 Westport Innovations high pressure direct injection (HPDI) dual fuel lean burn engines based on the Cummins ISX 15 liter long block. Cal Cartage's drayage business operates a variety of services and is planning to operate the demonstration vehicles in short and long drays.

California Cartage Company is committed to green initiatives and was honored with the 2010 Green Leadership Award for significant accomplishments in the areas of energy conservation and environmental sustainability. Partnership in this program will further benefit the South Coast with ultra-low NO_x emissions.

Sincerely,

Robert A. Lively
Vice President – Strategic Planning
California Cartage Company
2931 Redondo Avenue
Long Beach, CA 90806

THE CALIFORNIA CARTAGE FAMILY OF COMPANIES

RIVERSIDE Research and Economic Development

Office of the Vice Chancellor
[illegible] University Office Building
Riverside, CA [illegible]
Tel 951 827 5535
Web [illegible]

July 22, 2013

Dr. Wayne Eckerle, VP - Corporate Research & Technology Integration
Cummins Corporate Research and Technology
1900 McKinley Ave. MC 50185
Columbus, IN 47201-6414

RE: UCR Proposal No. 00009153, RFP #P2013-22

On behalf of The Regents of the University of California, we are presenting for your review a request for support of the following proposal:

Principal Investigator:	Dr. Kent Johnson College of Engineering - Center for Environmental Research and Technology
Title:	"Ultra-Low NOx NG Engine Development and Demonstration"
Support Requested:	$502,984
Period of Support:	December 14, 2013 through December 14, 2016
Type of Request:	New Research Subcontract

Your favorable consideration of this proposal is greatly appreciated. In the event this proposal is selected to be funded, we are committed to providing the appropriate programmatic and administrative personnel as necessary to the project and to fulfilling the obligations of the award.

The University reserves the right to negotiate terms and conditions consistent with University policy. As the University currently has a contract template with the AQMD, we ask that Cummins Corporate Research and Technology request those terms to govern the University's subcontract in regards to the prime flow down contract terms. We will agree to establish a subcontract agreement with Cummins Corporate Research and Technology that will ensure compliance with all pertinent federal, state and funding agency regulations and policies.

If additional information is required, please contact the undersigned by phone at (951) 827-2210 or via e-mail at mmadero@ucr.edu.

Sincerely,

Misty Madero
Principal Contract & Grant Officer

Volume III – Certifications and Representations

South Coast AQMD

Item	Description
1	Business Information Request
2	Disadvantaged Business Certification
3	Request for TIN and Certification (W-9 Form)
4	Withholding Exemption Certificate (California 590 Form)
5	EPA Cert re Debarment, Suspension, and Other Matters (Cummins and UCR, 1 page each)
6	Campaign Contributions Disclosure (Cummins and UCR. 2 pages each)
7	Direct Deposit Authorization

College of Engineering- Center for Environmental Research & Technology

South Coast Air Quality Management District

21865 Copley Drive, Diamond Bar, CA 91765-4178
(909) 396-2000 • www.aqmd.gov

BUSINESS INFORMATION REQUEST

Business Name	Cummins Inc.
Division of	
Subsidiary of	
Website Address	www.cummins.com
Type of Business *Check One:*	Individual DBA. Name ________, County Filed in ________ X Corporation. ID No. __35-0257090________ LLC/LLP. ID No. ________ Other ________

REMITTING ADDRESS INFORMATION

Address	2931 Elm Hill Pike		
City/Town	Nashville		
State/Province	TN	Zip	37122
Phone	(615) 514-7335 Ext	Fax	(615) 986-2490
Contact	Emma Allen	Title	Customer Collections Leader
E-mail Address	Emma.allen@cummins.com		
Payment Name if Different			

All invoices must reference the corresponding Purchase Order Number(s)/Contract Number(s) if applicable and mailed to:

Attention: Accounts Payable, Accounting Department

South Coast Air Quality Management District

21865 Copley Drive
Diamond Bar, CA 91765-4178

DISADVANTAGED BUSINESS CERTIFICATION

Federal guidance for utilization of disadvantaged business enterprises allows a vendor to be deemed a small business enterprise (SBE), minority business enterprise (MBE) or women business enterprise (WBE) if it meets the criteria below.

