Grant 06-08

DEVELOPMENT, DEMONSTRATION & COMMERCIALIZATION OF A 0.20 G/BHP-HR NOx NATURAL GAS ENGINE

FINAL REPORT

Conducted under a grant by the California Air Resources Board of the California Environmental Protection Agency

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Abstract

Cummins Westport commenced commercial production of the 8.9 liter ISL G natural gas engine in June, 2007, with ARB certification to the 2010 on-highway emission standard. The ISL G engine uses stoichiometric, cooled EGR, spark ignition (SESI) combustion technology in conjunction with a three way exhaust catalyst, a passive device which is highly effective at passive NOx conversion. The ISL G target markets at launch were transit buses and refuse collection trucks. Following ISL G launch, CWI and ARB executed ICAT Grant Agreement 06-08 to further develop & demonstrate the ISL G engine in medium duty truck applications, leading to factory availability from a major medium duty truck OEM. The scope of work included developing additional performance rating & hardware options to enable the ISL G engine to be installed in medium duty trucks, as well as enabling installation in a wide range of other commercial vehicle applications, including yard tractors, street sweepers, school buses, and shuttle buses. The project deliverable would be a version of the ISL G that is commercially available for use in medium duty trucks and the specialty vehicle applications identified above.

Cummins Westport has developed two additional ratings for the ISL G, and a new "low-mount" turbocharger option to enable ISL G integration in Freightliner's popular M2 truck model. These new options became commercially available in early 2009, and are in widespread commercial use by fleet customers. Pacific Gas & Electric has operated an ISL G-powered truck in its fleet operations for approximately 12 months. Freightliner has commercialized multiple ISL G-powered versions of its M2 truck. The OEM availability of ISL G-powered vehicles has expanded significantly during this ICAT project, and includes major vehicle manufacturers in each of the target market segments identified above.

Introduction

Cummins Westport Inc. (CWI), a joint venture company formed between Cummins Inc. and Westport Innovations Inc., is responsible for developing and commercializing advanced, low-emission, alternate fuel engines. Cummins Inc. is a global power leader comprised of complementary business units that design, manufacture, distribute and service engines and related technologies, including fuel systems, controls, air handling, filtration, emission solutions and electrical power generation systems. Westport Innovations Inc. is the leading developer of technologies that allow engines to operate on clean-burning fuels such as natural gas, hydrogen, and hydrogen-enriched natural gas (HCNG). CWI's sole mandate is to develop and commercialize low emission engines for medium and heavy duty applications. CWI develops and markets a range of high-performance low-emission engines for commercial vehicles, based on Cummins 5.9 liter through 8.9 liter engine platforms. CWI's engines are factory built as alternate fueled engines.

In June, 2007, CWI commenced commercial availability of a new 8.9 liter heavy-duty natural gas engine, following an extensive product development program which combined the low emission advantages of spark ignition, stoichiometric combustion and three way catalyst technology with the high torque, durability and efficiency enabled by cooled exhaust gas recirculation (EGR) systems. The resulting engine is the Cummins Westport ISL G, a dedicated natural gas engine based on the robust, proven, 8.9 liter ISL diesel engine manufactured by CWI parent company Cummins Inc. At launch in 2007, the ISL G engine was commercially available with features to suit installation and operation in transit buses and refuse collection trucks.

Following commercial launch of the ISL G engine, in mid 2007 CWI and ARB executed ICAT Grant Agreement 06-08. The objective of this ICAT project was to continue developing the ISL G engine to expand vehicle OEM availability and increase market penetration in other commercial vehicle market segments in California, North America, and around the world. This report is the final element of ICAT Grant Agreement 06-08.

