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Cummins Westport

VOLUME I – TECHNICAL PROPOSAL

Project Title:	Development & Demonstration of Advanced Heavy-Duty Natural Gas Engine with Near-Zero NOx Emissions
Date:	July 19, 2013
Offeror's Name & Address:	Cummins Westport Inc. 101-1750 West 75th Avenue Vancouver, BC Canada V6P 6G2
Submitted To:	South Coast Air Quality Management District 21865 Copley Drive Diamond Bar CA 91765-4178
Submitted In Response To:	SCAQMD Request for Proposal #P2013-22 "On-Road Heavy-Duty Development, Integration, and Demonstration of Ultra-Low Emission Natural Gas Engines"

Principal Investigator:

Scott Baize
Cummins Westport Inc.
Tel: (317) 506-7358 Fax: (812) 377-0795
Email: scott.baize@cummins.com

Business Contacts:

Diane Song, Controller
Cummins Westport Inc.
Tel: (604) 718-8346 Fax: (604) 718-8355
Email: diane.song@cummins.com

Scott Baker, Director, Product & Market Planning
Cummins Westport Inc.
Tel: (604) 718-2025 Fax: (604) 718-8355
Email: scott.baker@cummins.com

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Executive Summary

Cummins Westport Inc. (CWI) proposes to develop and demonstrate an advanced, production-intent version of its 8.9 liter spark ignited natural gas engine and aftertreatment system with 0.02 g/bhp-hr NOx, reduced ammonia (NH_3) emissions (targeting 10 ppm NH_3), and improved thermal efficiency vs. CWI's current production ISL G engine. CWI has assembled a comprehensive team comprising numerous industry leading organizations including Cummins Emission Solutions, Cummins Cal Pacific, Autocar, New Flyer, PACCAR, Waste Management, Los Angeles Metropolitan Transportation Authority, and Frito-Lay.

CWI proposes to commence the project by performing technology development activities to assess candidate technology advancements and design changes to reduce NOx & NH_3 emissions and to improve thermal efficiency. Within the first year of the project, CWI will conduct a technical feasibility and risk assessment for each of the candidate technologies, will filter for promising & feasible technologies, and will define the architecture of the advanced ISL G engine and aftertreatment system.

CWI proposes to develop an advanced, production-intent ISL G engine and aftertreatment engine system, in accordance with established CWI and Cummins product development procedures intended to validate engine performance, reliability, durability, emissions, and manufacturability.

CWI proposes to integrate the advanced, production-intent ISL G engine into two engineering vehicles to validate the vehicle integration design and assess vehicle performance prior to commencing customer vehicle demonstrations. CWI has secured the support of industry leading OEMs in the Class 8 truck and transit bus markets, and will leverage their expertise and design guidance for the pre-commercial, production-intent engine, aftertreatment system, and vehicle designs.

CWI intends to demonstrate the advanced, production-intent ISL G engine and aftertreatment system in a Class 8 tractor, a low cab forward refuse collection truck, and a 40 foot bus operated by leading fleets in the South Coast and San Joaquin Valley Air Basins for a period of up to 12 months.

In alignment with RFP #P2013-22, CWI has put forward a three year advanced technology and product development scope of work to mature an integrated engine and aftertreatment system. CWI anticipates four years of engineering effort will be necessary to fully mature and commercialize the advanced technologies necessary to meet the goals of the RFP and the market expectations of quality and reliability. CWI anticipates proceeding to commercialize the advanced, production-intent ISL G engine & aftertreatment system immediately following the conclusion of the proposed project.

CWI is exclusively focused on developing, commercializing, and supporting spark-ignited alternative fuelled engines. CWI is the leading natural gas engine supplier in North America and for emission leading markets globally, and has established broad OEM availability of CWI's engines. The proposed technology advancements and designs can be deployed and commercialized throughout CWI's product line, thus creating an opportunity to leverage CWI's proposed work throughout North American commercial vehicle applications. Various industry stakeholders, including consultants, government agencies, and OEMs, are projecting significant natural gas vehicle penetration in the North American heavy-duty commercial vehicle market, with some agencies forecasting 30 to 40% natural gas market share within the next decade. In parallel with the advanced, production-intent ISL G engine and aftertreatment system development & demonstration work proposed herein, CWI will conduct a commercial feasibility assessment to estimate potential end-user demand for near-zero NOx natural gas engines. This commercial feasibility assessment will include review of ARB's progress toward establishing optional low NOx certification standards, interviews with key customers and OEM stakeholders to evaluate market demand, and review of California State & regional regulatory policy (e.g. incentive funding and/or public fleet mandates) to motivate end-users to purchase vehicles with natural gas engines certified to NOx levels below the required emission standards.

CWI has successfully delivered multiple new engine development projects in conjunction with numerous government and industry funding partners. CWI and its project team are uniquely positioned to successfully deliver the proposed advanced, production-intent ISL G engine and aftertreatment system.

Section A – Statement of Work

Cummins Westport Inc. (CWI) recognizes the value of near-zero emissions technologies to improve the emissions footprint of our engines in commercial vehicle applications. The challenge of bringing a near-zero emissions solution to market is not simple. Typical techniques to reduce NOx can lead to modest improvements but at a negative impact on performance and fuel efficiency. CWI expects that, left unchecked, the deterioration in performance and fuel efficiency for even modest reductions in NOx can be unacceptable to the market. Pushing for the reductions in NOx necessary to achieve the near-zero emissions classification will require development and integration of multiple new technologies that simultaneously bring reductions in NOx & ammonia (NH_3) while improving fuel efficiency.

CWI proposes to develop and demonstrate an advanced, production-intent version of its 8.9 liter spark ignited ISL G natural gas engine with reduced NOx emissions, reduced NH_3 emissions, and improved fuel efficiency in comparison with the current, commercially available version of the ISL G engine. CWI proposes to demonstrate the resulting advanced, production-intent ISL G engine and three-way catalyst aftertreatment system in three heavy-duty commercial vehicles operated by major fleets in southern California.

CWI has identified the following objectives for this project:

- Demonstrate 0.02 g/bhp-hr NOx emissions and other regulated criteria emissions at or below the applicable EPA & CARB heavy-duty, on-highway emission standards (0.01 g/bhp-hr PM, 15.5 g/bhp-hr CO, 0.14 g/bhp-hr NMHC);
- Demonstrate reduced NH_3 emissions at the near-zero emissions NOx target, targeting 10 ppm NH_3 emissions measured over the certification cycles;
- Identify and validate cost effective technologies to improve thermal efficiency while meeting the near-zero emissions NOx target, targeting fuel efficiency equivalent to or better than the current production ISL G engine;
- Demonstrate the advanced, production-intent ISL G engine and aftertreatment system in a Class

8 tractor, a low cab forward refuse collection truck, and a 40 foot transit bus operated by leading fleets in the South Coast and/or San Joaquin Valley Air Basins for a period of up to 12 months.

CWI's established processes to design, develop, validate, and commercialize a new heavy-duty natural gas engine typically require a three year product development cycle, assuming that no fundamental research or technology development is required to achieve the product's goals. For products requiring significantly advanced technologies, one to two years of technology development work is typically required in advance of a three year product development program. For example, CWI and Cummins previously conducted an 18 month technology development program to research and develop the stoichiometric, cooled EGR spark ignition (SESI) technology in conjunction with a three-way catalyst. At the conclusion of the SESI technology development program, CWI initiated a three year product development program in 2004, culminating with the commercial release of the ISL G engine in 2007 using SESI technology.

CWI is confident in the ability to achieve sizable NOx reductions with the SESI technology via significant advancements in engine control and aftertreatment systems; however, this has not been demonstrated yet. Therefore, the NOx and NH_3 emission reduction targets specified by RFP #P2013-22 require technology development prior to entering CWI's product development cycle. RFP #P2013-22 specifies a three year maximum duration for the proposed work. As a result, during the first year of the proposed work, CWI intends to evaluate candidate emission reduction and efficiency improvement technologies via CWI's proven technology development protocol. Following confirmation of the technology recipe and product architecture definition, CWI intends to immediately start the product development phase. Product development will not be complete within the three year maximum duration prescribed by RFP #P2013-22. Therefore, the scope of work proposed herein will yield a pre-commercial, production-intent engine and aftertreatment system incorporating new technologies and engine designs enabling NOx emissions to meet the 0.02 g/bhp-hr target, improved thermal efficiency, and reduced tailpipe NH_3 emissions.

The following sub-sections within Section A describe the major Tasks and associated sub-tasks comprising the proposed statement of work. CWI has retained the major Tasks specified in RFP #P2013-22, but has categorized the associated work into sub-task descriptions that differ slightly from the sub-task descriptions suggested in Sections V & VII of RFP #P2013-22. The sub-tasks that CWI proposes herein address all of the content specified in Sections V & VII of RFP #P2013-22, and are structured in a manner that aligns with CWI's experience and expertise at performing natural gas engine development programs.

For reference, Section A also describes the follow-on commercialization work that CWI anticipates conducting beyond the proposal 's three year window in order to bring to market some or all of the technologies evaluated and developed under an anticipated contract with AQMD.

Task 1 – Fuel Specification

CWI's dedicated natural gas engines, including ISL G, are capable of using a wide range of natural gas fuels including compressed natural gas (CNG), liquefied natural gas (LNG), and renewable natural gas (RNG, e.g. biomethane) from a variety of natural gas feedstocks including biodigesters and landfills. The advanced, production-intent ISL G engine proposed herein will be capable of operating with CNG, LNG, or RNG (biomethane). CWI has identified vehicle demonstration fleets (see Task 4, Section C, and Appendix A), which are expected to operate CNG-fuelled vehicles for the vehicle demonstration phase of the project.

CWI will perform fuel composition analysis during the engine dynamometer and chassis dynamometer emission testing phases of the project. Engine dynamometer emission testing will be conducted at the Cummins Technical Center (CTC) in Columbus, IN. CTC has extensive engine dynamometer facilities including a number of test cells equipped with natural gas fuel supplied from the local natural gas utility's pipeline. CTC is equipped with gas chromatography equipment. Natural gas fuel coming into the building is sampled at least once per hour. Therefore, CWI will have extensive data to characterize the fuel composition during engine dynamometer emission testing. The CTC analyzer does not specifically report water content, CO, or hydrogen individually; however, the data does indicate if these three constituents combined are less than 0.1%. Samples can be sent outside CTC to acquire these three constituents if required by AQMD. Wobbe Index, BTU content, and other relevant natural gas parameters (e.g. Methane Number) are calculated values that will be determined based on fuel composition data from the analyzer. A typical daily report from the CTC fuel analyzer is attached. Based on historical fuel composition reports, CTC fuel typically complies with the natural gas fuel specifications in CCR Title 13 Section 2292.5.

Table 1 – Typical Fuel Composition Report for Natural Fuel Supply at CTC

Sample Date	OXYGEN	NITROGEN	METHANE	CO2	ETHANE	H2S	PROPANE	I_BUTANE	N_BUTANE	I_PENTANE	N_PENTANE	HEXANES	HEPTANES	OCTANES	NONANES	SITE
07/13/13 00:03:48	.005	1.044	93.205	.810	4.197	.000	.509	.058	.095	.023	.022	.016	.017	.000	.000	CTC
07/13/13 00:48:49	.005	1.036	93.204	.814	4.189	.000	.516	.059	.097	.024	.023	.016	.017	.000	.000	CTC
07/13/13 01:33:49	.005	1.030	93.219	.842	4.157	.000	.510	.060	.096	.024	.023	.017	.017	.000	.000	CTC
07/13/13 02:18:48	.005	1.015	93.245	.846	4.147	.000	.505	.060	.095	.024	.023	.017	.018	.000	.000	CTC
07/13/13 03:03:48	.005	1.004	93.239	.850	4.159	.000	.506	.060	.096	.024	.023	.016	.018	.000	.000	CTC
07/13/13 03:48:48	.004	1.004	93.233	.869	4.145	.000	.507	.060	.096	.024	.023	.017	.018	.000	.000	CTC
07/13/13 04:33:48	.005	1.006	93.250	.886	4.117	.000	.499	.060	.094	.024	.023	.017	.019	.000	.000	CTC
07/13/13 05:18:48	.005	.920	93.442	.926	4.003	.000	.476	.059	.090	.023	.022	.016	.019	.000	.000	CTC
07/13/13 06:03:48	.004	.618	93.929	1.007	3.899	.000	.402	.055	.073	.021	.018	.015	.019	.000	.000	CTC
07/13/13 06:48:48	.006	.586	93.981	1.001	3.924	.000	.402	.056	.072	.021	.018	.015	.020	.000	.000	CTC
07/13/13 07:33:48	.004	.572	94.037	1.000	3.794	.000	.393	.056	.071	.021	.018	.014	.020	.000	.000	CTC
07/13/13 08:18:48	.004	.555	94.057	.998	3.792	.000	.394	.056	.071	.021	.018	.014	.020	.000	.000	CTC
07/13/13 09:03:48	.004	.578	94.050	.997	3.778	.000	.395	.056	.071	.021	.017	.014	.019	.000	.000	CTC
07/13/13 09:48:48	.004	.587	94.032	.988	3.790	.000	.399	.055	.072	.021	.018	.015	.019	.000	.000	CTC
07/13/13 10:33:48	.004	.563	94.101	.987	3.765	.000	.386	.054	.070	.020	.017	.014	.019	.000	.000	CTC
07/13/13 11:18:48	.004	.511	94.212	.998	3.709	.000	.377	.053	.066	.020	.016	.014	.020	.000	.000	CTC
07/13/13 12:03:48	.004	.502	94.242	.994	3.700	.000	.371	.053	.065	.020	.016	.014	.019	.000	.000	CTC
07/13/13 12:48:48	.004	.452	94.331	.989	3.680	.000	.361	.053	.063	.019	.016	.013	.019	.000	.000	CTC
07/13/13 13:33:48	.003	.401	94.417	.990	3.556	.000	.354	.052	.061	.019	.015	.013	.019	.000	.000	CTC
07/13/13 14:18:48	.000	.370	94.488	.988	3.639	.000	.345	.052	.059	.019	.014	.013	.019	.000	.000	CTC
07/13/13 15:03:48	.000	.338	94.531	.990	3.629	.000	.339	.052	.058	.018	.014	.013	.019	.000	.000	CTC
07/13/13 15:48:47	.000	.306	94.587	.995	3.619	.000	.323	.051	.056	.018	.014	.013	.019	.000	.000	CTC
07/13/13 16:33:47	.000	.265	94.637	1.004	3.607	.000	.320	.051	.054	.018	.013	.012	.018	.000	.000	CTC
07/13/13 17:18:47	.000	.234	94.667	1.012	3.607	.000	.315	.051	.052	.018	.013	.012	.019	.000	.000	CTC
07/13/13 18:03:47	.000	.207	94.684	1.018	3.617	.000	.309	.052	.052	.018	.012	.012	.019	.000	.000	CTC
07/13/13 18:48:48	.000	.178	94.735	1.001	3.617	.000	.308	.051	.050	.017	.012	.012	.019	.000	.000	CTC
07/13/13 19:33:47	.000	.172	94.750	1.009	3.611	.000	.305	.050	.049	.017	.012	.012	.019	.000	.000	CTC
07/13/13 20:18:48	.000	.172	94.762	1.002	3.604	.000	.302	.050	.049	.017	.012	.012	.018	.000	.000	CTC
07/13/13 21:03:47	.000	.176	94.755	1.005	3.608	.000	.302	.051	.049	.017	.012	.012	.018	.000	.000	CTC
07/13/13 21:48:47	.000	.171	94.764	1.008	3.604	.000	.298	.050	.049	.017	.012	.012	.018	.000	.000	CTC
07/13/13 22:33:48	.000	.172	94.755	1.010	3.601	.000	.304	.050	.049	.017	.012	.011	.019	.000	.000	CTC
07/13/13 23:18:47	.000	.173	94.743	1.018	3.603	.000	.305	.050	.049	.017	.012	.012	.018	.000	.000	CTC

CWI will obtain fuel samples during chassis dynamometer emission testing within Task 4. CWI will coordinate with the chassis dynamometer emission testing contractor to ensure that fuel samples are obtained at least twice weekly during chassis dynamometer emission testing and will send the fuel samples to a 3rd party laboratory to characterize the fuel composition. CWI's Field Service Engineers are experienced with obtaining natural gas fuel samples and fuel composition analysis for in-use vehicles. CWI's engineers follow established protocols for sampling and transporting natural gas fuel samples using approved sample cylinders. Within southern California, CWI typically hires Quantum Analytical Services, a private laboratory in Carson, CA, to perform fuel composition analysis. CWI will instruct the laboratory to perform fuel analysis that includes, at a minimum, water content, BTU value, percent methane, ethane, propane, butane, CO, carbon dioxide, (CO2), hydrogen, oxygen, nitrogen, C3+, C6+, and contaminants. As explained above, Wobbe Index, BTU content, and Methane Number are calculated values based on the chemical composition of the fuel. CWI will perform the necessary calculations to quantify these attributes of the natural gas fuel used during emission testing.