- is certified by the Small Business Administration or
- is certified by a state or federal agency or
- is an independent MBE(s) or WBE(s) business concern which is at least 51 percent owned and controlled by minority group member(s) who are citizens of the United States.

Statements of certification:

As a prime contractor to the SCAQMD, Cummins Inc. (name of business) will engage in good faith efforts to achieve the fair share in accordance with 40 CFR Section 33.301, and will follow the six affirmative steps listed below **for contracts or purchase orders funded in whole or in part by federal grants and contracts.**

1. Place qualified SBEs, MBEs, and WBEs on solicitation lists.
2. Assure that SBEs, MBEs, and WBEs are solicited whenever possible.
3. When economically feasible, divide total requirements into small tasks or quantities to permit greater participation by SBEs, MBEs, and WBEs.
4. Establish delivery schedules, if possible, to encourage participation by SBEs, MBEs, and WBEs.
5. Use services of Small Business Administration, Minority Business Development Agency of the Department of Commerce, and/or any agency authorized as a clearinghouse for SBEs, MBEs, and WBEs.
6. If subcontracts are to be let, take the above affirmative steps.

Self-Certification Verification: Also for use in awarding additional points, **as applicable**, in accordance with SCAQMD Procurement Policy and Procedure:

Check all that apply:

☐ Small Business Enterprise/Small Business Joint Venture ☐ Women-owned Business Enterprise
☐ Local business ☐ Disabled Veteran-owned Business Enterprise/DVBE Joint Venture
☐ Minority-owned Business Enterprise

Percent of ownership: ________ %

Name of Qualifying Owner(s): ________________________ ________________________

I, the undersigned, hereby declare that to the best of my knowledge the above information is accurate. Upon penalty of perjury, I certify information submitted is factual.

Terry D Johnson [signature] — Director-Government Contract Compliance
A. NAME — TITLE

(812) 377-3401 — July 18, 2013
B. TELEPHONE NUMBER — DATE

Form **W-9**
(Rev. December 2011)
Department of the Treasury
Internal Revenue Service

Request for Taxpayer Identification Number and Certification

Give Form to the requester. Do not send to the IRS.

Print or type
See Specific Instructions on page 2.

Name (as shown on your income tax return)
Cummins Inc.

Business name/disregarded entity name, if different from above

Check appropriate box for federal tax classification:
☐ Individual/sole proprietor ☑ C Corporation ☐ S Corporation ☐ Partnership ☐ Trust/estate

☐ Limited liability company. Enter the tax classification (C=C corporation, S=S corporation, P=partnership) ▶ ☐ Exempt payee

☐ Other (see instructions) ▶

Address (number, street, and apt. or suite no.)
Box 3005, M/C 60113

Requester's name and address (optional)

City, state, and ZIP code
Columbus, IN 47202-3005

List account number(s) here (optional)

Part I Taxpayer Identification Number (TIN)

Enter your TIN in the appropriate box. The TIN provided must match the name given on the "Name" line to avoid backup withholding. For individuals, this is your social security number (SSN). However, for a resident alien, sole proprietor, or disregarded entity, see the Part I instructions on page 3. For other entities, it is your employer identification number (EIN). If you do not have a number, see *How to get a TIN* on page 3.

Note. If the account is in more than one name, see the chart on page 4 for guidelines on whose number to enter.

Social security number
☐☐☐ - ☐☐ - ☐☐☐☐

Employer identification number
3 5 - 0 2 5 7 0 9 0

Part II Certification

Under penalties of perjury, I certify that:

1. The number shown on this form is my correct taxpayer identification number (or I am waiting for a number to be issued to me), and
2. I am not subject to backup withholding because: (a) I am exempt from backup withholding, or (b) I have not been notified by the Internal Revenue Service (IRS) that I am subject to backup withholding as a result of a failure to report all interest or dividends, or (c) the IRS has notified me that I am no longer subject to backup withholding, and
3. I am a U.S. citizen or other U.S. person (defined below).