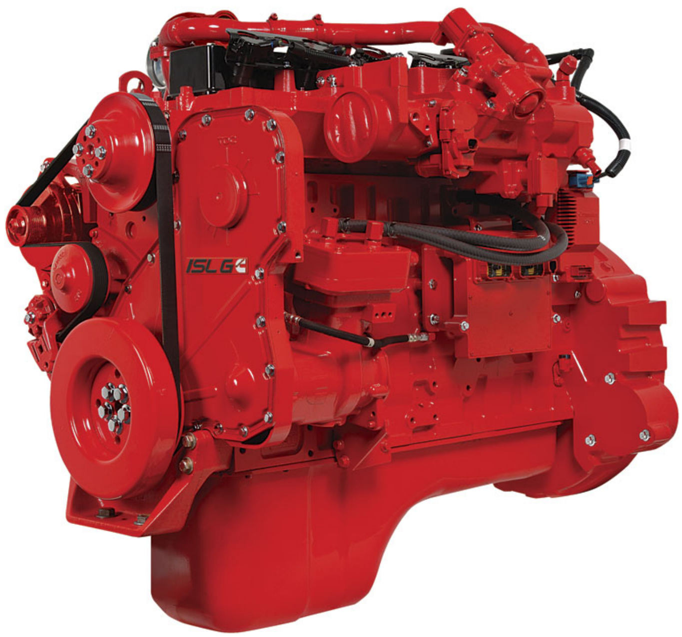


Figure 1 – ISL G Engine

Innovative Technology

The ISL G engine is based on a technology utilizing stoichiometric combustion, cooled EGR, spark ignition, and a three way catalyst. The stoichiometric, cooled EGR, spark ignition (SESI) technology, in conjunction with a three way catalyst (TWC), results in extremely low regulated emissions utilizing passive, maintenance free catalyst technology. CWI's SESI technology is significantly different than conventional stoichiometric combustion technology, which employs a three-way catalyst but does not use cooled EGR. SESI technology also differs from the lean-burn spark-ignited (LBSI) technology employed in CWI's prior generations of natural gas engines, which does not use cooled EGR and uses an oxidation catalyst rather than a three way catalyst due to the lean burn characteristics of the engine, and the associated excess oxygen content in the exhaust stream.

Early generation natural gas engines employed stoichiometric combustion concepts. Stoichiometric combustion offers low emissions potential when combined with three-way exhaust catalysts, due to the lack of excess oxygen in the exhaust stream, thus enabling very high NOx conversion rates in the three way catalyst. However, traditional stoichiometric engine technology has been limited by high in-cylinder temperatures, leading to very high engine out NOx emissions, knock limited power density, poor thermal efficiency and lower durability.

CWI's prior generations of natural gas engines utilized LBSI technology in order to provide a significantly improved combination of emissions, torque, durability and fuel economy vs. traditional stoichiometric engines. However, LBSI technology is generally unable to achieve NOx emissions lower than 1 g/bhp-hr without lean NOx aftertreatment (e.g. selective catalytic reduction, or lean NOx adsorbers), as further leaning of the air/fuel ratio mixtures to reduce NOx would result in ignition and combustion difficulties.

The introduction of cooled EGR to replace the excess charge air employed in an LBSI engine enables stoichiometric combustion conditions (and therefore oxygen-free exhaust) without incurring the performance limitations associated with conventional stoichiometric engines. Analysis and data show that a compelling combination of low emissions, increased power density and increased fuel efficiency is achieved by utilizing cooled EGR with a stoichiometric combustion principle, in combination with a TWC. Use of EGR technology for CWI's engines became feasible in recent years as the Cummins diesel engine platforms upon which CWI's engines are based implemented cooled EGR subsystems to meet emission regulations.