Task 2 – Development of Prototype Heavy-Duty Natural Gas Engine

CWI is currently conducting a preliminary technical feasibility assessment of various NOx reduction strategies and fuel efficiency improvements. AQMD funding will allow this work to continue and expand the scope to include NH_3 reductions and, most importantly, accelerate bringing these advanced technologies into the product development cycle. Evaluating the various alternatives for NOx, NH_3 and fuel efficiency improvements is expected to continue for up to six months after contract execution. Based upon analysis and testing, CWI will then select the appropriate controls strategies and technology to be adopted into the integrated architecture of the next generation ISL G engine. Architecture definition triggers the product development work to design, develop and build Alpha engines, conduct Alpha system development, and begin Alpha verification work including vehicle integration and demonstration, engine dynamometer durability testing, emissions demonstration, and fuel efficiency demonstration.

The objective of this task is to develop an advanced, production-intent ISL G natural gas engine and aftertreatment system intended for on-road heavy-duty vehicle applications including Class 8 tractors, low cab forward refuse collection trucks, and transit buses. In this task, CWI will conduct a detailed work plan comprised of activities and work elements described in the following sub-tasks:

2.1 Conceptual Testing, Analysis and Simulation

- 2.1.1 NOx Emission Reduction
- 2.1.2 NH_3 Emission Reduction
- 2.1.3 Fuel Efficiency
- 2.1.4 Technology Feasibility and Risk Assessment

2.2 Pre-Alpha Engine Design and Test

2.3 Alpha Engine Design

2.3.1 Alpha Mechanical Development

2.3.2 Alpha Engine Builds

2.3.3 Control & Ignition System – Alpha Development

2.3.4 Combustion & Performance & Emissions – Alpha Development

2.4 Engine Emission Demonstration and Fuel Efficiency Demonstration

2.1 Conceptual Testing, Analysis and Simulation

CWI has demonstrated that SESI technology is capable of achieving certification below the EPA/CARB 2014 on-highway emission standards. CWI's current ISL G engine is certified with NOx and particulate matter (PM) levels below the 2014 standards (0.20 g/bhp-hr NOx & 0.01 g/bhp-hr PM), for medium-heavy duty, heavy-heavy duty, and urban bus service classifications. Based on CWI's experience with SESI technology, the next generation ISL G engine with advanced technologies will be capable of meeting lower NOx emissions targets and NH_3 targets. CWI Engineering will work closely with Cummins Emission Solutions to identify, test, and select an optimal three-way catalyst design and formulation. CWI Engineering will specify new air handling, power cylinder, fuel system, and controls technologies and will develop the engine calibration (including fueling rates, EGR flow rates, and spark timing) to optimize emission performance while also optimizing vehicle performance and fuel efficiency.

For the first six months of the contract, CWI will be conducting a technical feasibility assessment of various strategies to reduce NOx emissions, NH_3 emissions, and to improve fuel efficiency. The following sub-sections identify and describe the candidate technologies & design attributes CWI intends to evaluate within Task 2.1.

2.1.1 NOx Emission Reduction

CWI's SESI technology includes three-way catalyst aftertreatment. A three-way catalyst is highly effective at converting NOx in the exhaust stream, but the NOx conversion reaction can only occur in an oxygen-free environment. Diesel engines continually operate with excess charge air and thus have oxygen in the exhaust stream. Therefore diesel engines cannot use three-way catalysts to treat NOx. Rather, most modern diesel engines use selective catalytic reduction (SCR) to treat NOx. SCR requires injection of a urea-based reagent (diesel exhaust fluid) into the exhaust system, thus increasing the operating cost of the aftertreatment system and adding installed cost and weight to the vehicle. CWI's customers have consistently provided feedback that the simplicity, ease of packaging, reduced weight, lack of maintenance, and lack of additional fluids onboard the vehicle are very appealing aspects of CWI's engine and three-way catalyst NOx control strategy. CWI is committed to maintaining a simple, passive, and maintenance-free aftertreatment system and believes that advanced three-way catalyst technology is capable of very low NOx levels. As a result, CWI's near-zero emission development plans are based upon stoichiometric engine operations and three-way catalyst aftertreatment.

In addition to catalyst changes, CWI believes that changes to air handling, fuel and controls techniques will also play critical roles in achieving near-zero NOx emissions. CWI has already begun a preliminary technical evaluation of various NOx reduction technology improvements. CWI has demonstrated NOx reduction potential via improvements in air/fuel ratio control and thermal management of the aftertreatment system. Further improvements are expected with modifications and additional tuning of the control system. Thorough analysis of the NOx production during the transient test cycle has shown that more than 60% of NOx emissions can occur immediately after coasting/motoring events and as much as 30% of FTP composite NOx emissions are from the first few minutes of the cold FTP cycle. Most of the NOx emissions reduction work will focus on reducing NOx emissions after coasting events and during the beginning of the cold cycle.

CWI expects to improve NOx emissions by optimizing air handling and fuel control during and after coasting events. Fuel is typically shut off during coasting events while air continues to pass through the catalyst, which oxidizes and cools the catalyst. This results in poor NOx conversion efficiency when fuel is turned back on. Air handling improvements will be investigated to reduce the oxidation and cooling of the catalyst during coasting. Fuel control improvements can be made to minimize the time it takes to reduce the stored oxygen level of the catalyst for improved NOx emissions. CWI has a suite of analysis tools that are part of the design optimization protocol which will be used to aid in the design evaluation process where appropriate. These tools include dynamic engine system simulation and aftertreatment models, detailed computational fluid dynamics (CFD) tools for combustion and manifold system design, and proprietary tools for engine calibration for systems with multiple degrees of freedom. Preliminary testing will be performed on a current production ISL G engine in an engine dynamometer emissions test cell.

CWI will investigate combustion controls strategies to reduce engine-out NOx emissions and improve cold catalyst conversion efficiency, and to reduce the time required to heat up the catalyst when cold. CWI and Cummins have extensive experience in engine thermal management strategies for aftertreatment warm up. Preliminary development will be performed on a current production ISL G engine in an engine dynamometer emissions test cell.

CWI will be evaluating the emissions improvement potential of more accurate lambda sensing architecture to enhance air/fuel ratio control. There are limitations with the current oxygen sensor under situations where it is desirable to run slightly rich of stoichiometry to reduce the catalyst quickly for improved NOx conversion efficiency. The current sensor is not able to accurately control air/fuel ratio outside a narrow band near stoichiometry. CWI will also be evaluating the locations of both oxygen sensors. Optimizing the locations of the oxygen sensors will result in better catalyst feedback control. Catalyst onboard diagnostics (OBD) capability will be considered while selecting the new locations. This work will be performed on an engineering vehicle and in an engine dynamometer emissions test cell with modifications to a current-production ISL G engine.

CWI will perform an evaluation of the benefits of intake port fuel injection. Port fuel injection will improve fuel transport delay times, which is expected to reduce the catalyst more quickly after coasting events. This is expected to result in an improvement in NOx emissions. In addition, faster and more accurate control of transient events can help with emission reductions. Hardware and software would need to be optimized to ensure proper air/fuel mixing and ensure consistent operation across all cylinders. An initial evaluation will be performed in an engine dynamometer performance test cell with extensive modifications to a current-production ISL G engine. Additional testing will be performed in an engine dynamometer emissions test cell if the technology demonstrates sufficient benefit in fuel control.

CWI will investigate improved catalyst designs and washcoat formulations to reduce NOx emissions. CWI will work with Cummins Emissions Solutions, an organization with the Cummins Component Business Unit, to obtain prototype catalyst designs and formulations targeting improved NOx conversion efficiency at low temperatures and at leaner air/fuel ratios. Further, CWI will be seeking catalyst systems that have improved deterioration tolerance to engine misfire. The prototype catalysts will be tested in an engine dynamometer emissions test cell on a current production ISL G engine.

CWI will also consider adding a small, close-coupled catalyst near the turbocharger, which would result in faster catalyst light off for improved cold start NOx emissions conversion. Adding a catalyst bypass valve to be opened when fuel is turned off would help keep the catalyst reduced and hot during coasting events. Diagnostic capability, vehicle integration, back pressure, catalyst durability and cost will be considered as part of the technical and commercial feasibility assessment of this technology advancement.

2.1.2 NH_3 Emission Reduction

Ammonia is currently unregulated for EPA heavy-duty on-highway vehicles. However, CWI has recent experience in reducing NH_3 emissions as required for Euro VI emissions certification. The Euro VI emissions standard includes a 10 ppm average limit over the World Harmonized Test Cycle (WHTC). Further NH_3 abatement strategies and technology development will be required to achieve 10 ppm NH_3 emissions over the FTP cycle, due to test and cycle differences between the WHTC and FTP cycles, and to mitigate anticipated NH_3 emission increases at near-zero NOx levels. As part of this proposal, CWI will investigate technology improvements to reduce NH_3 over the FTP cycle at the 0.02 g/bhp-hr NOx target.

Stoichiometric engines operating with three-way catalyst control typically exhibit a steep trade-off between reducing NOx and increasing NH_3 - see Figure 1. Ammonia is not present in the exhaust stream of stoichiometric combustion upstream of the three-way catalyst. Ammonia is generally created by the three-way catalyst under fuel-rich conditions. While NOx is primarily converted to N_2, H_2O, and CO_2, some hydrogen is produced from the available H_2O. This hydrogen may then be converted to NH_3, especially under the fuel-rich conditions necessary to aggressively reduce NOx. CWI intends to make improvements in air/fuel ratio sensing, and control all system parameters and their interaction to manage & optimize inherent trade-offs.

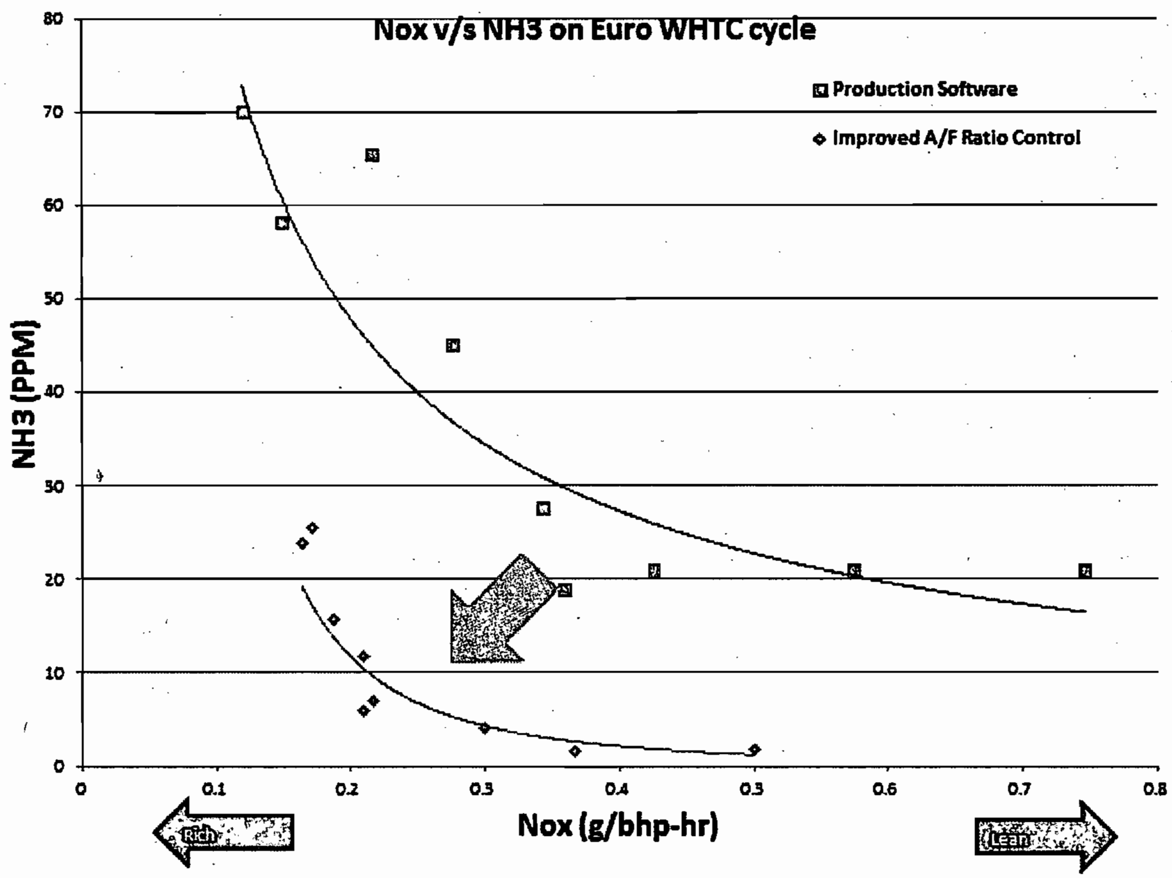

Figure 1 –NOx vs NH_3 tradeoff for ISL G Euro VI Engine on Euro WHTC Cycle

The 0.02 g/bhp-hr NOx target is a 10 fold reduction versus the current 2014 EPA/CARB emission standard. Left unchecked, this is expected to have a significant negative impact on NH_3 tailpipe emissions. CWI has been successful in reducing the NOx vs. NH_3 tradeoff with air/fuel ratio control improvements during Euro VI emissions development work. CWI will endeavor to reduce NH_3 emissions with the technology learning from its ISL G Euro VI development, changes in air handling and fuel system architecture, and via working directly with Cummins Emission Solutions on the integration of advanced catalyst elements. CWI will identify, evaluate, and implement technology advancements to reduce NH_3 emissions, and will target 10 ppm measured over the FTP emission certification cycle.

Many of the same air handling and fuel system technologies CWI is investigating for NOx improvement can improve the NOx versus NH_3 tradeoff. Improved air/fuel ratio control during and after coasting events, optimizing the oxygen sensor locations, and using more accurate oxygen sensors will be investigated as means of improving NH_3 emissions while minimizing impact on NOx emissions. Most of this work will be performed in an engine dynamometer emissions test cell as described in section 2.1.2. Ammonia emissions will be collected during emissions development testing.

CWI will work with Cummins Emissions Solutions to obtain catalyst formulations that are designed to reduce NH_3 emissions without negatively impacting NOx emissions. Research indicates that there are washcoat additives that help reduce the NOx vs. NH_3 tradeoff. Prototype catalysts will be tested in the emissions test cell with a current production ISL G engine. CWI will investigate the application of a small downstream SCR or ammonia oxidation (AMOX) catalyst element to reduce NH_3 spikes following fuel-off motoring events to determine effectiveness and cost justification.

2.1.3 Fuel Efficiency

To be acceptable to the market, the advanced, production-intent ISL G engine will be developed to have same or better fuel efficiency as the current production ISL G engine. Left unchecked, targeting a 10 fold NOx reduction necessary for near-zero NOx classification is expected to result in a fuel efficiency reduction of 3-5% in normal applications and could be as high as 10% on applications resembling the FTP certification cycle - see Figure 2. The tradeoff in fuel efficiency versus tailpipe NOx is related to the fuel-rich engine operation required to maintain high NOx conversion efficiency across the three-way catalyst as described above Fuel efficiency improvement technologies are needed to bring fuel efficiency back to current production levels or better.