Certification instructions. You must cross out item 2 above if you have been notified by the IRS that you are currently subject to backup withholding because you have failed to report all interest and dividends on your tax return. For real estate transactions, item 2 does not apply. For mortgage interest paid, acquisition or abandonment of secured property, cancellation of debt, contributions to an individual retirement arrangement (IRA), and generally, payments other than interest and dividends, you are not required to sign the certification, but you must provide your correct TIN. See the instructions on page 4.

Sign Here Signature of U.S. person ▶ Rhonda Evans Date ▶ 7/18/2013

General Instructions

Section references are to the Internal Revenue Code unless otherwise noted.

Purpose of Form

A person who is required to file an information return with the IRS must obtain your correct taxpayer identification number (TIN) to report, for example, income paid to you, real estate transactions, mortgage interest you paid, acquisition or abandonment of secured property, cancellation of debt, or contributions you made to an IRA.

Use Form W-9 only if you are a U.S. person (including a resident alien), to provide your correct TIN to the person requesting it (the requester) and, when applicable, to:

1. Certify that the TIN you are giving is correct (or you are waiting for a number to be issued),
2. Certify that you are not subject to backup withholding, or
3. Claim exemption from backup withholding if you are a U.S. exempt payee. If applicable, you are also certifying that as a U.S. person, your allocable share of any partnership income from a U.S. trade or business is not subject to the withholding tax on foreign partners' share of effectively connected income.

Note. If a requester gives you a form other than Form W-9 to request your TIN, you must use the requester's form if it is substantially similar to this Form W-9.

Definition of a U.S. person. For federal tax purposes, you are considered a U.S. person if you are:

- An individual who is a U.S. citizen or U.S. resident alien,
- A partnership, corporation, company, or association created or organized in the United States or under the laws of the United States,
- An estate (other than a foreign estate), or
- A domestic trust (as defined in Regulations section 301.7701-7).

Special rules for partnerships. Partnerships that conduct a trade or business in the United States are generally required to pay a withholding tax on any foreign partners' share of income from such business. Further, in certain cases where a Form W-9 has not been received, a partnership is required to presume that a partner is a foreign person, and pay the withholding tax. Therefore, if you are a U.S. person that is a partner in a partnership conducting a trade or business in the United States, provide Form W-9 to the partnership to establish your U.S. status and avoid withholding on your share of partnership income.

Cat. No. 10231X

YEAR

CALIFORNIA FORM

2013 Withholding Exemption Certificate 590

This form can only be used to certify exemption from nonresident withholding under California Revenue and Taxation Code (R&TC) Section 18662. Do not use this form for exemption from wage withholding.

File this form with your withholding agent. (Please type or print)

Withholding agent's name
South Coast Air Quality Management District

Payee's name	Payee's ☐ SSN or ITIN ☑ FEIN ☐ CA corp. no. ☐ CA SOS file no.
Cummins Inc.	3 5 - 0 2 5 7 0 9 0

Address (number and street, PO Box, or PMB no.)	Apt. no / Ste. no.
1900 McKinley Ave. M/C 50116	

City	State	ZIP Code
Columbus	IN	4 7 2 0 1 6 4 1 4

Read the following carefully and check the box that applies to the payee.

I certify that for the reasons checked below, the payee named on this form is exempt from the California income tax withholding requirement on payment(s) made to the entity or individual.

☐ **Individuals — Certification of Residency:**
I am a resident of California and I reside at the address shown above. If I become a nonresident at any time, I will promptly notify the withholding agent. See instructions for General Information D, Who is a Resident, for the definition of a resident.

☑ **Corporations:**
The above-named corporation has a permanent place of business in California at the address shown above or is qualified through the California Secretary of State (SOS) to do business in California. The corporation will file a California tax return and withhold on payments of California source income to nonresidents when required. If this corporation ceases to have a permanent place of business in California or ceases to do any of the above, I will promptly notify the withholding agent. See instructions for General Information F, What is a Permanent Place of Business, for the definition of permanent place of business.