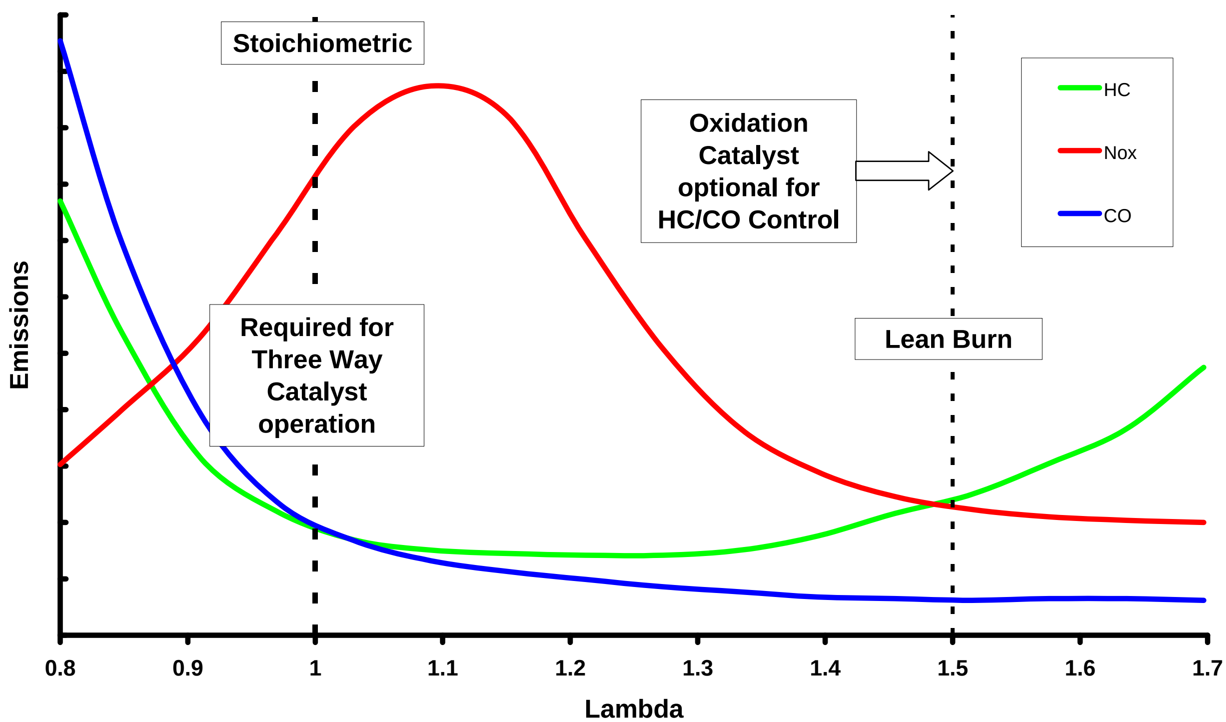


Figure 2 – Stoichiometric and Lean Burn Emissions vs. Air / Fuel Ratio (Lambda)

The ISL G engine, utilizing SESI technology, was certified to EPA and CARB 2010 on-highway emission standards at launch in 2007 utilizing passive, maintenance free three way catalyst aftertreatment. Appendix A shows the CARB Executive Order issued for the ISL G engine in August, 2007, and shows that all regulated emission constituents are below the applicable emission standards. In particular, the ISL G NOx emissions of 0.10 g/bhp-hr are 50% below the 2010 on-highway vehicle standard.

In addition to meeting or exceeding the 2010 on-highway standards for regulated emissions, the ISL G engine produces significantly lower greenhouse gas (GHG) emissions than comparable diesel engines. ISL G is capable of operating with biomethane in blends up to 100%. Per ARB's Low Carbon Fuel Standard analysis, CNG or LNG from conventional fuel pathways provides full fuel cycle GHG reductions of 12% to 28% in comparison with diesel fuel. CNG or LNG from renewable fuel pathways provides full fuel cycle GHG reductions of 70 to 88% vs. diesel fuel.

ICAT Project

Following commercial launch of the ISL G engine in June, 2007, CWI and ARB initiated this ICAT project to continue developing the ISL G engine to expand vehicle availability and increase market penetration. This additional product development was required in order to enable ISL G installation and operation in vehicle applications such as medium duty trucks, yard tractors, street sweepers, shuttle buses, and school buses. Due to the lower power requirements, different duty cycles, and typically smaller engine compartments in these vehicles, compared to transit buses and refuse collection trucks targeted at ISL G launch, there are different hardware and performance rating options required to satisfy the customer requirements in these markets. The purpose of this ICAT project was to support the development, demonstration and commercialization of these new options, in order to achieve broad OEM availability of the ISL G engine in the commercial vehicle market segments identified above.

Due to its large market size, CWI was particularly interested in developing the ISL G engine to enable OEM availability in the medium duty truck & tractor market. The original ICAT project plan was to work closely with one or more truck manufacturers to integrate the ISL G engine into their high volume medium duty truck product line. A medium duty truck fleet in California would operate an ISL G-powered vehicle for a demonstration period of up to one year. The deliverable from the ICAT project would be a version of the ISL G engine that is commercially available for use in medium duty truck applications, and that would be suited for additional medium- and heavy-duty vehicle applications such as yard tractors, street sweepers, shuttle buses, and school buses.

ICAT Grant Agreement 06-08 identifies the following technical tasks:

Task 1: Mechanical Development
The objective of this task was to design, validate, structure and release for commercial production a new, low mount turbocharger geometry, which will enable the ISL G engine to fit

within the engine bay of the popular Freightliner M2 truck, as well as other OEM vehicles. The work to be conducted within this task included: CAD modeling; selection of a new exhaust manifold (the turbocharger is connected to and supported by the exhaust manifold; therefore the spatial location of the turbocharger is dictated in part by the exhaust manifold geometry); thermal and vibration analysis and validation testing to ensure robust operation and durability of the new hardware combination; identifying and validating production suppliers for new components, and; releasing the new option into the Cummins customer specification system to enable engine orders.

Task 2: Combustion, Performance & Emission Development

The objective of this task was to develop, certify and release one new 250 hp rating to enable optimal performance, fuel economy and drive-train integration in the target market segments identified above. This task would demonstrate that the emissions associated with the new rating and the new turbocharger option are within the emission limits of the existing ISL G certification issued by ARB at ISL G launch. This task would involve extensive engine testing and calibration development in steady-state and transient engine dynamometer test cells at the Cummins Technical Center in Columbus, Indiana.

Task 3: Control System Development

The objective of this task was to tailor the ISL G control system and/or software as necessary to suit additional vehicle applications. The scope of work within this task was not expected to require control system hardware modifications (e.g. ECM, sensors, or wire harness), but if necessary, the scope of work would involve software development, validation, and commercial release.