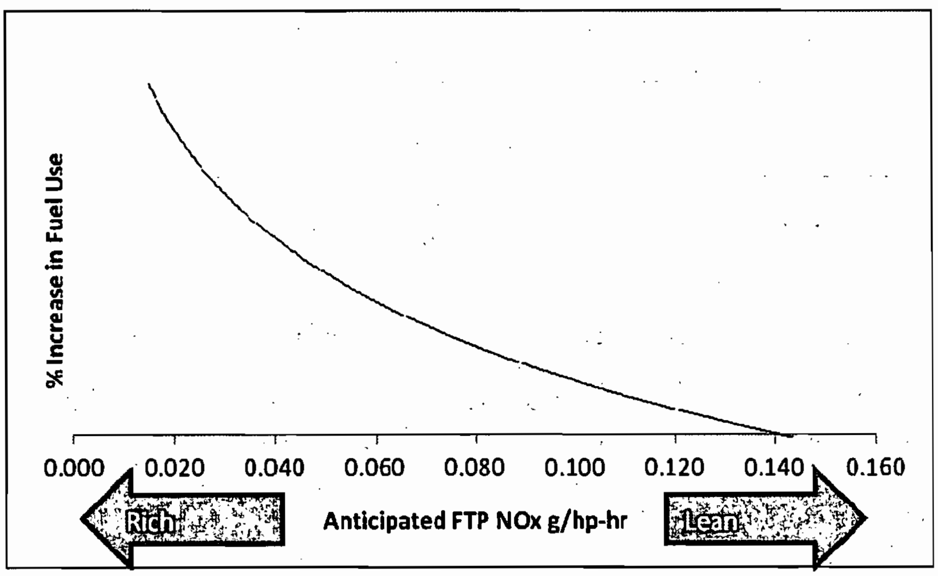

Figure 2 –Anticipated NOx vs Fuel Efficiency Tradeoff

CWI has started a preliminary investigation of possible hardware changes to improve thermal efficiency of the ISL G engine. CWI will use its proven suite of analysis tools and system tests to optimize the ISL G engine and aftertreatment for improved fuel efficiency.

Improved sensing and control of the air/fuel ratio are expected to have significant improvement in fuel efficiency at low NOx. Most of the air/fuel ratio control improvements suggested for NH_3 reduction would also improve fuel efficiency. Reducing the fuel-rich excursions by improved air/fuel ratio control during and after coasting events, more accurate lambda sensing, optimized oxygen sensor locations, and by air handling system modifications to avoid cooling and oxidation of the three-way catalyst will be critical. CWI anticipates between 1-2% improvement in fuel efficiency with application of these technologies at the near-zero NOx conditions. This testing will be performed in an engine dynamometer emissions test cell with modifications to a current-production ISL G engine.

Port fuel injection will be tested to determine possible fuel efficiency improvements. With intake port fuel injection, fuel can be controlled faster, more accurately, and reduce fuel overshoots. Fuel can also be turned off faster for coasting events. At idle, some cylinders could be turned off to save fuel. Additional innovation will be necessary to achieve low NOx levels with some cylinders turned off at idle. Testing will be performed on a heavily modified ISL G engine in an engine performance test cell.

Combustion system design changes will be considered which will include piston bowl design, piston material, intake port geometry, and compression ratio. Initial analysis indicates at least 1.5% improvement in combustion efficiency from higher compression ratios and corresponding bowl geometry changes. Further analysis is necessary to determine if this can be done without negatively impacting performance and durability of the engine. CWI will use the analysis to design new combustion chamber hardware and verify the analysis with hardware testing. Analysis will be performed with GT Power and either KIVA or Star CD. Any hardware changes identified from the analysis will be tested in an engine performance test cell.

Knock control improvements will lead to improved fuel efficiency at high engine loads. At high loads, spark timing is retarded to provide knock margin, but if accurate knock detection and control were available this would not be necessary. CWI intends to investigate improvements for ISL G knock detection. Piston material or combustion bowl geometry changes could also increase the allowable knock levels without compromising reliability and durability. CWI anticipates a 1% improvement in fuel efficiency with improved knock control and, hence, reduced knock margin. Testing will be performed on a modified ISL G engine in an engine performance test cell if research and analysis identifies potential improvements.

CWI will evaluate torque curve optimization in order to allow lower engine speed for a given vehicle cruise speed, thus enabling better fuel efficiency. A 100 rpm reduction in cruise speed generally results in as much as 1% fuel efficiency improvement, but this depends strongly upon the duty cycle.

Miller cycling is a commonly employed technique to improve fuel efficiency for spark ignited engines. CWI will evaluate, with GT Power analysis, the potential to employ both switchable and permanent Miller cycle cams as a means of improving thermal efficiency across the engine map. It is expected that the optimized solution may employ a higher geometric compression ratio and improved air handling turbo-machinery.

In addition to conventional fuel efficiency improvements, CWI is also planning to make additional improvements in greenhouse gas (GHG) emissions through methane emission reductions. CWI expects a 4% reduction in GHG emissions by developing a closed crankcase ventilation system for blow-by gases. If needed to meet future GHG regulatory requirements, CWI can also work with Cummins Emission Solutions to develop a catalyst formulation with optimized methane conversion efficiency.

Per CARB's Low Carbon Fuel Standard analysis conducted in 2009[1], CNG or LNG from renewable fuel pathways provides full fuel cycle GHG reductions of 70 to 88%. Like the existing production ISL G engine, the advanced, production-intent ISL G engine will be compatible with CNG or LNG, derived from conventional or renewable (i.e. biomethane) fuel sources.

2.1.4 Technology Feasibility and Risk Assessment

Based upon results of concept testing, analysis and simulation work performed in Task 2.1, go/no-go engine architecture decisions will be made for the new product development program. These go/no go decisions will be based upon technology feasibility and a risk assessment. Feasibility will be demonstrated by the analysis and testing performed in Task 2.1 with additional considerations for customer value, product quality, and technology maturity / market readiness. Feasible technologies will also undergo a risk assessment that will consider the reliability and durability of each technology.

2.2 Pre-Alpha Engine Design and Test

The design process will begin with system and component designs and acquisition of prototype parts. A prototype engine will be built to begin dynamometer testing. The pre-alpha engine will be used to conduct an initial verification of the concept modeling and development. Performance, emissions and fuel efficiency data acquired with this engine will be used to refine analytical models and refine the architecture. The results of this development phase will also be used to define Alpha engine design.

2.3 Alpha Engine Design

CWI will create an Alpha level engine design, incorporating the results of pre-Alpha engine testing, refined analytical models, CAD modeling in conjunction with vehicle OEMs to evaluate the engine fit in the target vehicle models, and input from Cummins manufacturing plant & supply chain experts. Any vehicle or manufacturing issues will be included to define the Alpha engine design.

Development will begin on Alpha level software and calibrations, including a limited electronic feature set, in preparation for supporting Alpha engine manufacturing and validation.

2.3.1 Alpha Mechanical Development

This task will focus on developing the mechanical & hardware aspects of the Alpha design. The task will include design analysis methods to assess the capability of the design as well as verification of the selected designs and validation of the components via laboratory testing of components, sub-systems, and engine systems. The design verification process is composed of two major elements: the DVP&R (Design Verification Plan & Report) and the Reliability Plan. The DVP&R is a product validation matrix that prescribes a comprehensive array of tests and tasks to verify the design including:

- Analysis-led design

1 http://www.arb.ca.gov/fuels/lcfs/lcfs.htm

- FMEAs for all new components and systems
- Design reviews for all new parts
- Engineering Standard Work (ESW) requirements for all new designs
- Verification of design parameters against established limits
- Component verification through bench & rig testing
- Accelerated verification through shaker rig testing

Engine mechanical components including base engine components, power cylinder components (pistons, rings, bores, liners, etc), intake/exhaust manifolds, cylinder heads, turbo machinery, fuel system components, and exhaust gas recirculation subsystems all have documented ESW and DVP&R requirements to ensure production of a high quality engine. All applicable ESW and DVP&R tasks will be performed on the parts that are redesigned to improve emissions and fuel efficiency. Any risks identified in Task 2.1 will be mitigated by adding additional tasks to the DVP&R plan.

The Reliability Plan includes engine dynamometer tests that stress the systems and components. These include abuse, accelerated, endurance and overstress tests. This reliability plan will include at least one endurance test with a minimum of 250 hours to be completed within this contract period. Additional testing of several thousand hours will be required by Engineering Standard Work. Durability & reliability testing is expected to commence within the scope of this proposal, and is expected to continue in the anticipated follow-on tasks, which are described in the Commercialization section later in Section A of this proposal. The Reliability Plan also includes field validation of the design by operating several engines in customers' vehicles as well as in engineering vehicle tests to simulate customer operation. The vehicle demonstration assessment focuses on covering the anticipated duty cycles for production engines. Vehicle-based testing is described in Tasks 3 & 4 of this proposal.

2.3.2 Alpha Engine Builds

This task will focus on building Alpha engines at the Cummins Rocky Mount Engine Plant (RMEP) in Rocky Mount, NC, where CWI's current-production ISL G is manufactured. CWI is planning to build nine (9) Alpha engines. The Alpha engines will be used in the subsequent engine development and verification tasks described herein, and for vehicle demonstration testing per Tasks 3 & 4.

2.3.3 Control & Ignition System – Alpha Development

This task will develop the control & ignition system designs and concepts defined for the advanced, production-intent ISL G engine. This task will include testing to validate that the electronic control & ignition systems (hardware, software, and calibrations) meet the requirements for heavy-duty vehicle operation, including onboard diagnostic development work. CWI will consider EPA Heavy Duty OBD requirements, which become mandatory for natural gas engines in 2018, in anticipation of commercializing the advanced, production-intent ISL G engine. Special attention will be given to assessing the capability to calibrate OBD diagnostics capable of detecting 0.03 g/bhp-hr NOx as would be required at a 0.02 g/bhp-hr NOx certification level. Significant improvements will need to be made to diagnostic algorithms for 2018 OBD, especially at 0.03 g/bhp-hr NOx levels. Diagnostic improvements and changes to the engine sensor architecture required to meet the NOx, NH_3 and fuel efficiency targets of this program will drive changes to the electronic control module (ECM). The ECM will require additional sensor inputs and changes to circuitry for these sensors.

Hardware designs, including ECM, wire harnesses, sensors and ignition system components, will be validated and upgraded as required to ensure that the designs meet the installation, operation, and service-access requirements for heavy-duty commercial vehicles. Software and calibration development will take place to create, validate and release the full electronic feature set required. The advanced, production-intent ISL G engines will be supportable via INSITE, the Cummins electronic service tool used by service technicians to interface with all Cummins & CWI engines. INSITE is used by the Field Service organization to troubleshoot field issues and diagnose problems with the product to service the engine.

2.3.4 Combustion & Performance & Emissions – Alpha Development

The primary purpose of this task is to refine the preliminary engine combustion and performance strategies defined for the advanced, production-intent ISL G engine. This task will require extensive calibration development and engine testing in an engine dynamometer test cell. This task will include analysis and testing, in conjunction with catalyst design & development experts at Cummins Emission Solutions. Transient emissions testing will be conducted to confirm the three-way catalyst design and emission control strategies. Calibrations will be refined to meet 2017 EPA/CARB emissions standards (including EPA GHG regulations), 0.02 g/bhp-hr NOx emissions, minimize NH_3 emissions, meet customer transient performance requirements, and optimize fuel efficiency. CWI will also perform preliminary analysis of engine-to-engine emissions variability and durability of the aftertreatment system. This may include emissions testing with a bench aged catalyst. Official certification-grade emission Deterioration Factor (DF) testing is not expected to commence within the timeframe of this proposed project, and is included in the anticipated follow-up work described in the Commercialization section of this proposal.

2.4 Engine Emission Demonstration and Fuel Efficiency Demonstration

CWI will demonstrate emissions of the advanced, production-intent ISL G engine at or below EPA / CARB 2017 on-highway emission standards. CWI will target a NOx emissions level of 0.02 g/bhp-hr over the heavy-duty on-highway certification cycles. CWI will also seek to minimize NH_3 emissions. An Alpha engine will be used for this testing and will be updated with production intent parts as necessary. Testing will be conducted in a 40 CFR 1065 certified emissions test cell at the Cummins Technical Center in Columbus, IN. Emissions will be collected pre- and post-catalyst to understand and quantify the catalyst effectiveness behavior.

As part of this task, CWI will quantify secondary pollutants over the EPA / CARB certification test cycles, including ammonia, ultrafine particles, HC, CO, PM, CO2, N2O and NO2. Cummins Technical Center uses an AVL 489 for ultrafine emissions measurement. The AVL 489 is configured to count the number of dry particles that are 23 nm and larger. FTIR equipment will be used to measure ammonia, N_2O and NO_2.

CWI will measure the engine fuel consumption of the advanced, production-intent ISL G peak rating in an engine dynamometer test cell to determine the brake-specific fuel consumption (BSFC) over the US FTP transient emission test cycle. CWI will compare BSFC data to the current production ISL G engine. Carbon-balance analysis based on emission data for the ISL G engine will be used to confirm the accuracy of the fuel consumption measurements.

The production-intent engine will be capable of achieving EPA & CARB emission certification. However, emission certification is not included within the scope of this proposal. The anticipated follow-on emission certification testing and associated documentation are described in the Commercialization section of this proposal.

2.5 Engine Availability for Independent Emissions Testing

In the event that AQMD chooses to conduct independent engine dynamometer emissions testing during the duration of a subcontract between CWI and AQMD for the work proposed herein, CWI will provide one (1) engine and aftertreatment system to AQMD for emissions testing. This engine and aftertreatment system will be the property of CWI and will be available to AQMD or its designated emission testing contractor for a period of time to be mutually agreed between AQMD and CWI. CWI will make available a technician or engineer to provide information and interface specifications to enable AQMD or its designated contractor to install the engine & aftertreatment system in an engine dynamometer test cell. Following completion of AQMD's independent emissions testing, CWI will require AQMD to return the engine & aftertreatment system to Columbus, IN.

Task 3 – Engine Vehicle Chassis Integration

The objective of this task is to integrate the advanced, production-intent ISL G engine and aftertreatment system into commercially-viable on-road heavy-duty vehicles. In this task, CWI will execute a detailed work plan comprising the following activities:

- Identify vehicle specifications and confirm the conceptual design strategy, specifically targeting Class 8 tractor, low cab forward refuse collection truck, and 40 foot transit bus applications;
- Conduct detailed vehicle design, including CAD modeling and review of proposed engine, component, and installation designs with Cummins Customer Engineering and Vehicle Integration teams, and OEM engineers;
- Build two CNG-fuelled engineering vehicles (one Class 8 tractor and one transit bus);
- Operate the vehicles in and around Columbus, Indiana to perform on-road engine and aftertreatment development and design optimization.

CWI's existing ISL G engine is available as a factory-installed option from a broad range of heavy-duty bus & truck OEMs. Table 2 identifies the OEM makes and models that are available with the current production ISL G engine in North America. CWI has established strong relationships with all OEMs throughout the North American truck, transit bus, and school bus markets. CWI will leverage the existing ISL G installations and OEM relationships to integrate the advanced ISL G engine and aftertreatment system into heavy-duty commercial vehicle chassis.