☐ **Partnerships or limited liability companies (LLC):**
The above-named partnership or LLC has a permanent place of business in California at the address shown above or is registered with the California SOS, and is subject to the laws of California. The partnership or LLC will file a California tax return and will withhold on foreign and domestic nonresident partners or members when required. If the partnership or LLC ceases to do any of the above, I will promptly inform the withholding agent. For withholding purposes, a limited liability partnership (LLP) is treated like any other partnership.

☐ **Tax-Exempt Entities:**
The above-named entity is exempt from tax under California Revenue and Taxation Code (R&TC) Section 23701 _______ (insert letter) or Internal Revenue Code Section 501(c) ______ (insert number). The tax-exempt entity will withhold on payments of California source income to nonresidents when required. If this entity ceases to be exempt from tax, I will promptly notify the withholding agent. Individuals cannot be tax-exempt entities.

☐ **Insurance Companies, Individual Retirement Arrangements (IRAs), or Qualified Pension/Profit Sharing Plans:**
The above-named entity is an insurance company, IRA, or a federally qualified pension or profit-sharing plan.

☐ **California Trusts:**
At least one trustee and one noncontingent beneficiary of the above-named trust is a California resident. The trust will file a California fiduciary tax return and will withhold on foreign and domestic nonresident beneficiaries when required. If the trustee becomes a nonresident at any time, I will promptly notify the withholding agent.

☐ **Estates — Certification of Residency of Deceased Person:**
I am the executor of the above-named person's estate. The decedent was a California resident at the time of death. The estate will file a California fiduciary tax return and will withhold on foreign and domestic nonresident beneficiaries when required.

☐ **Nonmilitary Spouse of a Military Servicemember:**
I am a nonmilitary spouse of a military servicemember and I meet the Military Spouse Residency Relief Act (MSRRA) requirements. See instructions for General Information E, MSRRA.

CERTIFICATE: Please complete and sign below

Under penalties of perjury, I hereby certify that the information provided in this document is, to the best of my knowledge, true and correct. If conditions change, I will promptly notify the withholding agent.

Payee's name and title (type or print) Terry D Johnson Dir Gv Compliance Daytime telephone no. 812-377-3401

Payee's signature ▶ Terry D Johnson Date 7/18/13

United State Environmental Protection Agency
Washington, DC 20460

Certification Regarding Debarment, Suspension, and Other Responsibility Matters

The prospective participant certifies to the best of its knowledge and belief that it and the principals:

(a) Are not presently debarred, suspended, proposed for debarment, declared ineligible, or voluntarily excluded from covered transactions by any Federal department or agency;

(b) Have not within a three year period preceding this proposal been convicted of or had a civil judgement rendered against them or commission of fraud or a criminal offense in connection with obtaining, attempting to obtain, or performing a public (Federal, State, or local) transaction or contract under a public transaction: violation of Federal or State antitrust statute or commission of embezzlement, theft, forgery, bribery, falsification or destruction of records, making false statements, or receiving stolen property:

(c) Are not presently indicted for or otherwise criminally or civilly charged by a government entity (Federal, State, or local) with commission of any of the offenses enumerated in paragraph (b) of this certification; and

(d) Have not within a three-year period preceding this application/proposal had one or more public transactions (Federal, State, or local) terminated for cause or default.

I understand that a false statement on this certification may be grounds for rejection of this proposal or termination of the award. In addition, under 18 USC Sec. 1001, a false statement may result in a fine of up to $10,000 or imprisonment for up to 5 years, or both.

Dr. Wayne A. Eckerle VP - Corporate Research & Technology Integration
Typed Name & Title of Authorized Representative

Wayne A. Eckerle 7/23/13
Signature of Authorized Representative Date

❐ I am unable to certify to the above statements. My explanation is attached.