Task 4: Vehicle Integration

The objective of this task was to work with a prominent, market leading manufacturer of medium duty trucks to integrate the ISL G engine into a high-volume truck model for factory production. Due to its market share leadership position, CWI's target OEM was Freightliner Trucks, and specifically Freightliner's M2 truck model. CWI intended to work closely with Freightliner to integrate the ISL G engine into the M2, resulting in factory availability of an ISL G-powered Freightliner M2 truck.

Task 5: Field Demonstration

The objective of this task was to demonstrate the new hardware & performance rating options in a California-based fleet, in order to generate awareness of and demand for the new ISL G-powered medium duty truck, as well as to gather data to quantify the performance of the engine and vehicle in this medium duty truck market. The intent was to operate the demonstration truck in a high-profile fleet for an extended period of time, up to 12 months.

Figure 3 – Freightliner M2 truck model configured with utility body

Actual Accomplishments

This section summarizes the work performed within each of the tasks.

Task 1: Mechanical Development

- CWI obtained CAD models for the Freightliner M2 truck engine bay. CAD modeling confirmed that the existing ISL G turbocharger interferes with Freightliner's air cleaner assembly. The air cleaner assembly interfaces with the air intake hardware, which is incorporated in the truck's hood; therefore, relocating the air cleaner assembly is not trivial. This confirmed that CWI must re-design the ISL G to offer a different exhaust manifold in order to relocate the turbocharger. This also required re-design of the piping (engine coolant, lubrication oil, air and exhaust connections) that interface with the turbocharger.
- CWI Engineering designed new components to enable a low-mount installation of the ISL G turbo-charger. The existing ISL G turbo-charger can be used, but the turbo compressor housing must be rotated to a different orientation to interface with the vehicle charge-air plumbing. The compressor housing cannot be rotated at CWI's engine manufacturing plant; therefore, the turbo-charger supplier must release a new part number and establish procedures to supply the turbo-charger with alternate geometry. CWI Engineering has determined that an existing exhaust manifold from the Cummins ISL diesel engine family can be used with the ISL G low mount turbo geometry.
- The prototype hardware was test-fitted on engines at the Cummins Technical Center and the ISL G engine manufacturing plant. While all the prototype hardware fit on the engine without interference or assembly concerns, an issue was identified regarding

insufficient access to a coolant tube for service procedures. As a result of this review, the coolant tube was re-designed and another fit-check performed.

- Flow rig testing was conducted to validate oil and coolant flow rates through the re-designed turbo plumbing, demonstrating that all results are within CWI's engineering specifications.
- Strain gage analysis indicated that maximum strains during engine operation were within acceptable limits.
- A Design Failure Modes and Effects Analysis (DFMEA) was completed for the prototype hardware. No issues were identified during this analysis.
- All hardware (exhaust manifold, turbo-charger, turbo-charger plumbing) was released into the Cummins specification systems, following cross-functional design reviews to validate that the component design and validation data meets Cummins Westport's engineering standards. See Figure 4 & Appendix C for details.