Table 2 – ISL G OEM Availability in North America

Market Segment / Application	**OEM**	**Market Segment / Application**	**OEM**
Conventional Truck / Tractor	Freightliner	*Transit Bus / Shuttle Bus*	ElDorado
	International		Foton America Bus Company
	Kenworth		Gillig
	Peterbilt		NABI
	Volvo		New Flyer
Low Cab Forward Truck	American LaFrance	*School Bus*	Blue Bird
	Autocar		Thomas Built
	Crane Carrier	*Highway Coach*	DesignLine USA
	Mack		Motor Coach Industries (MCI)
	Peterbilt	*Yard Spotter*	Autocar
Street Sweeper	Elgin		Capacity of Texas
	Schwarze		Ottawa

3.1 Vehicle Specifications & Conceptual Design Strategy

CWI will identify key vehicle specifications and develop a conceptual design strategy for Class 8 truck / tractor and transit bus applications. CWI's vehicle integration design strategy will leverage existing OEM installations by retaining the following existing components, systems or specifications:

- CNG or LNG fuel systems, including fuel level display(s)
- Key mechanical interfaces with the vehicle including engine mounts, flywheels and flywheel housings for transmission interfaces, and accessory components such as starter motors, air conditioning compressors, and alternators
- Electronic interface protocols including J1939 connections, location of OEM diagnostic connectors, 12 VDC power supply, electronic throttle pedal interface specifications, instrumentation / dashboard displays, and diagnostic lamps (e.g. red and amber fault lamps)

The following components, systems and/or specifications are expected to change vs. existing production ISL G installations:

- Aftertreatment system envelope & heat shielding requirements
- Engine coolant and/or charge air heat rejection

The following components, systems and/or specifications may change vs. existing production ISL G installations:

- Aftertreatment system inlet / outlet connection diameter
- Driveline gearing recommendations to yield optimal engine speeds for a given vehicle cruise speed and optimal vehicle acceleration, startability, and gradeability
- ECM design and wire harness pin-out assignments
- Engine and aftertreatment sensor locations and/or wire harness pin assignments

- Vehicle based control systems that interface with the engine ECM, including traction control, collision avoidance systems, and lane departure warning systems

CWI will work closely with Cummins Emission Solutions to review the external dimensions and installation / mounting provisions of a range of existing diesel and natural gas aftertreatment systems, in order to size the advanced ISL G aftertreatment system for commonality with existing OEM aftertreatment space claim and mounting provisions to the extent possible.

Options to increase heat rejection will include accessory drive modifications to increase cooling fan speed, installing higher capacity cooling fans, and/or upgrading to a larger charge air cooler and/or radiator.

Options to influence driveline gearing will include selection of drive tire sizes and rear axle ratios, as well as selection of transmission gear ratios and, in the case of automatic transmissions, working with the transmission manufacturer to tailor shift calibrations for the vehicle design and duty cycle.

CWI, in conjunction with the Cummins Customer Engineering and Vehicle Integration teams, and OEM engineers, will conduct a feasibility and risk assessment of the afore-mentioned engine / vehicle integration components and sub-systems within the conceptual vehicle design strategy. Risks identified through this process, and the corresponding measures to mitigate those risks, will be considered in the vehicle integration design and the on-road vehicle development plan.

3.2 Vehicle Integration Design

CWI's Application Engineering group will lead the vehicle integration design, in consultation with engineers from truck and bus OEMs that currently offer ISL G-powered vehicles. Specific activities within this task will include:

- CAD modeling of the concept and Alpha ISL G engine & aftertreatment system designs to ensure no fit issues with targeted transit bus, conventional Class 8 trucks & tractors, and Class 8 low cab forward trucks. Via Cummins, CWI has access to an extensive library of OEM vehicle CAD models. CWI is accustomed to performing CAD modeling at the early stages of product development programs. CAD modeling will include evaluation of the space claim for the on-engine fuel module, turbo-charger, intake & exhaust connections, and ignition system, all of which influence the engine envelope and the engine / vehicle interface.
- Review of CAD modeling results with OEM engineers to identify options to resolve interference issues, if any, with the production-intent low NOx ISL G engine & catalyst design. Autocar, New Flyer, and PACCAR have expressed their intent to provide design guidance and feedback to CWI for this program (see letters of support in Appendix A). CWI also anticipates working with one or more Class 8 tractor OEMs to review CAD models and receive OEM feedback regarding the proposed engine and catalyst designs.
- Review of all existing CES-supplied diesel and natural gas aftertreatment dimensions and installation geometries to identify ISL G low NOx catalyst installation using existing OEM mounting brackets and interface hardware.

- Cummins frequently conducts vehicle cooling system performance tests on behalf of OEMs as part of the Installation Quality Assurance (IQA)[2] process, to ensure adequate engine coolant and charge air cooling capability for Cummins diesel and CWI natural gas engines. Therefore CWI has access, via Cummins, to extensive cooling system performance capability data for all OEM trucks and buses that offer CWI engines. CWI will review engine heat rejection data and compare it to the current ISL G data and cooling package margin for each of the target chassis for the vehicle demonstration phase. If increased cooling system capacity is required, then CWI's application engineers will recommend the required design changes, which may include changing the fan and / or fan shroud design to increase air flow, change the belt drive arrangement to increase fan speed, or increase the core size of the radiator and/or charge air cooler.
- Determine if any changes are required to conventional CNG and LNG on-vehicle fuel storage and delivery systems in order to meet the fuel inlet pressure, temperature, and flow rate specifications for the proposed low NOx engine.

3.3 Build Engineering Vehicles

CWI proposes to build two engineering vehicles to evaluate engine and catalyst performance throughout the development program. Due to significantly different engine installation, cooling, driveline, and vehicle performance attributes between typical bus and truck applications, CWI proposes to build one Class 8 tractor and one 40 foot transit bus, each equipped with the advanced ISL G engine and aftertreatment system and fuelled with CNG. CWI anticipates using one of the existing current-product ISL G Class 8 tractor engineering vehicles currently in operation in Columbus, Indiana. This vehicle is already equipped with a CNG fuel system. CWI anticipates purchasing a used 40 foot transit bus to serve as the second vehicle. CWI will consider used diesel and natural gas buses, and will identify the most cost-effective option taking into consideration potential costs for CNG fuel system installation or upgrades, cooling package changes, and driveline changes (e.g. rear axle re-gearing, if necessary, to suit the operating speed range and torque curve of the advanced ISL G engine).

All engine and catalyst installation work will be conducted at the Cummins Pilot Center in Columbus Indiana, which specializes in prototype engine installations and support of pre-commercial engineering and customer demonstration vehicles. If a new CNG fuel system is required for the engineering bus, then CWI will coordinate fuel system acquisition and installation with an established 3rd party fuel system provider, such as Agility Fuel Systems.

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2 Prior to initiating commercial availability of ISL G at any OEM, CWI and the OEM jointly complete the Cummins Installation Quality Assurance (IQA) process, which includes a series of vehicle tests to confirm that the vehicle design meets Cummins Westport's engine and catalyst installation requirements and recommendations. The IQA process includes, but is not limited to, vehicle cooling tests to validate the vehicle's cooling system (radiator and charge air cooler), measurement of the CNG or LNG fuel delivery system to ensure adequate fuel supply pressure, measurement of intake and exhaust restrictions, and review of exhaust system temperatures and catalyst installation location. Some of the tests, including the vehicle cooling test, are typically conducted by Cummins or CWI customer engineering department at the Cummins Technical Center. All results are formally reviewed jointly by the OEM, Cummins, and CWI prior to approving the OEM to proceed with commercial sales of ISL G powered vehicles.

3.4 Engineering Vehicle Validation

CWI Engineering will operate the engineering vehicles in and around Columbus, Indiana. The vehicles will primarily be used to assess the vehicle-specific performance specifications identified in the DVP&R created in Task 2. Vehicle-specific test activities will include evaluation of engine and vehicle transient performance and drivability, including evaluation of transmission shift quality, refining ECM calibrations, and confirming that programmable electronic features (e.g. cruise control) operate as expected.

CWI anticipates conducting chassis dynamometer cooling testing at CTC, in accordance with IQA test procedures, to confirm the heat rejection analysis performed in Task 4.2 and confirm that the vehicle integration design meets CWI's vehicle integration and cooling requirements. If cooling tests reveal discrepancies with the prior cooling analysis, then CWI's application engineering team will re-evaluate the cooling system modifications, if any, planned for the customer demonstration vehicles in Task 4.

CWI will upgrade the engineering vehicles with new component designs and calibrations as the engine and catalyst designs evolve, to ensure that the production-intent hardware, software and calibrations developed in Task 2 have been validated prior to deployment of the customer demonstration vehicles in Task 4.

3.5 Vehicle Availability for Independent Emissions Testing

In the event that AQMD chooses to conduct independent chassis dynamometer emissions testing during the duration of a subcontract between CWI and AQMD for the work proposed herein, CWI will coordinate the availability of one (1) test vehicle to AQMD for emission testing. The vehicle will be available to AQMD or its designated emission testing contractor for a period of time to be mutually agreed between AQMD and CWI. CWI will make available a technician or engineer to support AQMD or its designated contractor with engine and aftertreatment information during the testing.

Task 4 – Vehicle Demonstration

The objective of this task is to demonstrate the advanced, production-intent ISL G engine and aftertreatment system in commercial revenue service in a diversity of heavy-duty commercial vehicles, based on the vehicle integration designs developed in Task 3. CWI intends to demonstrate the advanced version of the ISL G engine & aftertreatment system in three (3) commercial vehicles in the South Coast and/or San Joaquin Valley Air Basins in order to evaluate performance, reliability, and emissions. Specifically, CWI intends to conduct vehicle demonstrations in the following vehicle applications:

- Curbside refuse collection truck
- 40 foot transit bus
- Class 8 tractor

In this task, CWI will execute an on-road demonstration plan incorporating the following activities and vehicle validation elements:

- Confirm demonstration fleets and identify specific existing ISL G-powered demonstration vehicles and operating locations;
- Preparation and commissioning of the customer demonstration vehicles, to be conducted by Cummins Cal Pacific in accordance with the vehicle integration design developed in Task 3;
- Operation of demonstration vehicles in end-user revenue service for up to 12 months;
- Collect data to assess vehicle operation, maintenance, reliability, and operating costs;
- Perform vehicle testing by CWI to evaluate transient response and to evaluate specific conditions unique to the demonstration vehicles (e.g. high ambient temperature testing, unique customer duty cycles);
- Perform chassis dynamometer emission & fuel consumption testing.

4.1 Confirm Demonstration Fleets & Vehicles

CWI has initiated discussions with the following existing ISL G fleet customers, all of which have stated their support for CWI's advanced, production-intent ISL G development and demonstration program (see Appendix A):

- Waste Management
- Los Angeles Metropolitan Transportation Authority
- Frito-Lay

In this task, CWI will confirm the participation of each fleet in the vehicle demonstration, and if necessary will identify and secure the participation of alternate vehicle demonstration customers. CWI and the demonstration fleets will identify specific existing ISL G-powered vehicles from each fleet's operations in the South Coast and/or San Joaquin Valley Air Basins.

Waste Management has agreed to demonstrate the advanced, production-intent ISL G engine and aftertreatment system in a curbside refuse collection truck operating in the South Coast or San Joaquin Valley Air Basin. Waste Management has made a public commitment to adopting natural gas powered refuse collection vehicles throughout its fleet, and currently operates more than 2000 natural gas powered vehicles, the majority of these being ISL G-powered refuse trucks and tractors. Waste Management operates numerous natural gas-equipped facilities throughout southern California. The specific operating location for the ISL G demonstration, and the particular equipment and operation (e.g. residential side-loader vs. commercial front-loader vs. roll-on / roll-off truck) will be confirmed with Waste Management during 2014 in preparation for the field demonstration. In the event that AQMD requires a demonstration vehicle in the San Joaquin Valley Air Basin, CWI anticipates working with Waste Management to identify a suitable demonstration location meeting the objectives of AQMD and its funding partners. Appendix A includes a letter of support from Waste Management expressing its intent to demonstrate the advanced ISL G engine system in its southern California operations.

Los Angeles Metropolitan Transportation Authority (LA Metro) has provided a letter of support for CWI's program and has indicated its potential interest in demonstrating the advanced, production-intent ISL G engine system in a 40 foot transit bus operating in the South Coast Air Basin. LA Metro is an existing CWI customer, and is currently operating approximately 1600 ISL G-powered transit buses. LA Metro recently awarded a contract to New Flyer for the purchase of up to 900 ISL G-powered buses, to be delivered from 2013 through 2015[3].

Frito-Lay has stated that it is interested in participating in the advanced, production-intent ISL G vehicle demonstration. Frito-Lay, a division of PepsiCo, operates a corporately owned logistics fleet to distribute snack food products from Frito-Lay production facilities to a network of distribution centers, and from distribution centers to retail stores. Frito-Lay currently operates ISL G-powered Class 8 tractors in the South Coast Air Basin, and is experienced with natural gas refueling and maintenance practices.

Each of these fleets is an experienced natural gas user with extensive numbers of ISL G – powered vehicles in their fleets. Accordingly, each of these fleets operates existing on-site natural gas refueling stations, and has fully-integrated natural gas into their operations, including maintenance facilities, maintenance procedures, driver training, and technician training.

Each of these fleets has previously participated in CWI and/or Cummins pre-commercial field test programs. For example, LA Metro operated a bus powered by a pre-commercial ISL G engine during CWI's ISL G development program in 2005-07, and Waste Management is currently operating multiple trucks powered by pre-commercial 11.9 liter natural gas engines as part of CWI's ISX12 G development program. Accordingly, each of these fleets is familiar with the data-gathering and reporting practices employed by CWI during pre-commercial field demonstration programs.

4.2 Prepare & Deploy Demonstration Vehicles

The production-intent demonstration vehicles will be prepared and deployed by Cummins Cal Pacific. As described above, each demonstration fleet will contribute an existing ISL G-powered vehicle from their operation. Cummins Cal Pacific will remove the existing ISL G engine and three-way catalyst and install the advanced, production-intent ISL G engine and aftertreatment system developed in Task 2. Cummins Cal Pacific will install the advanced, production-intent engine and aftertreatment system in accordance with the vehicle integration design derived during Task 3. At the conclusion of the vehicle preparation, Cummins Cal Pacific will commission the vehicles to ensure proper operation and integration of the advanced, production-intent ISL G engine, aftertreatment system, and associated vehicle integration systems.

Cummins Cal Pacific is well versed at performing engine installations in existing vehicles, and has previously conducted commercial engine repower programs for fleets throughout southern California. Cummins Cal Pacific has also performed engine replacements for numerous prior CWI and Cummins field demonstration programs. CWI's Application Engineering and Field Service Engineering departments will coordinate the installation and vehicle commissioning work with Cummins Cal Pacific throughout this task.

Appendix A includes a letter of support confirming Cummins Cal Pacific's capabilities and intent to support Task 4.

3 http://www.newflyer.com/index/news-app/story.130

The engines for the field demonstration phase of the project will operate under emission exemption permits, which CWI expects to receive from ARB via a process that is consistent with prior pre-production engine development and demonstration programs.

4.3 Vehicle Demonstration & Data Acquisition

Following vehicle commissioning, CWI's Field Service Engineering department will hold a vehicle demonstration kickoff meeting with each of the customer demonstration fleets to confirm contact information and maintenance and data gathering expectations throughout the vehicle demonstration. CWI will designate a CWI Field Service Engineer and a Cummins Cal Pacific technician for each vehicle demonstration fleet to contact when engine or catalyst trouble-shooting and repairs are required. Data gathering will include fuel & oil consumption reporting, mileage accumulation, reporting control system faults and engine / catalyst failures, if any, and tracking maintenance events. This information will enable CWI and the fleets to calculate the operating costs associated with the advanced, production-intent ISL G engine and aftertreatment system. CWI may require the fleets to return specific maintenance items (e.g. spark plugs) to CWI for analysis in order to confirm the appropriate scheduled maintenance intervals for the future commercial release of the engine. All vehicles will be equipped with electronic dataloggers, which CWI will be able to access remotely for data acquisition and to assist with trouble-shooting. CWI will also work with the fleets to track vehicle downtime related to the engine, aftertreatment system, or associated vehicle integration systems, including proactive hardware or calibration upgrades, scheduled maintenance, and repairs.

The customer fleets will operate the field demonstration vehicles in their southern California operations in normal revenue service for up to one year. The field test fleets will be responsible for all normal operating expenses, including vehicle insurance, driver labor, fuel costs, and scheduled maintenance activities. CWI will be responsible for the cost of engine or catalyst repairs, as well as the cost of providing any unique pre-production maintenance items that are not yet released into the Cummins Parts & Service network (e.g. if Task 2 yields a new spark plug design).