EPA Form 5700-49 (11-88)

United State Environmental Protection Agency
Washington, DC 20460

Certification Regarding Debarment, Suspension, and Other Responsibility Matters

The prospective participant certifies to the best of its knowledge and belief that it and the principals:

(a) Are not presently debarred, suspended, proposed for debarment, declared ineligible, or voluntarily excluded from covered transactions by any Federal department or agency;

(b) Have not within a three year period preceding this proposal been convicted of or had a civil judgement rendered against them or commission of fraud or a criminal offense in connection with obtaining, attempting to obtain, or performing a public (Federal, State, or local) transaction or contract under a public transaction: violation of Federal or State antitrust statute or commission of embezzlement, theft, forgery, bribery, falsification or destruction of records, making false statements, or receiving stolen property:

(c) Are not presently indicted for or otherwise criminally or civilly charged by a government entity (Federal, State, or local) with commission of any of the offenses enumerated in paragraph (b) of this certification; and

(d) Have not within a three-year period preceding this application/proposal had one or more public transactions (Federal, State, or local) terminated for cause or default.

I understand that a false statement on this certification may be grounds for rejection of this proposal or termination of the award. In addition, under 18 USC Sec. 1001, a false statement may result in a fine of up to $10,000 or imprisonment for up to 5 years, or both.

__Misty Madero, Principal Contract & Grant Officer______________________________
Typed Name & Title of Authorized Representative

Misty Madero 7/22/13
Signature of Authorized Representative Date

❑ I am unable to certify to the above statements. My explanation is attached.

EPA Form 5700-49 (11-88)

CAMPAIGN CONTRIBUTIONS DISCLOSURE

In accordance with California law, bidders and contracting parties are required to disclose, at the time the application is filed, information relating to any campaign contributions made to South Coast Air Quality Management District (SCAQMD) Board Members or members/alternates of the MSRC, including: the name of the party making the contribution (which includes any parent, subsidiary or otherwise related business entity, as defined below), the amount of the contribution, and the date the contribution was made. 2 C.C.R. §18438.8(b).

California law prohibits a party, or an agent, from making campaign contributions to SCAQMD Governing Board Members or members/alternates of the Mobile Source Air Pollution Reduction Review Committee (MSRC) of more than $250 while their contract or permit is pending before the SCAQMD; and further prohibits a campaign contribution from being made for three (3) months following the date of the final decision by the Governing Board or the MSRC on a donor's contract or permit. Gov't Code §84308(d). For purposes of reaching the $250 limit, the campaign contributions of the bidder or contractor *plus* contributions by its parents, affiliates, and related companies of the contractor or bidder are added together. 2 C.C.R. §18438.5.

In addition, SCAQMD Board Members or members/alternates of the MSRC must abstain from voting on a contract or permit if they have received a campaign contribution from a party or participant to the proceeding, or agent, totaling more than $250 in the 12-month period prior to the consideration of the item by the Governing Board or the MSRC. Gov't Code §84308(c).

The list of current SCAQMD Governing Board Members can be found at the SCAQMD website (www.aqmd.gov). The list of current MSRC members/alternates can be found at the MSRC website (http://www.cleantransportationfunding.org).

SECTION I.

Contractor (Legal Name): Cummins Inc.

☐ DBA, Name ______________________, County Filed in ______________________

☒ Corporation, ID No. 35-0257090

☐ LLC/LLP, ID No. ______________________

List any parent, subsidiaries, or otherwise affiliated business entities of Contractor:
(See definition below).

____

____

SECTION II.

Has Contractor and/or any parent, subsidiary, or affiliated company, or agent thereof, made a campaign contribution(s) totaling $250 or more in the aggregate to a current member of the South Coast Air Quality Management Governing Board or member/alternate of the MSRC in the 12 months preceding the date of execution of this disclosure?