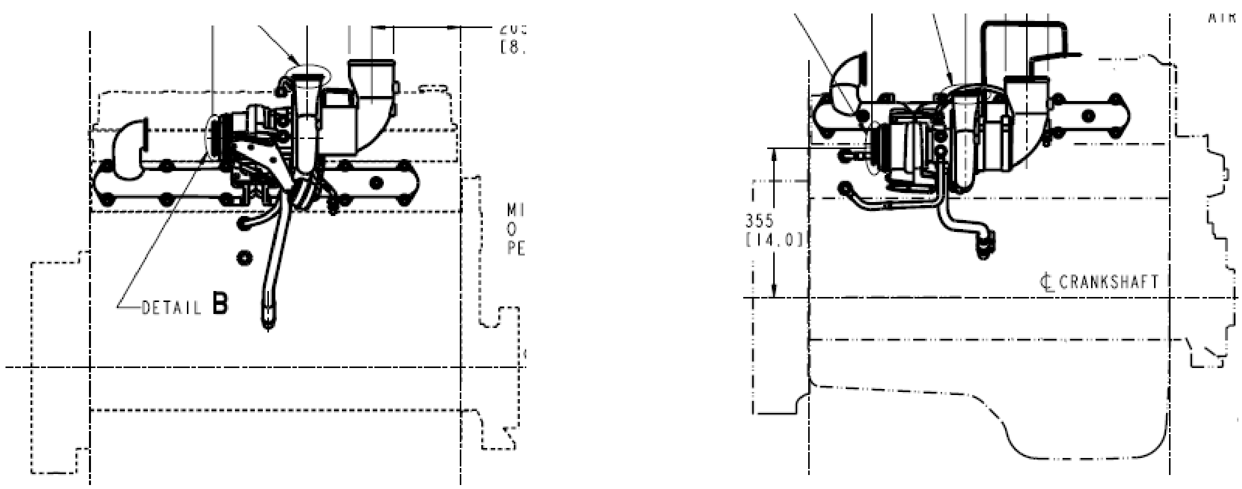


Figure 4 – New low-mount turbo (right) is lower and further rearward

Task 2: Combustion, Performance & Emissions Development

- New performance ratings were defined, as the result of extensive discussions with vehicle manufacturers in the target market segments, review of current and historical competing ratings (including diesel engines), and review of power/torque/speed limitations for driveline components most commonly used in the target vehicle applications (e.g. automatic and manual transmissions, rear axles). The result was a decision to develop two additional ISL G ratings, defined as 250 hp peak power, 730 lb-ft peak torque and 260 hp peak power, 660 lb-ft peak torque. The decision to offer two additional ratings, rather than one, was made in order to ensure the optimal engine/driveline compatibility for the new target market segments. This is a scope change from the original project proposal, in which CWI contemplated developing one new rating.
- Preliminary demonstration of the new ratings in a test laboratory. This provided a preliminary confirmation that the engine can meet the target peak power and torque levels while meeting the emission targets.

- Extensive additional rating development is required to ensure that the engine meets performance guidelines and emissions requirements throughout the operating range (e.g. charge air cooler inlet temperature limitations, max boost pressures, engine knock limits, steady state and transient emissions).
- CWI Engineering finalized the emissions validation work, which confirmed that the emissions with the new ISL G ratings are within the certification levels for the existing ISL G engine. At the conclusion of this testing, CWI submitted certification documents to EPA and ARB to add the new ratings to the ISL G emission certifications (see Appendix B).
- The new ratings were released into the Cummins engine specification system, enabling customers to order ISL G engines with the new ratings.

Task 3: Control System Development

- CWI monitored the vehicle integration progress throughout the project and determined that no control system development (i.e. no hardware changes and no unique software) was required in order to tailor the ISL G engine to suit medium duty trucks or the other commercial vehicle applications targeted within this project. Due to the extensive control system development conducted for the ISL G engine prior to commencing this ICAT project, no additional development work was required within this project. Therefore, no work was conducted within this Task.

Task 4: Vehicle Integration

- At the outset of the ICAT project, CWI initiated discussions with Daimler Trucks North America (DTNA) regarding offering the ISL G engine in DTNA's Freightliner brand, specifically the Freightliner M2, which is a very popular medium and heavy duty truck purchased by a wide range of fleet customers, including but not limited to pickup and delivery trucks, street sweepers, city tractors, and municipal/utility work trucks. Street sweepers and utility trucks are demonstrated, established markets for natural gas engines, while CWI views the other markets as key growth opportunities for natural gas engines sales.
- In late 2007, DTNA made a corporate decision not to offer the ISL G in the Freightliner M2 truck chassis. Rather, DTNA committed to offer the ISL G in one of the medium-heavy duty truck models within its Sterling brand. While the Sterling truck represented a new and potentially high growth vehicle application for CWI, utility and street sweeper customers that have demonstrated a demand for natural gas trucks in the past expressed concerns that the planned Sterling / ISL G product may not meet their needs due to size of the vehicle. Therefore, Cummins Westport continued to see the market need for a Freightliner M2 / ISL G product. In order to demonstrate the market demand, Cummins Westport and ARB's ICAT Grant Manager agreed to proceed with an aftermarket engine installation into a Freightliner M2 truck for the purpose of conducting a field demonstration.
- Cummins Westport began discussions with Complete Coach Works, a vehicle conversion specialist and aftermarket upfitter located in Riverside, California. Complete Coach Works has extensive experience with vehicle modifications and customized engine installations, including previous natural gas engine installations in Freightliner M2

trucks for Pacific Gas & Electric (PG&E), the intended field demonstration partner for this project. Complete Coach Works agreed to install the ISL G engine in the Freightliner M2.