Cummins Cal Pacific will be the first point of contact to support the field demonstration fleets throughout the ISL G field demonstration program. Cummins Cal Pacific and CWI's Field Service Engineering department will work closely together to coordinate engine trouble-shooting, repairs, and proactive engine and/or calibration updates throughout the vehicle demonstration program.

During the field demonstration program, CWI anticipates temporarily using one or more of the production-intent demonstration vehicles for performance validation testing, including assessing transient response, overall drivability, and electronic controls and feature integration. While the majority of these items will be assessed in Task 3 using CWI-owned vehicles, it will be necessary and valuable to test unique features, duty cycles, and environmental conditions that are specific to the customer demonstrations. As an example, CWI anticipates operating the Class 8 demonstration tractor under fully loaded conditions while ascending freeway grades at high ambient temperatures in order to assess the vehicle cooling capability and the effectiveness of the engine protection derate strategies in the engine's electronic control system.

Data and experience gathered throughout the vehicle demonstration phase, including customer and CWI operation of the vehicles, will be fed back to CWI's Product Engineering team to continually improve and develop the engine and aftertreatment system designs, including components, sub-systems, and electronic control features. Throughout the vehicle demonstration phase, CWI's Field Service engineers will visit with Cummins Cal Pacific technicians and fleet representatives to monitor the vehicle performance and ensure collection of the required data.

4.4 Chassis Dynamometer Testing

CWI will engage a 3rd party chassis dynamometer emissions testing contractor to conduct a comprehensive array of chassis dynamometer emission & fuel consumption tests using at least one of the ISL G production-intent customer demonstration vehicles. CWI anticipates conducting the chassis dynamometer emission testing during the second half of the customer demonstration phase. CWI has identified a number of potential chassis dynamometer emissions contractors operating in California, many of which CWI has worked with on prior projects. CWI has initiated discussions with UC-Riverside's CE-CERT laboratory regarding the chassis dynamometer testing for this project. CWI anticipates that final selection of the chassis dynamometer testing contractor will occur early in Task 4.

The chassis dynamometer emission & fuel consumption testing will be conducted over at least three different driving cycles per vehicle, with the specific driving cycles and emission test plan to be established in consultation with AQMD and the emission testing contractor selected for this task. Measurements will include BSFC, HC, NOx, CO, PM, NH_3, and greenhouse gases. As described in Task 1, CWI and the chassis dynamometer contractor will coordinate fuel sampling and analysis to ensure that the fuel composition complies with CCR Title 13 Section 2292.5.

4.5 Vehicle Availability for Independent Emissions Testing

In the event that AQMD chooses to conduct independent chassis dynamometer emissions testing during the duration of a subcontract between CWI and AQMD for the work proposed herein, CWI will coordinate the availability of one or more of the production-intent, fleet-owned test vehicles to AQMD for emission testing, as directed by AQMD. CWI will make available a technician or engineer to support AQMD or its designated contractor with engine and aftertreatment information during the testing.

Task 5 - Reporting

This task will incorporate face to face meetings, teleconferences, invoicing, and written reports at intervals to be agreed between AQMD and CWI. CWI proposes to submit quarterly written reports throughout the duration of the proposed work.

Commercialization Plan

As explained earlier in Section A, CWI anticipates that the three year maximum project duration specified by RFP #P2013-22 will not provide adequate time to complete all technology development and subsequent product development activities required to initiate commercial production of a new heavy-duty ISL G engine. Tasks 1 through 4 above are expected to yield a pre-commercial, production-intent ISL G engine and three-way catalyst design incorporating various technologies and control strategies to reduce NOx and NH_3 emissions and improve thermal efficiency. Following completion of Tasks 1 through 4 described above, CWI anticipates continuing product development activities to commercialize the technologies developed and demonstrated with the advanced, production-intent ISL G engine and aftertreatment system. The anticipated follow-on commercialization activities are described here for reference. For clarity, the work described in this Commercialization Plan section is not included within the scope of work proposed to AQMD herein.

The pre-commercial work proposed in Tasks 1 through 4 will evaluate NOx & NH_3 emission reduction and thermal efficiency improvement levers based on CWI's SESI technology applied to the 8.9 liter ISL G platform. The SESI technology is also used with CWI's 11.9 liter ISX12 G engine and CWI is currently developing the 6.7 liter ISB6.7 G engine using SESI technology, with commercial availability anticipated by 2015. The technology advancements developed and demonstrated via the work proposed herein may be commercialized on any or all of the ISB6.7 G, ISL G, and ISX12 G platforms.

The work proposed in Tasks 1 through 4 will enable CWI to evaluate the technical feasibility of achieving reduced NOx & NH_3 emissions, and to evaluate the technical feasibility of increasing thermal efficiency. In parallel with the technical feasibility assessment, CWI will evaluate the market demand and commercial feasibility of investing further to commercialize the resulting technology advancements throughout the CWI product line. This commercial feasibility assessment will include review of then-current and projected future natural gas vehicle penetration into the California and North America heavy-duty commercial vehicle markets. Various industry stakeholders, including consultants, government agencies, and OEMs, are projecting significant natural gas vehicle penetration in the North American heavy-duty commercial vehicle market, with some agencies forecasting 30 to 40% natural gas market share within the next decade[4]. CWI's commercial feasibility assessment will also include review of ARB's progress toward establishing optional low NOx certification standards[5], interviews with key customers and OEM stakeholders to evaluate market demand, and review of California State & regional regulatory policy (e.g. incentive funding and/or public fleet mandates) to motivate end-users to purchase vehicles with natural gas engines certified at NOx levels below the required emission standards. CWI's advanced, production-intent ISL G engine and aftertreatment system is anticipated to be capable of commercialization with modest incremental capital costs vs. natural gas engines certified to the 0.20 g/bhp-hr NOx standard, with the modest incremental costs expected to be largely associated with the advanced aftertreatment system. Due to anticipated modest incremental end-user pricing, CWI anticipates that future near-zero emission CWI engines employing the technology advancements developed within this project will offer highly cost-effective emission reductions in comparison with other zero and near-zero emission driveline systems and technologies currently used or anticipated for heavy-duty commercial vehicle applications.

4 U.S. Dept. of Energy, National Petroleum Council, "Advancing Technology for America's Transportation Future (2012)"
ACT Research "The Future of Natural Gas Engines in Heavy Duty Trucks: The Diesel of Tomorrow?"
5 http://www.arb.ca.gov/msprog/onroad/optionnox/optionnox.htm

Commercialization activities would include:

- Beta design and validation
- Parts sourcing
- Design finalization, structure, and release
- Production readiness
- Emission certification
- OEM integration, including the IQA process
- Reliability assessment and production launch

These follow-on activities would be conducted in accordance with the Cummins product development and commercialization process, which ensures cross-functional participation from all affected internal and external stakeholders, including CWI and Cummins engineering, marketing, purchasing, manufacturing, parts and service, and application engineering, as well as OEM engineering, sales, and marketing departments, and related 3rd party suppliers such as CNG and LNG fuel system integrators and refueling station providers.

CWI has extensive experience certifying engines to ARB and EPA heavy-duty, on-highway emission standards. In preparation for applying for emission certification to heavy-duty, on-highway engine standards, CWI would conduct the following tests:

- Emissions deterioration testing to quantify emissions changes from a single engine and catalyst system throughout the EPA-prescribed useful life (185,000 miles for Medium Heavy Duty engines such as ISB6.7 G and ISL G; 435,000 miles for Heavy Heavy Duty engines such as ISX12 G). This testing involves operating an engine and catalyst in an engine dynamometer test cell under a high load factor duty cycle that represents accelerated in-use operation, and periodically conducting emission testing at prescribed intervals to establish an emissions slope and emissions deterioration factor for each regulated pollutant.
- Internal pre-certification emission testing with at least three production-intent engines and catalysts to characterize the emissions distribution and quantify the engine to engine and test to test emissions variability.
- Certification testing with one new engine and catalyst in accordance with the EPA on-highway emission certification test procedures in 40 CFR 1065.

Collectively, these data sets will enable CWI to quantify the end-of-useful life emissions upon which EPA and CARB emission certifications are based.

CWI's path to market is via OEM factory installation of CWI engines in commercial trucks and buses. CWI's ISL G and ISX12 G engines are available as factory-installed options from all of the leading commercial heavy-duty vehicle OEMs in North America, including Daimler (via its Freightliner and Thomas Built Buses brands), PACCAR (Kenworth and Peterbilt), Volvo Trucks North America (via its Volvo & Mack brands), Navistar (International), Blue Bird, New Flyer, NABI, Gillig, and Novabus. CWI's ISB6.7 G engine is expected to be commercially available from many of these same OEMs at the conclusion of the ISB6.7 G development program. By leveraging existing and future planned OEM availability of CWI's natural gas engines, CWI's future low emissions, high efficiency natural gas engines will have an established path to market with scalable, high volume production capability. CWI will work closely with all targeted OEMs to enable OEM factory installations of the advanced, next generation CWI engines, including IQA-caliber cooling tests and engineering validation testing in support of the established IQA process to ensure that all engine installations meet CWI's requirements and recommendations.

Section B – Program Schedule

Figure 3 identifies the program schedule, with stars indicating key milestones throughout the project.

Task #	Task / Subtask Description	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12
1	**Fuel Specification**							■	■	■	■	■	■
2	**Development of Prototype HD NG Engine**	■	■	■	■	■	■	■	■	■	■	■	■
2.1	Conceptual Testing, Analysis and Simulation	■	■										
2.1.1	NOx Emission Reduction	■	■										
2.1.2	NH3 Emission Reduction	■	■										
2.1.3	Fuel Efficiency	■	■										
2.1.4	Technology Feasibility and Risk Assessment		★										
2.2	Pre-Alpha Engine Design and Test		■	■	■	■	■						
2.3	Alpha Engine Design				■	■	■						
2.3.1	Alpha Mechanical Development								■	■	■	■	■
2.3.2	Alpha Engine Builds						■	■ ★					
2.3.3	Control & Ignition System – Alpha Development							■	■	■	■	■	■
2.3.4	Combustion & Performance & Emissions – Alpha Development							■	■	■	■	■	■
2.4	Engine Emission Demonstration and Fuel Efficiency Demonstration										■	■	■
2.5	Engine Availability for Independent Emission Testing											■	■
3	**Engine Vehicle Chassis Integration**			■	■	■	■	■	■	■	■	■	■
3.1	Vehicle Specifications & Conceptual Design Strategy			■	■								
3.2	Vehicle Integration Design				■	■ ★							
3.3	Build Engineering Vehicles						■ ★						
3.4	Engineering Vehicle Validation							■	■	■	■	■	■
3.5	Vehicle Availability for Independent Emission Testing									■	■	■	■
4	**Vehicle Demonstration**						■	■	■	■	■	■	■
4.1	Confirm Demonstration Fleets & Vehicles						■	■ ★					
4.2	Prepare & Deploy Demonstration Vehicles								■	■ ★			
4.3	Vehicle Demonstration & Data Acquisition									■	■	■	■ ★
4.4	Chassis Dynamometer Testing												■ ★
4.5	Vehicle Availability for Independent Emission Testing											■	■
5	**Reporting**	■	■	■	■	■	■	■	■	■	■	■	■

Figure 3 – Project Schedule with Key Milestones

Section C - Project Organization

CWI has assembled a team of industry leading companies to perform the proposed work. The team is comprised of the following organizations:

- Cummins Westport
- Cummins Emission Solutions
- Cummins Cal Pacific
- Autocar
- New Flyer
- PACCAR
- Waste Management
- Los Angeles Metropolitan Transportation Authority
- Frito-Lay

Appendix A contains letters of support from each team member expressing their support for the proposed project.

CWI will be the prime contractor and will coordinate all aspects of the work, including obtaining regulatory permits, conducting engine development, formalizing agreements with field test fleets, scheduling and coordinating engine and aftertreatment integration into the target vehicle chassis, identifying and engaging a chassis dynamometer emission testing contractor, obtaining and analyzing data, and reporting project progress and results to AQMD. CWI has assigned Mr. Scott Baize to this project as Principal Investigator. CWI will manage the overall project in accordance with product development and project management practices that are well established within CWI and Cummins. These processes include formation of a cross-functional "Core Team" comprised of members from relevant functions throughout the CWI and Cummins organizations, such as Engineering, Marketing, Purchasing, Finance, Manufacturing, Operations, Customer Engineering, and Parts & Service. At recurring intervals throughout the project (approximately every six months) the Core team will report the project status to a cross-functional review group comprised of senior managers and executives from CWI and its parent companies, Cummins Inc. and Westport Innovations Inc. In the management review meetings, the Core Team will present evidence to gauge the project's progress vs. pre-determined schedule, budget, performance, cost, and/or quality measures. At each meeting the Core Team will request authorization from the management review group to proceed with the next phase of the project.

CWI will conduct the work proposed in Tasks 1, 2, 3 & 5. For Task 2, CWI will work in consultation with Cummins Emission Solutions to identify and evaluate candidate three-way catalyst designs. During Task 3, CWI will exchange information with Autocar, New Flyer, PACCAR, and other commercial vehicle OEMs to assist with vehicle integration.

Cummins Emission Solutions is a division within the Cummins Components Business Unit, and specializes in developing, manufacturing and supporting advanced aftertreatment systems for diesel and natural gas engines. Cummins Emission Solutions and CWI have a long history of working collaboratively to identify, evaluate and select new catalyst designs, including during the CWI product development programs leading to ISL G and ISX12 G production. For the work proposed herein, Cummins Emission Solutions will identify, design and produce prototypes of candidate three-way catalyst configurations during Task 2. Cummins Emission Solutions engineers will then collaborate with CWI's engineering staff to evaluate the emissions data obtained from engine testing with the prototype catalysts, and will identify a preferred catalyst design for Tasks 3 & 4.

Cummins Cal Pacific is the exclusive distributor for Cummins and CWI engines for southern California. Cummins Cal Pacific specializes in service support and parts supply for all Cummins and CWI engines, and has extensive experience supporting and servicing multiple generations of natural gas engines. Cummins Cal Pacific also has expertise with integrating new engines and aftertreatment systems into existing vehicles, via repower programs conducted by Cummins Cal Pacific technicians for fleets that make a commercial decision to change engines at the mid-life of their vehicle, and via pre-commercial vehicle conversions in support of the field test phase of numerous prior Cummins and CWI engine development programs. Cummins Cal Pacific has performed more than 300 natural gas engine repower programs, and has provided technical oversight and engine / vehicle integration testing services for fleet-implemented repower programs for many hundreds more. Within Task 4 of the proposed project, Cummins Cal Pacific will conduct the vehicle integration work for the field demonstration vehicles. Specifically, Cummins Cal Pacific technicians will remove the existing ISL G engines and catalysts from the three field demonstration vehicles provided by the demonstration fleets and will install new, prototype ISL G engines and catalysts per the designs developed in Tasks 2 & 3. Cummins Cal Pacific will commission the vehicles to ensure the engines, catalysts, and vehicles are operating properly, and then will deliver the vehicles to the vehicle demonstration fleets. Throughout the vehicle demonstration program, Cummins Cal Pacific technicians will provide trouble-shooting and service support for the demonstration vehicles when necessary, working in conjunction with CWI's Field Service Engineering team. Cummins Cal Pacific technicians may also upgrade ECM calibrations and install new parts if required by CWI's development engineers throughout the field test program.

Autocar is a manufacturer and marketer of Low Cab Forward Class 8 trucks for use in refuse collection and other vocational applications. Autocar and CWI have worked collaboratively for the past decade to integrate natural gas engines and catalysts into Autocar's trucks. Autocar currently offers the CWI ISL G natural gas engine in the Xpeditor (refuse collection) and Xspotter (yard tractor) models, and also offers the CWI ISX12 G natural gas engine in the Xpeditor product line. Within the proposed project, Autocar will review CWI's advanced, production-intent ISL G engine and aftertreatment designs to provide engine and catalyst design feedback as well as to provide guidance related to vehicle integration.