☐ Yes ☒ No **If YES, complete Section II below and then sign and date the form. If NO, sign and date below. Include this form with your submittal.**

Campaign Contributions Disclosure, *continued:*

Name of Contributor ______________________________

______________________ Governing Board Member or MSRC Member/Alternate | ______ Amount of Contribution | ______ Date of Contribution

Name of Contributor ______________________________

______________________ Governing Board Member or MSRC Member/Alternate | ______ Amount of Contribution | ______ Date of Contribution

Name of Contributor ______________________________

______________________ Governing Board Member or MSRC Member/Alternate | ______ Amount of Contribution | ______ Date of Contribution

Name of Contributor ______________________________

______________________ Governing Board Member or MSRC Member/Alternate | ______ Amount of Contribution | ______ Date of Contribution

I declare the foregoing disclosures to be true and correct.

By: Wayne A. Eberle 7/23/13
Date

Title: VP – Corporate Research & Technology Integration

Date: July 12, 2013

DEFINITIONS

Parent, Subsidiary, or Otherwise Related Business Entity (2 Cal. Code of Regs., §18703.1(d).)

(1) Parent subsidiary. A parent subsidiary relationship exists when one corporation directly or indirectly owns shares possessing more than 50 percent of the voting power of another corporation.

(2) Otherwise related business entity. Business entities, including corporations, partnerships, joint ventures and any other organizations and enterprises operated for profit, which do not have a parent subsidiary relationship are otherwise related if any one of the following three tests is met:

(A) One business entity has a controlling ownership interest in the other business entity.

(B) There is shared management and control between the entities. In determining whether there is shared management and control, consideration should be given to the following factors:

(i) The same person or substantially the same person owns and manages the two entities;
(ii) There are common or commingled funds or assets;
(iii) The business entities share the use of the same offices or employees, or otherwise share activities, resources or personnel on a regular basis;
(iv) There is otherwise a regular and close working relationship between the entities; or

(C) A controlling owner (50% or greater interest as a shareholder or as a general partner) in one entity also is a controlling owner in the other entity.

CAMPAIGN CONTRIBUTIONS DISCLOSURE

In accordance with California law, bidders and contracting parties are required to disclose, at the time the application is filed, information relating to any campaign contributions made to South Coast Air Quality Management District (SCAQMD) Board Members or members/alternates of the MSRC, including: the name of the party making the contribution (which includes any parent, subsidiary or otherwise related business entity, as defined below), the amount of the contribution, and the date the contribution was made. 2 C.C.R. §18438.8(b).

California law prohibits a party, or an agent, from making campaign contributions to SCAQMD Governing Board Members or members/alternates of the Mobile Source Air Pollution Reduction Review Committee (MSRC) of more than $250 while their contract or permit is pending before the SCAQMD; and further prohibits a campaign contribution from being made for three (3) months following the date of the final decision by the Governing Board or the MSRC on a donor's contract or permit. Gov't Code §84308(d). For purposes of reaching the $250 limit, the campaign contributions of the bidder or contractor *plus* contributions by its parents, affiliates, and related companies of the contractor or bidder are added together. 2 C.C.R. §18438.5.

In addition, SCAQMD Board Members or members/alternates of the MSRC must abstain from voting on a contract or permit if they have received a campaign contribution from a party or participant to the proceeding, or agent, totaling more than $250 in the 12-month period prior to the consideration of the item by the Governing Board or the MSRC. Gov't Code §84308(c).

The list of current SCAQMD Governing Board Members can be found at the SCAQMD website (www.aqmd.gov). The list of current MSRC members/alternates can be found at the MSRC website (http://www.cleantransportationfunding.org).

SECTION I.

Contractor (Legal Name): The Regents of the University of California, on behalf of its Riverside campus

☐ DBA, Name ____________________, County Filed in ____________________

☐ Corporation, ID No. ____________________

☐ LLC/LLP, ID No. ____________________

List any parent, subsidiaries, or otherwise affiliated business entities of Contractor: ***(See definition below).***

____

____

SECTION II.

Has Contractor and/or any parent, subsidiary, or affiliated company, or agent thereof, made a campaign contribution(s) totaling $250 or more in the aggregate to a current member of the South Coast Air Quality Management Governing Board or member/alternate of the MSRC in the 12 months preceding the date of execution of this disclosure?