- The engine / vehicle integration plan was for Complete Coach Works to take delivery of a Freightliner M2 truck without an engine, and to install the ISL G engine in the vehicle. PG&E would then send the truck to a commercial body builder for installation of the crew truck body, at which time a CNG fuel system would be installed.
- Cummins Westport ordered a new, factory built ISL G engine, to be built and delivered to Complete Coach Works with the existing, high mount turbo-charger. Separately, CWI Engineering provided one set of prototype low mount turbo hardware to upfit the engine with the low mount turbo option.
- PG&E delivered one new Freightliner M2 truck to Complete Coach Works (Riverside, CA). This was a new, factory built truck, without an engine.
- Complete Coach Works installed the ISL G engine in the Freightliner M2 truck, with the support of Cummins Cal Pacific, the Cummins distributor in southern California. Complete Coach Works conducted engine and vehicle performance testing on a chassis dynamometer at Cummins Cal Pacific. During this testing, the engine operated with 260 hp and 300 hp calibrations. Cooling system data was gathered to provide an informal assessment of the vehicle cooling system capability to accommodate the heat rejection rates (engine coolant and charge air) at each of these two ratings. Based on the data gathered, it appears that the Freightliner M2 cooling package is capable of cooling the ISL G 260 hp rating, and may be capable of meeting CWI's cooling system requirements for the ISL G 300 hp rating. In order to finalize the cooling system approval for both ratings, a formal cooling test, with more precise control of operating conditions and more accurate measurement of engine and ambient conditions, will be required in the future.
- The ISL G powered Freightliner M2 truck was publicly launched at the Alternative Fuels & Vehicles National Conference & Exposition, Las Vegas, NV, May 11 to 14, 2008. Complete Coach Works displayed and promoted the truck. Cummins Westport sales and marketing staff attended the conference to promote the ISL G engine to prospective customers.
- In mid 2008, Complete Coach Works delivered the truck to PG&E, in preparation for the vehicle demonstration per Task 5.
- In October, 2008 DTNA announced that it would discontinue its Sterling brand effective March, 2009. Coincident with this announcement, DTNA announced that it would continue to offer a natural gas truck by integrating ISL G in the Freightliner M2 as a factory-offered product, with little or no interruption in commercial availability of ISL G powered trucks from DTNA.
- This announcement occurred near the conclusion of the low-mount turbocharger development in Task 1. Because the low mount turbocharger design was complete and prototype hardware was available, CWI was able to very quickly provide DTNA with the low mount turbocharger hardware required for the M2 integration project.
- CWI worked with DTNA throughout the ISL G / M2 integration project, including formal cooling testing and other installation validation procedures in accordance with the Cummins Installation Quality Assurance (IQA) process.

- DTNA commenced production of factory-built ISL G-powered Freightliner M2s in mid 2009. Freightliner now offers the vehicle in a variety of configurations, including straight trucks and tractors, with CNG & LNG fuel storage options. See Figure 5, which shows an ISL G-powered Freightliner M2 tractor equipped with CNG cylinders.
- The ability to expedite the Sterling to Freightliner transition and minimize the interruption in ISL G truck availability from DTNA is directly attributable to the low mount turbocharger development completed within this ICAT project.
- As a result of unanticipated business decisions involving DTNA's Sterling and Freightliner brands, this ICAT project has resulted in two separate ISL G / M2 integration activities – the first via an aftermarket installation conducted by Complete Coach Works, and the second via a factory installation program conducted by DTNA.

Figure 5 – ISL G-powered Freightliner M2 tractor with equipped with CNG storage

Task 5: Field Demonstration

- Pacific Gas & Electric (PG&E) agreed to participate in this project as the field demonstration fleet. PG&E confirmed that the truck would be used as a "crew truck" in PG&E's fleet following the completion of Task 4.
- After receiving the truck from Complete Coach Works, PG&E delivered the truck to a commercial body builder to install the necessary crew truck body. The vehicle is configured as a 33,000 lb crew truck equipped to tow a 40,000 lb trailer. Following the crew truck body installation PG&E installed additional equipment to prepare the truck for revenue service in its fleet.
- In April, 2009, PG&E placed the truck into revenue service at its Concord, California operations.

- As of April, 2010, PG&E had accumulated more than 5000 miles of operation and 400 engine hours of revenue service with the ISL G truck. This mileage accumulation rate is consistent with data provided by PG&E for comparative diesel-powered crew trucks, which indicates mileage accumulation ranging from approximately 1000 to 2000 miles per quarter, or 4000 to 8000 miles per truck per year.
- Due to the nature of its operations, the ISL G demonstration truck is well suited to overnight, “slow-fill” refueling at PG&E’s Concord facility. For the majority of the demonstration period, the demonstration truck has refueled using the slow fill facility, which is unmetered. As a result, the demonstration program has not produced a comprehensive data set to quantify the fuel economy of the ISL G-powered truck in PG&E’s utility duty cycle.

Accomplishments vs. Goals

At the conclusion of the ICAT project, the original project goals have been met and in some cases exceeded. See Table 1 for further details. This has been achieved despite some unanticipated changes to the scope of work and the project schedule. Not only has Freightliner commenced factory-production of ISL G-powered M2 trucks and tractors, CWI has achieved ISL G availability in a wide range of commercial vehicle applications via most of the leading commercial vehicle manufacturers in the target market segments