New Flyer is the leading manufacturer of urban transit buses in North America. New Flyer has a long history of providing natural gas transit buses powered by CWI engines to leading transit bus fleets in southern California including Los Angeles Metropolitan Transportation Authority, Orange County Transportation Authority, and numerous other public transit agencies throughout the South Coast region. New Flyer currently offers the CWI ISL G natural gas engine in 40 foot transit buses, with over 1600 ISL G-powered buses sold to-date and many more on order. Within the proposed project, New Flyer will review CWI's advanced, production-intent ISL G engine and aftertreatment designs to provide engine and catalyst design feedback as well as to provide guidance related to vehicle integration.

PACCAR, headquartered in Bellevue, Washington, 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. PACCAR currently offers the CWI ISL G and ISX12 G natural gas engines in numerous Kenworth and Peterbilt conventional chassis models and the Peterbilt Model 320 low cab forward truck for vocational applications. Within the proposed project, PACCAR will review CWI's advanced, production-intent ISL G engine and aftertreatment designs to provide engine and catalyst design feedback as well as to provide guidance related to vehicle integration.

Waste Management is the largest environmental solutions provider in North America, serving more than 20 million customers in the U.S., Canada and Puerto Rico. Waste Management currently operates more than 2000 natural gas powered refuse collection trucks throughout North America, including numerous locations equipped with CNG or LNG refueling stations to support operation of ISL G-powered trucks within the South Coast and San Joaquin Valley Air Basins. Waste Management is an experienced natural gas truck fleet and has integrated CNG or LNG refueling and maintenance practices into many of its operating locations. Waste Management has participated in numerous prior CWI pre-commercial field test programs, including the ISL G and ISX12 G field tests. For Task 4, Waste Management will operate a low cab forward refuse collection truck equipped with the proposed advanced ISL G engine & catalyst system. CWI and Waste Management have not yet identified a specific operating location for the ISL G vehicle demonstration, and anticipate some flexibility with selecting a demonstration vehicle in either the South Coast Air Basin or San Joaquin Valley Air Basin.

Los Angeles Metropolitan Transportation Authority (LA Metro) is the largest public transit operator in southern California. LA Metro exclusively operates alternate-fuelled transit buses, including more than 1600 ISL G-powered 40 foot and 60 foot articulated buses. LA Metro recently awarded a contract to New Flyer for the purchase of up to 900 new ISL G-powered 40 foot buses from 2013 through 2015. LA Metro has fully integrated CNG refueling and maintenance practices throughout its operating depots. LA Metro has participated in prior CWI pre-commercial field test programs, including operating a 40 foot transit bus powered by a prototype ISL G engine during the ISL G engine development program in 2005-07. LA Metro has stated its support for CWI's advanced, production intent ISL G project, and is a prospective vehicle demonstration partner for Task 4. CWI intends to formally engage LA Metro to operate a 40 foot transit bus equipped with the advanced production-intent ISL G engine & catalyst system. An LA Metro demonstration vehicle would operate in the South Coast Air Basin.

Frito-Lay, a key business unit with PepsiCo, is a market leader in the snack food industry. Frito-Lay's corporately owned logistics fleet distributes snack food products from Frito-Lay production facilities to a network of distribution centers, and from distribution centers to retail stores. Frito-Lay currently operates ISL G-powered Class 8 tractors in the South Coast Air Basin, and is experienced with natural gas refueling and maintenance practices. For Task 4, Frito-Lay will operate a Class 8 tractor equipped with the proposed advanced ISL G engine & catalyst system. The Frito-Lay field demonstration vehicle is anticipated to operate in the South Coast Air Basin.

Section D - Qualifications

CWI is a joint venture company with 50/50 ownership by Cummins Inc. and Westport Innovations Inc. Established in 2001, CWI's sole mission is to develop, commercialize and support alternative fueled engines for commercial vehicle applications. CWI has developed industry leading SESI technology, and has a wealth of technical, marketing, customer support, and management experience related to developing, commercializing and supporting natural gas engines in North America and globally. In the natural gas vehicle market, CWI is recognized worldwide as the premier supplier of engines for a variety of demanding commercial vehicle applications. By leveraging Cummins' market leading diesel engine platforms, established product development processes, high-volume engine production facilities, and broad OEM relationships, CWI has unrivalled access to all leading commercial vehicle OEMs in North America, and has the capability to commercialize products with the inherent production efficiencies and production scalability enabled by manufacturing dedicated natural gas engines in Cummins manufacturing facilities.

The CWI Product Engineering team has brought numerous natural gas engine products to market dating back to the early 1990s, prior to the inception of CWI. CWI follows the Cummins product development and commercialization process, which is focused on delivering robust products that meet critical customer requirements such as emissions, performance, cost and quality. Specific activities within this product development and commercialization process include:

- Conducting extensive component and engine verification testing in normal and extreme operating conditions, such as extreme temperatures, vibrations, over-power, and over-speed

- Conducting extensive vehicle-based field tests to validate engine operation in a variety of real-world conditions, including extreme temperatures and high altitude operation
- Identifying and validating suppliers for all new engine components, including proving production quality for high volume manufacturing
- Introducing the new engine into Cummins manufacturing plants
- Providing prototype engines, data and technical support to vehicle OEMs to enable engine / vehicle integration
- Creating owner's manuals and service documentation, and preparing the Cummins distribution and service network to provide customer support.
- Preparing sales and marketing literature, advertisement, and promotional materials.
- Obtaining emission certification to EPA / CARB and Euro on-highway emission standards.

Since the formation of CWI in 2001, CWI has developed and commercialized numerous alternative fueled engines including:

- 8.3. liter lean burn spark ignited C Gas Plus (launched in 2001)
- 5.9 liter lean burn spark ignited B Gas Plus (2002)
- 5.9 liter lean burn spark ignited B LPG Plus (2003)
- 8.9 liter lean burn spark ignited L Gas Plus (2004)
- 5.9 liter lean burn spark ignited B Gas International (2005)
- 8.9 liter stoichiometric cooled EGR ISL G (2007)
- 5.9 liter lean burn spark ignited ISB5.9 G (2010)
- 11.9 liter stoichiometric cooled EGR ISX12 G (2013)

The majority of the CWI engine development and commercialization programs referenced above were conducted with funding assistance from various government agencies and alternative fuel industry stakeholders including:

- National Renewable Energy Laboratory
- South Coast Air Quality Management District
- Gas Technology Institute
- California Energy Commission
- Propane Education & Research Council
- California Air Resources Board
- Advanced Technologies & Fuels Canada Inc.

Table 3 provides specific information regarding engine development contracts executed by CWI within the past five years. The ISL G & ISX12 G projects referenced below were successfully completed, meeting all project objectives and deliverables. The ARB funded project led directly to expanded applications and market penetration of the industry leading ISL G engine. The CEC / GTI and NREL projects led directly to the recently launched and highly anticipated ISX12 G engine.

Table 3 – Recent Government Funded Projects Successfully Completed by CWI

Project Title	**Description**	**Contracting Agency**	**Contract Number**	**Contact(s)**
Development, Demonstration & Commercialization of a 0.20 g/bhp-hr NOx Natural Gas Engine	Development and release of additional ISL G ratings and vehicle applications	California Air Resources Board	ICAT Grant No. 06-08	Steve Mara, ARB, Research Engineer, 916-323-3920
Ultra-Low Emissions 12-13 Liter Heavy Duty Natural Gas Engine Development	ISX12 G Alpha Development	California Energy Commission (in conjunction with Gas Technology Institute)	CEC Grant Agreement PIR-08-044	Rey Gonzalez, PIER Program Engineer, CEC, 916-327-1334 Tony Lindsay, Director of Research & Development, GTI, 847-768-0530
Natural Gas Engines and Vehicles Research, Development and Demonstration (NG RD&D) Program	ISX12 G Final Stage Development	National Renewable Energy Laboratory	ZXH-1-40455-01	Brad Zigler, NREL, Senior Engineer, 303-275-4267
Late Stage Development, Demonstration & Product Launch of Cummins Westport ISX11.9 G Natural Gas Engine	ISX12 G Final Stage Development	California Energy Commission (in conjunction with Gas Technology Institute)	CEC Contract ARV-09-013	Rey Gonzalez, PIER Program Engineer, CEC, 916-327-1334 Tony Lindsay, Director of Research & Development, GTI, 847-768-0530
Advanced 6.7 Liter Natural Gas Engine Development	ISB6.7 G Alpha Development	California Energy Commission (in conjunction with GTI)	CEC funding awarded and approved by CEC Board, but contract not yet executed.	Rey Gonzalez, PIER Program Engineer, CEC, 916-327-1334 Tony Lindsay, Director of Research & Development, GTI, 847-768-0530

Section E - Assigned Personnel

CWI has extensive experience successfully completing major engine development programs, frequently in conjunction with government and industry stakeholder funding partners. CWI is exclusively focused on developing, commercializing and supporting spark ignited alternative fuel engines for medium- and heavy-duty commercial vehicle applications, and offers a broad range of natural gas engines. CWI's engines are factory built in Cummins engine manufacturing facilities, and are offered as factory-installed options from a wide range of OEMs throughout the commercial vehicle market segments identified in RFP #P2013-22. As a result, CWI can leverage significant economies of scale and a scalable, high-volume path to market for current and new natural gas engines. Therefore, CWI is uniquely qualified to perform the emission reduction and efficiency improvement work proposed herein.

The CWI Product Development Engineering team, based in Columbus, Indiana, will conduct the technical tasks described in Section A. This Product Development Engineering team has been intact within CWI for many years, and has been responsible for all recent and current CWI spark-ignited engine development activities. Figure 4 identifies the CWI Product Development Engineering team structure, along with identification of key technical team members that will be directly involved in the proposed project.

CWI's Principal Investigator, Mr. Scott Baize, has spent the majority of his career within CWI Engineering and is one of CWI's most knowledgeable and experienced technical team members, with significant experience managing a group of engineers and managing cross-functional projects. Since 2007, Mr. Baize has been the group leader for the Combustion Performance and Emissions (CPE) group within CWI Engineering, and has served as Technical Project Leader for a prior engine development program. He will continue to have responsibility for leading CPE development work outlined in this proposal.

Mr. Stephen Abedian is CWI's Director, Controls & Ignition Systems. Stephen is responsible for the design and development of the ignition system components required to ensure reliable ignition of the cylinder charge at all operating conditions. The system includes spark plugs, high voltage extensions, ignition coils and ignition system controller. As part of Stephen's role, he is responsible for ensuring that CWI Engineering is aligned with Cummins technical procedures, best practices, and Engineering Standard Work.

Mr. Charles Crowder is the manager of the design and mechanical development group. He will lead design work and DVP&R activities required to demonstrate the capability of the design to meet the program targets.

Mr. Norbert Rehm is responsible for software development for the engine. This includes development of the required algorithms, software and software testing.

Mr. Aaron Homoya is the group leader for the Controls team. Aaron's role in the project will include the definition & validation of the needed sensors, actuators, and wire harnesses. His team is also responsible for the engine control module and for OBD development work.

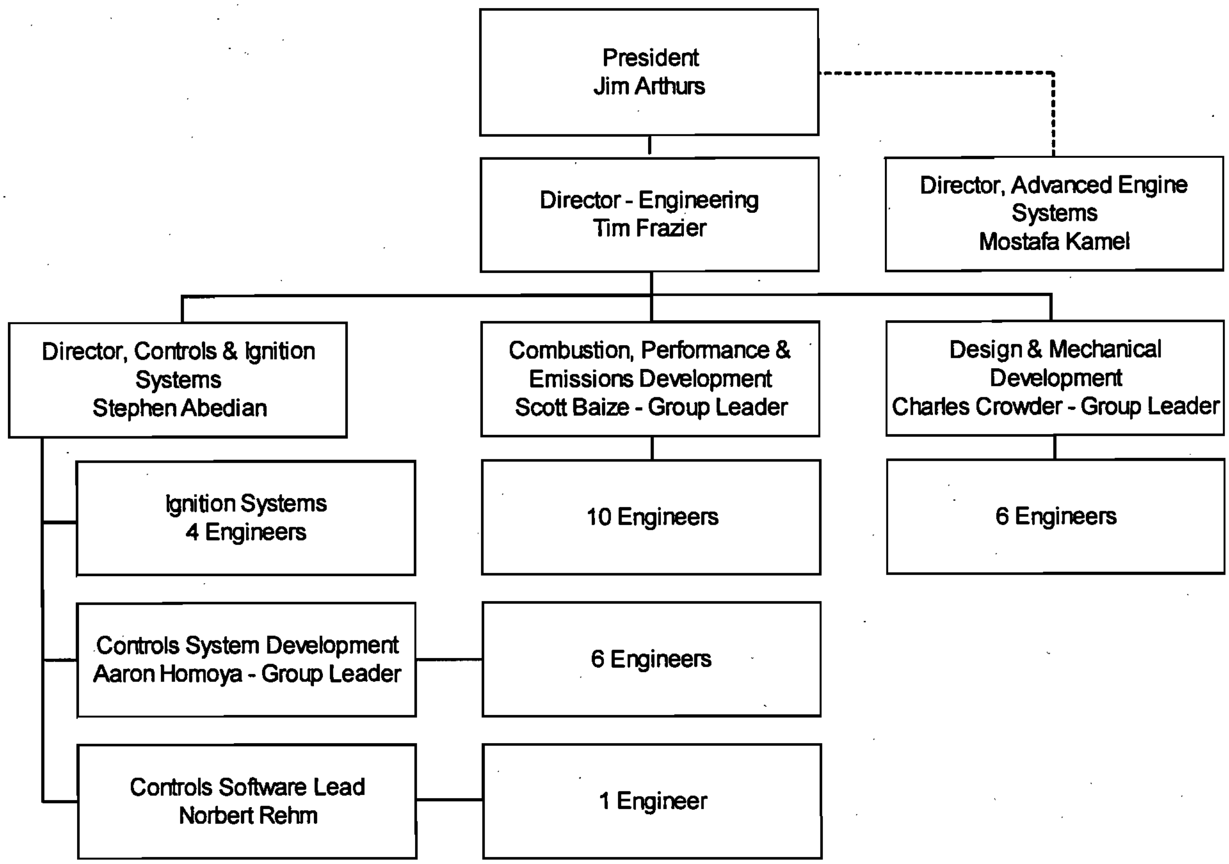

Figure 4 – Cummins Westport Product Development Engineering Team Structure

Ms. Diane Song, CWI's Controller, is the designated business contact for the proposed project. Ms. Song has been directly involved in all CWI funding contracts for the past five years and has extensive experience interacting with numerous funding agencies on all aspects of invoicing and financial reporting.

Mr. Scott Baker, CWI's Director of Product & Market Planning, will lead the reporting and general management relationship with AQMD. Mr. Baker has led CWI's funding applications and reporting relationships with all funding partners since 2004.

In addition to the direct project team identified above, CWI's proposed work will be overseen by Dr. Tim Frazier and Dr. Mostafa Kamel. Dr. Frazier is CWI's Director of Engineering, and has extensive experience managing technology and product development projects within Cummins, including managing funding contracts and reporting relationships with Federal and State funding agencies. Dr. Kamel is the Director of Advanced Engine Systems, and formerly CWI's Director of Engineering. Dr. Kamel has managed numerous natural gas engine development projects and government reporting relationships for nearly two decades, preceding the inception of CWI.

Table 4 summarizes the total labor hours for the proposed statement of work, by Task and by labor category.