☐ Yes ☒ No **If YES, complete Section II below and then sign and date the form. If NO, sign and date below. Include this form with your submittal.**

Campaign Contributions Disclosure, *continued:*

Name of Contributor ____________________

____________________ Governing Board Member or MSRC Member/Alternate | ____________ Amount of Contribution | ____________ Date of Contribution

Name of Contributor ____________________

____________________ Governing Board Member or MSRC Member/Alternate | ____________ Amount of Contribution | ____________ Date of Contribution

Name of Contributor ____________________

____________________ Governing Board Member or MSRC Member/Alternate | ____________ Amount of Contribution | ____________ Date of Contribution

Name of Contributor ____________________

____________________ Governing Board Member or MSRC Member/Alternate | ____________ Amount of Contribution | ____________ Date of Contribution

I declare the foregoing disclosures to be true and correct.

By: Misty Madr[illegible]

Title: Principal Contract & Grant Officer

Date: 7/22/13

DEFINITIONS

Parent, Subsidiary, or Otherwise Related Business Entity (2 Cal. Code of Regs., §18703.1(d).)

(1) Parent subsidiary. A parent subsidiary relationship exists when one corporation directly or indirectly owns shares possessing more than 50 percent of the voting power of another corporation.

(2) Otherwise related business entity. Business entities, including corporations, partnerships, joint ventures and any other organizations and enterprises operated for profit, which do not have a parent subsidiary relationship are otherwise related if any one of the following three tests is met:

(A) One business entity has a controlling ownership interest in the other business entity.

(B) There is shared management and control between the entities. In determining whether there is shared management and control, consideration should be given to the following factors:

(i) The same person or substantially the same person owns and manages the two entities;
(ii) There are common or commingled funds or assets;
(iii) The business entities share the use of the same offices or employees, or otherwise share activities, resources or personnel on a regular basis;
(iv) There is otherwise a regular and close working relationship between the entities; or

(C) A controlling owner (50% or greater interest as a shareholder or as a general partner) in one entity also is a controlling owner in the other entity.

South Coast
AIR QUALITY MANAGEMENT DISTRICT
21865 Copley Dr., Diamond Bar, CA 91765
www.aqmd.gov

Direct Deposit Authorization

STEP 1: Please check all the appropriate boxes

- ☐ Individual (Employee, Governing Board Member)
- ☐ Vendor/Contractor
- ☐ Changed Information
- ☐ New Request
- ☐ Cancel Direct Deposit

STEP 2: Payee Information

Last Name	First Name	Middle Initial	Title
Allen	Emma		Customer Collections Leader

Vendor/Contractor Business Name (if applicable): Cummins Inc.

Address	Apartment/P.O. Box Number
2931 Elm Hill Pike	

City	State	Zip	Country
Nashville	TN	37122	US

Taxpayer ID Number	Telephone Number	Email Address
35-0257090	615-514-7335	Emma.allen@cummins.com

Authorization

1. I authorize South Coast Air Quality Management District (AQMD) to direct deposit funds to my account in the financial institution as indicated below. I understand that the authorization may be rejected or discontinued by AQMD at any time. If any of the above information changes, I will promptly complete a new authorization agreement. If the direct deposit is not stopped before closing an account, funds payable to me will be returned to AQMD for distribution. This will delay my payment.
2. This authorization remains in effect until AQMD receives written notification of changes or cancellation from you.
3. I hereby release and hold harmless AQMD for any claims or liability to pay for any losses or costs related to insufficient fund transactions that result from failure within the Automated Clearing House network to correctly and timely deposit monies into my account.

STEP 3:
You must verify that your bank is a member of an Automated Clearing House (ACH). Failure to do so could delay the processing of your payment. You must attach a voided check or have your bank complete the bank information and the account holder must sign below.

To be Completed by your Bank

Staple Voided Check Here

Bank of America

Cummins Inc.

☐ Saving X☐ Checking

8188600746

026009593

ACCOUNT HOLDER SIGNATURE

2-18-13

For AQMD Use Only Input By ______ Date ______