Goal	Project Accomplishments
Design & develop a new "low-mount" turbo-charger option	Low mount turbocharger option TB91780 developed, validated, and released for commercial production in January, 2009.
Develop one new performance rating, nominally planned to be a 250 hp rating	Two new performance ratings developed (250 hp / 730 lb-ft and 260 hp / 660 lb-ft), added to EPA & ARB emission certification documentation, and released for commercial production in January, 2009.
Work with a prominent manufacturer of medium duty trucks to integrate ISL G into a high-volume truck model	Following DTNA's decision in October, 2008 to discontinue its Sterling brand and integrate the ISL G engine into the Freightliner M2 chassis, worked with DTNA to enable factory availability of ISL G-powered Freightliner M2 trucks. In 2009, Freightliner commenced factory production of ISL G-powered M2 models, configured as either straight trucks or tractors.
Install ISL G with new options in a Freightliner M2 truck and demonstrate at a California fleet	One ISL G engine installed in a Freightliner M2 truck by Complete Coach Works in 2008, and delivered to PG&E prior to Freightliner's decision to offer factory-built M2 trucks with ISL G. PG&E has operated the ISL G powered demonstration truck in fleet service since April, 2009. In addition to the PG&E demonstration, CWI has sold more than 400 ISL G-powered vehicles incorporating the new options in 2009 and 2010.
Expand OEM availability of ISL G, to enable natural gas engine sales in additional target market segments including medium duty truck, yard tractor, street sweeper, school bus, and shuttle bus	The ISL G engine is now commercially available from multiple leading vehicle manufacturers in each of the target market segments.

Table 1 – Summary of Project Accomplishments vs. Goals

Status of the Technology

The ISL G engine was commercially available prior to launching this ICAT project, but with limited market penetration in a limited number of commercial vehicle applications. The objective of this project was to develop new hardware and performance rating options to enable expanded OEM availability in a broad range of commercial vehicle applications.

The new ratings and hardware options developed during this program were released for commercial availability in January, 2009. During this time, these new options have been used by a variety of vehicle OEMs, and have directly enabled expanded usage of ISL G in Californian, North American, and global commercial transportation markets. In particular, during the ICAT project, the following North American commercial vehicle OEMs began offering ISL G powered vehicles:

- Medium Duty & Heavy Duty Trucks
    - Freightliner
    - Kenworth
    - Peterbilt
- Refuse Collection Trucks
    - Mack Trucks
- School Buses
    - Blue Bird
    - Thomas Built
- Street Sweepers
    - Elgin
    - Schwarze
- Yard Tractor
    - Capacity of Texas
    - Autocar

The ISL G hardware options and ratings developed during the ICAT project have directly enabled many of the new OEM offerings listed above. For example, the engine bay geometries of the vehicles offered by market share leaders Freightliner and Mack are such that the ISL G engine can only be installed using the low mount turbocharger option developed during this project. Similarly, yard tractors and street sweepers exclusively use lower ratings than were available with ISL G prior to this ICAT project. Many school bus applications are also expected to use the new, lower ratings developed during this project. OEM availability of ISL G has also expanded significantly in Europe and Asia during the ICAT project, with many of the overseas OEMs specifying the new options for their vehicles.

During the first 12 months following commercial availability of the new options developed during the ICAT project, CWI has received orders for more than 180 engines equipped with either the 250 hp or 260 hp rating, and has received orders for more than 400 engines equipped with the low-mount turbocharger option. While these order volumes represent a minority of the overall demand for ISL G engines, the new ratings have been instrumental in achieving OEM availability at many of the vehicle manufacturers identified above. As demand for natural gas engines continues to increase, the expanded OEM availability of ISL G-powered vehicles is anticipated to result in significantly more demand for vehicles equipped with the features developed, demonstrated, and commercialized via this ICAT project.

APPENDIX A
CARB EXECUTIVE ORDER (August, 2007)

This is the Executive Order issued by ARB shortly after ISL G commercial launch in 2007, prior to the ICAT project. Note that the Executive Order identifies two ratings for the ISL G engine at launch: 300 & 320 hp.

California Environmental Protection Agency AIR RESOURCES BOARD	CUMMINS INC.	EXECUTIVE ORDER A-021-0456 New On-Road Heavy-Duty Engines

Pursuant to the authority vested in the Air Resources Board by Health and Safety Code Division 26, Part 5, Chapter 2; and pursuant to the authority vested in the undersigned by Health and Safety Code Sections 39515 and 39516 and Executive Order G-02-003;

IT IS ORDERED AND RESOLVED: The engine and emission control systems produced by the manufacturer are certified as described below for use in on-road motor vehicles with a manufacturer's GVWR over 14,000 pounds. Production engines shall be in all material respects the same as those for which certification is granted.