Table 4 – Summary of Labor Hours

Labor Hours	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Total
Principal Investigator	520	520	520	520	520	520	520	520	520	520	520	520	6,240
Program Manager	260	260	260	260	260	260	260	260	260	260	260	260	3,120
Configuration Manager	0	0	104	156	260	260	260	260	260	260	260	260	2,340
Combustion, Performance, Emissions Engineer	1,040	1,040	1,040	1,040	1,040	1,040	1,092	1,092	1,144	1,144	1,196	1,144	13,052
Mechanical/Design Engineer	520	1,040	1,040	1,040	1,040	1,040	1,092	1,092	1,144	1,144	1,144	1,144	12,480
Controls Engineer	780	780	780	780	780	780	1,092	1,092	1,144	1,144	1,144	1,144	11,440
Ignition Engineer	260	260	260	260	260	260	312	312	364	364	364	364	3,640
Application Engineer	0	0	0	260	520	520	208	104	0	0	0	0	1,612
Field Service Engineer	0	0	0	0	0	104	104	104	208	208	364	234	1,326
Product Manager / Regional Manager	0	0	0	0	0	104	104	52	26	26	26	26	364
Engine Technician Cross Charges	0	0	0	0	0	1,040	52	52	52	52	52	52	1,352
Driver	0	0	0	0	0	0	260	260	260	260	260	260	1,560
Total Hours	3,380	3,900	4,004	4,316	4,680	5,928	5,356	5,200	5,382	5,382	5,590	5,408	58,526

The work described in Task 4 – Vehicle Demonstration will be conducted within the South Coast Air Basin. The work described in Tasks 1 through 3 will be primarily conducted in Columbus Indiana at CWI's offices and the Cummins Technical Center. Therefore, less than 90% of the overall work proposed herein will be conducted within the geographical boundaries of the SCAQMD.

Section F - Subcontractors

CWI, in conjunction with other divisions within Cummins, has extensive in-house expertise for engine design, natural gas power cylinder, fuel system and control system development, turbo-charging and air handling (via Cummins Turbo Technologies), aftertreatment development (via Cummins Emission Solutions), filtration (via Cummins Filtration), and engine dynamometer facilities (via the Cummins Technical Center). Based on this extensive in-house expertise, CWI anticipates that all technical development and modeling work will be conducted within CWI and the existing natural gas component development teams within the Cummins Components Business Unit.

CWI will contract for chassis dynamometer emission testing work. CWI has worked with numerous third-party chassis dynamometer testing facilities on prior projects, including UC-Riverside's College of Engineering – Center for Environmental Research & Technology (CE-CERT) laboratory and West Virginia University. CWI has already initiated discussions with UC-Riverside and has obtained a budgetary quote, which is reflected in CWI's accompanying Volume II - Cost Proposal. CWI will select a chassis dynamometer testing contractor during the vehicle demonstration program. CWI anticipates that the selection decision will be dictated in part by the timing, logistics, and availability of each organization's testing facilities and staff at the time.

Section G - Conflict of Interest

CWI is not aware of any conflict(s) of interest that would arise amongst the project team members and AQMD by executing a contract with AQMD for the work proposed herein.

Section H - Additional Information

CWI is confident that the work described in this proposal directly addresses the intent and objectives of RFP #P2013-22, and that CWI and the project team described herein are uniquely qualified to develop and demonstrate the advanced, production-intent ISL G engine and aftertreatment system while preparing for follow-on commercialization activities. In addition to the information described in preceding sections of this proposal, CWI would like to highlight the following points:

- The emission reduction and efficiency improvement technology advancements proposed herein are based on CWI's SESI technology, which CWI is in the process of deploying throughout its product line of engines from 6 to 12 liters. Cummins Inc, one of the parent companies of the CWI joint venture, is also developing the 15 liter ISX15 G engine based on SESI technology. Therefore, emission reduction and efficiency improvement technology advancements funded by AQMD and conducted within CWI may be commercially deployed across multiple engine displacements covering all heavy-duty on-highway commercial vehicle applications from 6.7 to 15 liters.
- Cummins Cal Pacific and LA Metro, both of whom feature prominently in the work proposed herein, are local businesses based in the South Coast Air Basin.
- CWI has engaged vehicle demonstration customers with extensive natural gas fuelled fleets and multiple natural gas-equipped operating locations throughout California, including numerous potential demonstration locations in the South Coast and San Joaquin Valley Air Basins. The team members selected will enable CWI to include vehicle demonstrations in both the South Coast and San Joaquin Valley Air Basins if desired by AQMD and its funding partners.
- All CWI component and hardware sourcing is coordinated through the Cummins Engine Business Purchasing organization. As a result, all CWI component purchasing is conducted in compliance with the Cummins Inc. Minority, Women-owned, and Disadvantaged Business Enterprises, Small Business Subcontracting Commercial Plan. The afore-mentioned plan specifies the percentage of Cummins purchasing and subcontracting activity by business category on an annual basis, and is overseen by the Cummins Director of Diversity Procurement. For 2010, the Cummins plan specified that 38% of the value of Cummins purchasing would be directed to small business concerns. CWI's purchasing activity is encompassed within Cummins' overall annual purchasing activity; therefore, CWI anticipates a similar level of small business purchasing activity within the work proposed herein.
- CWI has an established track record of successfully completing prior projects funded by AQMD, CEC, SoCal Gas and other industry & government stakeholders.

APPENDIX A

LETTERS OF SUPPORT

1. Cummins Emission Solutions
2. Cummins Cal Pacific
3. Autocar
4. New Flyer
5. PACCAR
6. Waste Management
7. Los Angeles Metropolitan Transportation Authority
8. Frito-Lay (email of support from Ken Marko, Senior Fleet Engineer, Frito-Lay)

Emission Solutions

July 15, 2013

Mr. Scott Baker
Director, Product & Market Planning
Cummins Westport Inc.
101-1750 W. 75th Ave
Vancouver BC V6P 6G2

Dear Mr. Baker:

This letter confirms Cummins Emission Solutions' intent to work with Cummins Westport to support pre-commercial development & demonstrations of Cummins Westport's proposed ultra-low NOx ISL G natural gas engines.

Cummins Emission Solutions (CES) is a leader in catalytic exhaust products, with over 2 million units in service and 30 years experience in exhaust engineering and manufacturing. Cummins Emission Solutions has become the market share leader for emission solutions to on-highway truck manufacturers for the medium and heavy-duty, Euro IV/V and EPA/CARB markets. Cummins Emissions Solutions if the exclusive supplier of three way catalysts for Cummins Westport's ISL and ISX12 G engines, and has worked closely with Cummins Westport through multiple engine & catalyst development programs.

As part of the proposed work, Cummins Emission Solutions will work with Cummins Westport to design prospective catalyst substrate and washcoat formulations to achieve the project's emission reduction targets. Cummins Emission Solutions will produce prototype catalysts for engineering development and evaluation, as well as for the vehicle demonstration phase of the program.

Cummins Emission Solutions looks forward to working with Cummins Westport to further reduce the emissions of the ISL G engine.

Sincerely,

Ken Federle
Executive Director, Research & Engineering
Cummins Emission Solutions

Cummins Emission Solutions
301 Jackson Street
Mail Code 91687
Columbus, IN 47201 USA
cummins.com

Cal Pacific

July 5, 2013

Mr. Scott Baker
Director, Product & Market Planning
Cummins Westport Inc.
101-1750 W. 75th Ave
Vancouver BC V6P 6G2

Dear Mr. Baker:

This letter confirms Cummins Cal Pacific's intent to work with Cummins Westport to support pre-commercial demonstrations of Cummins Westport's proposed ultra-low NOx ISL G natural gas engines. Cummins Cal Pacific understands that Cummins Westport intends to further develop the ISL G engine with an objective of achieving 0.02 g/bhp-hr NOx emissions, and that Cummins Westport intends to demonstrate the resulting, pre-production, near-zero NOx engine system in a variety of heavy-duty commercial vehicle applications in the South Coast and/or San Joaquin Valley Air Basins.

Cummins Cal Pacific is the authorized Cummins Distributor serving customers in Southern California, through our network of locations in Ventura, Los Angeles, Orange County, Inland Empire and San Diego. Cummins Cal Pacific sells and services Cummins products for the automotive, industrial, construction, marine and power generation markets. We stock extensive inventories of our quality products and are committed to the highest service standard in the industry. Our scope of responsibilities includes the Cummins Westport product line of automotive natural gas engines. Working with our staff of Cummins trained application engineers, our service center have performed over 300 natural gas repowers.

On October 1st, 2013, Cummins Cal Pacific will merge with Cummins West to form a new Cummins distributor under Cummins Cal Pacific management to be responsible for all of California and Hawaii. In addition to the locations identified above, this newly merged distributor will have locations in the Bay area, Sacramento, Fresno, Bakersfield, Redding, Arcata and Honolulu.

As part of the proposed work, Cummins Cal Pacific will lead the integration and installation of the proposed 0.02 g/bhp-hr NOx ISL G engine and aftertreatment into numerous field demonstration vehicles, potentially including transit buses, refuse collection trucks, and Class 8 goods movement trucks. Following successful deployment of these field demonstration vehicles, Cummins Cal Pacific technicians will work closely with Cummins Westport and the field demonstration fleets to gather operational data, and to perform engine maintenance and repair tasks as necessary during the field demonstration.

Thank you for inviting Cummins Cal Pacific to partner with Cummins Westport for this important project. I look forward to commencing the field demonstration program.

Sincerely,

Jonathan Evans
Cummins Cal Pacific
Vice President – Sales and Marketing
1939 Deere Avenue
Irvine, CA 92688

Cummins Cal Pacific, LLC
1939 Deere Avenue
Irvine, California 92606
949 253 6000
www.CumminsCalPacific.com

Service Center Locations

Inland Empire	3061 S. Riverside Ave. Bloomington, CA 92316	800 653 4373
Los Angeles	9520 Stewart & Gray Rd. Downey, CA 90241	866 934 4373
Orange County	1939 Deere Ave. Irvine, CA 92606	800 746 5757
San Diego	310 N. Johnson Ave. El Cajon, CA 92020	800 993 4373
Ventura	3958 Transport Street, Ventura CA 93003	800 881 1159

Follow us: Facebook.com/CumminsCalPac Twitter.com/CumminsCalPac

AUTOCAR

Mr. Scott Baker
Director, Product & Market Planning
Cummins Westport Inc.
101-1750 W. 75th Ave
Vancouver BC V6P 6G2

Dear Mr. Baker:

This letter confirms Autocar's support for Cummins Westport's proposed ultra-low NOx ISL G pre-commercial development and demonstration program.

Autocar, LLC, headquartered in Hagerstown, Indiana, is a manufacturer and marketer of Low Cab Forward Class 8 trucks for use in refuse collection and other vocational applications. Our customers include municipalities, fleets, and private haulers, nationwide and abroad. With a steady stream of innovations to our Xpeditor line, Autocar has staked out a position as the industry's technology and innovation leader. Autocar currently offers the Cummins Westport ISL G natural gas engine in the Xpeditor and Xspotter models, and also offers the Cummins Westport ISX12 G natural gas engine in the Xpeditor product line.

Autocar recognizes the importance of continuing to develop natural gas engines to further reduce exhaust emissions and to maximize fuel efficiency in order to provide cost-effective, environmentally sound products to our customers. While Autocar understands that Cummins Westport's proposed ultra-low NOx ISL G development and demonstration program is pre-commercial in nature, Autocar anticipates future commercial availability of the resulting engine and catalyst technologies. Autocar intends to work collaboratively with Cummins Westport during the vehicle integration phase to provide engine and catalyst design feedback as well as to provide guidance related to vehicle integration.

I look forward to continuing the long-standing collaborative relationship between Autocar and Cummins Westport, and expanding natural gas usage in the refuse collection market via further development and optimization of Cummins Westport's ISL G engine.

Sincerely,

James M. Johnston
President - Autocar, LLC
jjohnston@autocartruck.com
Office: 765-489-6060
Mobile: 765-994-5650
Assistant: 765-489-1920
jjohnston@autocartruck.com

WASTE MANAGEMENT

Fleet Excellence

Waste Management
Marty Tufte
Corporate Fleet Director
623.879.7614 Office
952.412.8279 Cell

July 15, 2013

Mr. Scott Baker
Director, Product & Market Planning
Cummins Westport Inc.
101-1750 W. 75th Ave
Vancouver BC V6P 6G2

Dear Mr. Baker:

This letter confirms Waste Management's intent to demonstrate Cummins Westport's proposed near-zero NOx ISL G natural gas engine system in a refuse collection truck as part of Cummins Westport's proposed near-zero NOx engine development and demonstration program. Waste Management understands that Cummins Westport intends to further develop the ISL G engine with an objective of achieving 0.02 g/bhp-hr NOx emissions, and that Cummins Westport intends to demonstrate the resulting, pre-production, near-zero NOx engine system in a variety of heavy-duty commercial vehicle applications in the South Coast Air Basin.

Waste Management is the largest environmental solutions provider in North America, serving more than 20 million customers in the U.S., Canada and Puerto Rico. As part of our strategy, we are committed to developing new waste solutions that can help communities and organizations achieve their green goals. To this end, Waste Management is committed to operating a significant portion of our heavy duty vehicle fleet with natural gas engines. Waste Management currently operates more than 2000 natural gas powered refuse collection trucks throughout North America, including numerous locations operating ISL G-powered trucks within the South Coast and San Joaquin Valley Air Basins.

Waste Management anticipates operating one refuse collection truck powered by the near-zero NOx ISL G engine in revenue service in our southern California operations, for a period of approximately 12 months. During the field demonstration period, we understand that the vehicle may be used temporarily for chassis dynamometer emission testing.

Thank you for inviting Waste Management to partner with Cummins Westport for this important project. I look forward to commencing the field demonstration program and continuing our support of the SCAQMD natural gas efforts.

Sincerely,

Marty Tufte

ADVANCED TRANSIT VEHICLE CONSORTIUM

Los Angeles County Metropolitan Transportation Authority
470 Bauchet Street, MS 30-2-1
Los Angeles, CA 90012

JUNE 17, 2013

Mr. Scott Baker
Director, Product & Market Planning
Cummins Westport Inc.
101-1750 W. 75th Ave
Vancouver BC V6P 6G2

Dear Mr. Baker:

This letter confirms that the Advanced Transit Vehicle Consortium (ATVC) and Los Angeles County Metropolitan Transportation Authority (Metro) support Cummins-Westport's proposed program to develop a future lower emission or "*Near-zero emission*" ISL G engine.

Metro understands that Cummins Westport proposes to further develop and test an advanced ISL G engine with an objective of achieving 0.02 g/bhp-hr or less NOx emissions, and that Cummins Westport intends to demonstrate the resulting, pre-production, near-zero NOx engine system in a variety of heavy-duty commercial vehicle applications in the South Coast Air Basin. Metro recognizes that there would be potential emission and air quality benefits if such an engine were developed and ultimately commercialized.

Metro operates one of the cleanest transit fleets in the world, and currently operates 100% natural gas powered vehicles in its bus fleet (over 2,300 CNG buses). In addition to achieving cleaner air and reduced greenhouse gases, natural gas has proven to be a lower cost alternative to diesel fuel for Metro's bus fleet.

Sincerely,

John Drayton
Executive Vice President

RE: Low NOx ISL G field test
Marko, Ken {FLNA}
to:
scott.baker@cummins.com
12/07/2013 03:27 PM
Cc:
"jim.c.harmon@cummins.com"
Hide Details
From: "Marko, Ken {FLNA}" <ken.marko@pepsico.com>

To: "scott.baker@cummins.com" <scott.baker@cummins.com>

Cc: "jim.c.harmon@cummins.com" <jim.c.harmon@cummins.com>

History: This message has been replied to.

Frito Lay is interested but it may be a challenge to get you a signed copy of the letter by today.

Ken Marko
Senior Fleet Engineer
972-334-5120 (office)
940-597-7508 (cell)
ken.marko@pepsico.com

From: scott.baker@cummins.com [mailto:scott.baker@cummins.com]
Sent: Wednesday, July 03, 2013 4:08 PM
To: Marko, Ken {FLNA}
Cc: jim.c.harmon@cummins.com
Subject: Low NOx ISL G field test

Hi Ken,

As a follow-up to my lengthy voicemail, would Pepsi / FritoLay be interested in field testing an ISL G truck / tractor in southern California with ultra-low NOx emissions, and potentially some other technology improvements aimed at improving the thermal efficiency of the engine? Cummins Westport is pursuing some development and demonstration funding from the South Coast air district in response to their recent RFP targeting natural gas engines with 0.02 g/bhp-hr NOx. If CWI's application is successful, then the ISL G engine development work will be conducted in 2014 & 2015, with field testing in the South Coast air basin in the 2015-16 timeframe. While this is a few years away, we need to submit our application by mid-July and are required to identify prospective field test partners in the application.

If this of potential interest to you, then I would like to get a letter of support from you that I could append to Cummins Westport's funding proposal. Attached is a draft letter that we've used with other customers for this type of project in the past. Signing this letter would not obligate Pepsi / FritoLay in any way. If this project moves ahead and if Frito Lay remained interested in field testing the next-generation ISL G engine, then we would need to establish a formal field test agreement in the future (2015) specifying the logistics, costs and responsibilities of a field test. This process and field test agreement would be very similar to the standard Cummins field test agreement that you may be familiar with from prior projects. At a high level, I expect the terms to be as follows:

- FritoLay to identify an existing ISL G-powered truck
- CWI to pay for Cummins Cal Pacific to repower the truck with a new engine and catalyst incorporating the advanced technologies.
- FritoLay to operate the truck for up to one year in revenue service in the South Coast Air Basin. FritoLay to pay for all normal operating & maintenance expenses. CWI to pay for failures of any of the non-production engine and/or catalyst hardware.
- CWI and/or AQMD to pay for chassis dyno emission testing of the field test vehicle at some point during the field test period. The vehicle would not be available to the fleet during this time (approx. one week).
- At the conclusion of the test, CWI to pay for Cummins Cal Pacific to return the vehicle to its pre-test condition. This assumes that CWI will not have completed product development and emission certification of the 0.02 g/bhp-hr NOx product by the conclusion of the field test. If CWI has included the near-zero NOx engine in its product line by 2016, then there may be an option to upgrade the engine system to a production-equivalent, emission certified configuration.

If you have questions, then please don't hesitate to contact me. If you're willing to sign the field test letter, then please edit the attached to your satisfaction, print it on corporate letterhead, and email a signed copy to me by July 12. Alternatively, if you're not interested or are unable to provide a signed letter on short notice, then please let me know that ASAP so that we can pursue other potential demonstration fleets.

Thanks,

Scott Baker
Director - Product & Market Planning
Cummins Westport Inc.
(604) 718-2025

APPENDIX B

RESUMES

Comprehensive Resume

Name: Scott Baize	Cummins Inc. P.O. Box 3005 Columbus, Indiana 47202
Title: Combustion/Performance/Emissions Manager	
Phone Number: 317-506-7358	
E-mail Address: scott.baize@cummins.com	

Summary (one paragraph about technical experience):

Mr. Baize oversees the group responsible for combustion, performance and emissions development for all Cummins Westport Inc. Alternative Fuels Engines. His group is responsible for new product development as well as current product support. The range of engines supported covers 130 to 400 hp in B, C and L series with NG, LPG and Hythane fuels. Mr. Baize has been working in Alternative Fuels engine development area for over eleven years and has personally been responsible for the emissions development and certification of the ISL G and ISX12 G stoichiometric engines. The ISL G engine was the first heavy duty automotive engine to be certified to EPA 2010 emissions levels in early 2007. In addition to leading the C/P/E team, he has spent the past 1.5 years as the program leader for the ISC G Euro V engine development program that will launch at the end of 2013. He has completed a Design for Six Sigma project for fuel economy improvement that was applied to the ISL G engine with 5% improvement in fuel consumption. Mr. Baize is the principal inventor of two patents related to turbocharger speed protection. Mr. Baize received both a B.S. and a M.S. degree in Mechanical Engineering from Purdue University-West Lafayette Indiana.

Education:

University	Degree	Area of Specialization	Year
Purdue University – West Lafayette, Indiana	MSME	Controls & Vehicle dynamics	2005
Purdue University – West Lafayette, Indiana	BSME	Mechanical Engineering	2002

Positions:

Cummins Westport Inc – Columbus, Indiana, Technical Project Leader (2012 – Present)
Manage the ISC G Euro V engine development program. Design, develop, test, and launch a lean burn ISC G engine meeting Euro V emissions and OBD regulations.

Cummins Westport Inc- Columbus, Indiana, C/P/E Group Leader (2007 - Present)
Oversees the group responsible for combustion, performance and emissions development for all Cummins Westport Inc. Alternative Fuels Engines for automotive applications. This group is responsible for new product development and current product support.

Cummins Westport Inc- Columbus, Indiana, C/P/E Engineer (2002-2007)
Experience includes emissions transparency testing, emissions development, transient performance testing and development, controls algorithm development, turbocharger matching, 2 turbocharger speed limiting patents, knock detection calibration, combustion recipe development, design for six sigma, vehicle dynamics, automatic transmission matching

Delphi Automotive, Flint, Michigan, Engineer Co-op (2000-2001)
Experience in fuel systems group and catalyst development group

Other Positions:

Metalworking Lubricants, Indianapolis, Indiana, Lab Technician, Co-op, 2 years

Professional Affiliations:

Former member of SAE and ASME

Comprehensive Resume

Name: Stephen S. Abedian	Cummins Inc. P.O. Box 3005 Columbus, Indiana 47202
Title: Director, Control & Ignition Systems	
Phone Number: 812-377-4924	
E-mail Address: s.abedian@cummins.com	

Summary (one paragraph about technical experience):

Mr. Abedian is a functional team manager overseeing the work of four groups developing, releasing and supporting Alternative fuels engines for Cummins-Westport JV company. He joined Cummins in 1991 and has since worked on Alternative fuels engines as a project engineer, Controls team leader, and since 2006 as the functional lead for C/P/E, Controls, Ignition and Mechanical development teams. His first experience with alternative power sources was on a solar powered Stirling engine project at Cummins, which he was a technical project manager. Cummins later sold this business and started on the development of NG and LPG powered engines which he joined the electronics team in 1993 as a project manager. Since then he has been a member of a technical team that has designed and released over 10 engines in the B, C, and L series automotive and K series for HHP applications.

Mr. Abedian has previously worked at Bendix (currently Honeywell) for seven years as hardware design engineer in charge of design and development of digital electronic controllers for military applications, and later as project engineer on the development of the electronic controllers for the M1A1 Military tank. Prior to that he worked at the University of Michigan Space Physics Research Lab as an engineer on a project to explore and identify the composition of various gasses present in the auroras (Northern Lights). In 1979 Mr. Abedian received his B.S. degree in Electrical Engineering from The University of Michigan in Ann Arbor, Michigan and in 1980 his B.S. in Computer Engineering. He also holds a minor degree in Aerospace Engineering.

Education:

University	Degree	Area of Specialization	Year
The University of Michigan, Ann Arbor	BSEE	Digital Electronic Design	1979
The University of Michigan, Ann Arbor	BSCE	Computer hardware design	1980

Positions:

Cummins Inc. Columbus Indiana – Director, Engineering Functional Lead (2007- Present)
Functional lead engineer for Controls, C/P/E, Ignition and Mechanical development team. As part of the Cummins-Westport Joint Venture company, the team designs, develops and releases Alternative Fuels Engines for on highway applications.

Cummins Inc. Columbus Indiana – Electronic Controls Lead Engineer (1991- 2007)
Lead the Electronics Controls team in development and release of software, electronic modules, and calibrations for solar powered Stirling engines, and later for Alternative Fuels Engines for on highway and HHP-Gen set applications. Managed the design, development and release of all the Electronic Controllers for B,C,L and K series engines.

Bendix (currently Honeywell) company. South Bend, Indiana – Electronic Engineer/Project manager (1984- 2001)
Designed and developed Electronic Engine controllers for military applications. Project manager for the electronic controls on the M1A1 military tank.

The University of Michigan Space Physics Research Lab. Ann Arbor, Michigan – Engineer (1979- 1984)
Member of a research team in charge of the design and development of instruments to measure gas composition in Auroras (Northern Lights).

Comprehensive Resume

Name: Aaron Homoya
Title: Control Systems Group Leader
Phone Number: 812-377-0766
E-mail Address: aaron.homoya@cummins.com

Cummins Inc.
P.O. Box 3005
Columbus, Indiana 47202

Summary (one paragraph about technical experience):

Mr. Homoya leads the group responsible for control systems development for all Cummins-Westport Inc. alternative fuels engines. His group is responsible for new product development, current product support and new technology research. Mr. Homoya joined Cummins-Westport Inc. in 2006 and has been part of the development of the ISL G, ISB5.9 G and ISX12 G engines. As Group Leader, Mr. Homoya oversaw Euro V OBD development and certification of the ISL G and ISB5.9. He is Six Sigma trained and has completed projects on gas flow control robustness and exhaust temperature protection.

Mr. Homoya received a B.S. in Electrical Engineering from Arizona State University and a M.S. degree in Electrical Engineering from Stanford University.

Education:

University	Degree	Area of Specialization	Year
Stanford University - Palo Alto, California	MSEE	Controls & Semiconductor Optics	2006
Arizona State University - Tempe, Arizona	BSEE	Electrical Engineering	2004

Positions:

Cummins Westport Inc- Columbus, Indiana, Control Systems Group Leader (2010 - Present)
Leads the group responsible for control systems development for all Cummins Westport Inc. engines. This group is responsible for new product development, current product support, and new technology research. Responsibilities include diagnostic system development and certification, sensor and actuator system integration, algorithm design and testing and calibration development, testing and integration. Lead control system team development for the ISX12 G program.

Cummins Westport Inc- Columbus, Indiana, Control Systems Engineer (2006-2010)
Designed and calibrated engine control systems include vehicle dynamic controls, fuel system, air handling and emissions controls and system diagnostics. Tested and integrated sensors and actuators.

Other Positions:

Willoughby Industries, Indianapolis, Indiana, Electronics Engineer Intern, 2 years

Professional Affiliations:

Former member of IEEE

Timothy R. Frazier, PhD

Cummins Inc.,
1900 McKinley Avenue
Columbus, IN 47201
tim.r.frazier@cummins.com
812-377-6174

Work History

Director of Engineering and Chief Engineer, Cummins Westport

(2013 – Present): Responsible for all engineering activities associated with the Cummins Westport (CWI) product line of natural gas engines. Engineering activities include current product support, new product and technology development, and engineering functional excellence development. CWI current product support maintains both domestic and broad international sales of 5.9L, 8.3L, 8.9L, and 11.9L spark ignited natural gas engines. Annual budget for engineering tasks is approximately $25M.

Director, Advanced Component Integration, Cummins Inc.

(2012 – 2013): Led an initiative to enable systems integration sales of CMI components to a global customer base. Designed a flexible and efficient system integration framework that can be developed centrally and implemented in a distributed fashion. Created system integration rules and tools to support integration of CMI components without compromising optimality or IP protection. Developed a prototype engine control module structure (hardware, software, and controls topology) which provides agility, rapid response, and robust performance to a dynamic customer base. Aligned the CMI component PPT engineering efforts to meet around the critical market gaps.

Director, Advanced Performance and Systems Integration, Cummins Inc. (2007-2012): Led an organization of 58 engineers responsible for the performance development of next generation Cummins powertrain solutions. Team has delivered the technology recommendations to most Class 1 VPI since 2004. This included product ranging from light duty to high horsepower, on-road and off-road, as well as diesel and alternate fuel concepts. Specific tasks include research and development of advanced combustion and air handling strategies for low emissions and high efficiency, research and development in next generation emissions aftertreatment solutions, research and optimization of hybrid powertrain solutions and vehicle integration.

Led an organization which was responsible for the development of static and dynamic models used in analysis-led design efforts and controls optimization. The organization also owned the development of advanced statistical tools for calibration optimization, embedded models and adaptive feedback. Responsibilities also include company-wide ownership of performance development workflow and training, calibration tools, and engine performance Engineering Standard Work (ESW). This role is recognized as a leader in the application of Six Sigma tools and processes in the area of technology development, as well as financial modeling to access customer total cost of ownership and company net present value analyses. This requires cross business unit analyses, including input from the subcomponent level through the integrated vehicle.

Technical Advisor Advanced Systems Integration, Cummins Inc. (2004- 2007): Created and led an organization of 15 engineers responsible for integrated performance of the 2010 automotive and 2011 non-road applications.

Technical Project Leader for Cummins Westport High Horse Power Product, Cummins Inc. (2003-2004): Program leader of an advanced technology natural gas power generation program targeting high efficiency and ultra low emissions by through that application of advanced homogeneous charge compression ignition (HCCI) strategies.

Performance Leader for Cummins Westport High Horse Power Product, Cummins Inc. (2001-2003): Responsible for the development, calibration and transient validation of HCCI solutions for high efficiency and ultra low emissions.

Senior Engineer for Advanced Combustion Research, Cummins Inc. (1999-2001): Responsible for engine testing, analysis, architecting, sensor development, and control development for both diesel and natural gas HCCI combustion

Engineering Intern Systems Engineering, Ford Motor Company (1995): Supported systems engineering analysis on the Taurus SHO alpha engine development program.

Education

2000, Ph.D., Mechanical Engineering, University of Illinois @ Urbana-Champaign

Thesis Title: Quantifying the Level of Reactant Unmixedness and Analyzing Its Impact Upon Combustion in a Lean Premixed Gas Turbine Combustor Using Production-Like Premixer Hardware

1997, M.S., Mechanical Engineering, University of Illinois @ Urbana-Champaign

Thesis Title: Development and Comparison of One and Two-zone Heat Release Models for Combustion Diagnostics and Knock Analysis

1992, B.S., Mechanical Engineering, University of Illinois @ Urbana-Champaign

Comprehensive Resume

Name: Mostafa M Kamel	Cummins Inc, Advanced Product Development 1900 Mckinley Avenue Columbus, IN 47201
Title: Director, Advanced Engine Systems	
Phone Number: 812-377-7253	
E-mail Address: mostafa.m.kamel@cummins.com	

Summary (one paragraph about technical experience):

Dr. Kamel has been involved with engine performance and product development at Cummins for over 32 years. For the last 15 years, he has had leadership responsibility for Product Development of automotive alternative fuels engine development at Cummins. These products have leading edge technology and are dominant in this emerging market. Some of the work in both diesel and gas engine development is published in several technical journals and he has been awarded several US and international patents.

Education:

University	Degree	Area of Specialization	Year
Cairo University	BS	Mechanical Engineering	1970
University of London	MS	Mechanical Engineering	1973
University of London	Ph.D.	Mechanical Engineering	1977

Positions:

Currently has responsibility for directing the development of next generation technologies for Automotive Natural Gas Engines leading to lower emissions, increased fuel economy and reduced systems cost.

Cummins Inc & Cummins Westport Inc, Alt. Fuels Product Development, Director, 15 years
Leadership responsibility for product development of alternative fuels engines for use in Automotive markets. Responsibility included current product support, reliability improvements and new product development. Work cross-functionally to develop and support products and with external organizations for program management. Program launch responsibilities through leadership of a crossfunctional new product introduction team.

Cummins Inc, Alt. Fuels Product Development, Manager/Chief Engineer, 7 years
Technical leadership responsibilities for the development of state-of-the-art electronic controlled engines for automotive use fueled by natural gas and propane fuels. Also responsible for product launch and customer support.

Cummins Inc, K19 Gas Product Development, Assistant Chief Engineer, 1 year
Technical leadership responsibilities for the design and development of an advanced technology electronically controlled natural gas engine for Genset applications.

Cummins Inc, KH38 Engine Development, Group Leader/Assistant Chief Engineer, 5 years
Development of a very high BMEP 38 liter engine for Industrial, Powergen, and Marine use. Responsibilities included customer engineering support, technology evaluation, power cylinder and performance development.

Company Inc, Performance Development, Department, Sr. Engineer/Group Leader, 5 years
Performance development support for Automotive and Industrial diesel engines. Work elements included cycle simulation, thermodynamic analysis, combustion system development, turbocharging, cooling system and overall engine rating development.

Research Fellow, University of London, 1 year
Responsible for computerization of the engine test lab including computer system layout and software development.

Other Positions:

Research Assistant, Cairo University, 2 years
Research in Internal combustion engines and lecture assistant in machine design courses in the Mechanical Engineering Department.

Professional Affiliations: Associations: Member SAE Patents: Three US patents Awards: SAE's Arch T Colwell merit award Thesis: "Thermodynamic Analysis of an Indirect Injection Diesel Engine", 1977
Other Useful Information: Languages: English & Arabic Publication: Several SAE and technical journal technical papers in the fields of: thermodynamics, heat transfer, engine performance and natural gas engine development.