MODEL YEAR	ENGINE FAMILY	ENGINE SIZES (L)	FUEL TYPE [1]	STANDARDS & TEST PROCEDURE	INTENDED SERVICE CLASS [2]	ECS & SPECIAL FEATURES [3]
2008	8CEXH0540LBC	8.8	CNG/LNG	Diesel	MHDD	TBI, TC, CAC, ECM, EGR, TWC, HO2S

ENGINE (L)	ENGINE MODELS / CODES (rated power, in hp)
8.8	ISL G 320 / 0887;FR94242 (320), ISL G 300 / 0887;FR92104 (300)
*	*
*	*
*	*

* =not applicable; GVWR=gross vehicle weight rating; 13 CCR xyz=Title 13, California Code of Regulations, Section xyz; 40 CFR 86.abc=Title 40, Code of Federal Regulations, Section 86.abc; L=liter; hp=horsepower; kw=kilowatt;
1 CNG/LNG=compressed/liquefied natural gas; LPG=liquefied petroleum gas; E85=85% ethanol fuel; MF=multi fuel a.k.a. BF=bi fuel; DF=dual fuel; FF=flexible fuel;
2 L/M/H HDD=light/medium/heavy heavy-duty diesel; UB=urban bus; HDO=heavy duty Otto;
3 ECS=emission control system; TWC/OC=three-way/oxidizing catalyst; WU (prefix) =warm-up catalyst; DPF=diesel particulate filter; PTOX=periodic trap oxidizer; HO2S/O2S=heated/oxygen sensor; HAFS/AFS=heated/air-fuel-ratio sensor (a.k.a., universal or linear oxygen sensor); TBI=throttle body fuel injection; SFI/MPI=sequential/multi port fuel injection; DGI=direct gasoline injection; GCARB=gaseous carburetor; IDI/DDI=indirect/direct diesel injection; TC/SC=turbo/super charger; CAC=charge air cooler; EGR=exhaust gas recirculation; PAIR/AIR=pulsed/secondary air injection; SPL=smoke puff limiter; ECM/PCM=engine/powertrain control module; EM=engine modification; 2 (prefix)=parallel; (2) (suffix)=in series (2006DEC22)

Following are: 1) the FTP exhaust emission standards, or family emission limit(s) as applicable, under 13 CCR 1956.1 (urban bus) or 13 CCR 1956.8 (other than urban bus); 2) the EURO and NTE limits under the applicable California exhaust emission standards and test procedures for heavy-duty diesel engines and vehicles (Test Procedures); and 3) the corresponding certification levels, in g/bhp-hr, for this engine family. "Diesel" CO, EURO and NTE certification compliance may have been demonstrated by the manufacturer as provided under the applicable Test Procedures in lieu of testing. (For flexible- and dual-fueled engines, the CERT values in brackets [ ] are those when tested on conventional test fuel. For multi-fueled engines, the STD and CERT values for default operation permitted in 13 CCR 1956.1 or 13 CCR 1956.8 are in parentheses.)

	NMHC		NOx		NMHC+NOx		CO		PM		HCHO	
	FTP	EURO	FTP	EURO	FTP	EURO	FTP	EURO	FTP	EURO	FTP	EURO
STD	0.14	0.14	0.20	0.20	*	*	15.5	15.5	0.01	0.01	*	*
FEL	*	*			*	*	*	*	*	*	*	*
CERT	0.13	0.04	0.10	0.01	*	*	1.2	0.4	0.009	0.000	*	*
NTE	0.21		0.30		*		19.4		0.02		*	

* g/bhp-hr=grams per brake horsepower-hour; FTP=Federal Test Procedure; EURO=Euro III European Steady-State Cycle; NTE=Not-to-Exceed; STD=standard or emission test cap; FEL=family emission limit; CERT=certification level; NMHC/HC=non-methane/hydrocarbon; NOx=oxides of nitrogen; CO=carbon monoxide; PM=particulate matter; HCHO=formaldehyde;

BE IT FURTHER RESOLVED: Certification to the FEL(s) listed above, as applicable, is subject to the following terms, limitations and conditions. The FEL(s) is the emission level declared by the manufacturer and serves in lieu of an emission standard for certification purposes in any averaging, banking, or trading (ABT) programs. It will be used for determining compliance of any engine in this family and compliance with such ABT programs.

BE IT FURTHER RESOLVED: For the listed engine models the manufacturer has submitted the materials to demonstrate certification compliance with 13 CCR 1965 (emission control labels) and 13 CCR 2035 et seq. (emission control warranty).

Engines certified under this Executive Order must conform to all applicable California emission regulations.

The Bureau of Automotive Repair will be notified by copy of this Executive Order.

Executed at El Monte, California on this 23rd day of August 2007.

Annette Hebert, Chief
Mobile Source Operations Division

APPENDIX B
CARB EXECUTIVE ORDER (February, 2009)

This Executive Order was issued by ARB in February 2009, and includes the new 250 hp and 260 hp ISL G ratings developed within this ICAT project.

California Environmental Protection Agency AIR RESOURCES BOARD	CUMMINS INC.	EXECUTIVE ORDER A-021-0491 New On-Road Heavy-Duty Engines Page 1 of 1 Pages

Pursuant to the authority vested in the Air Resources Board by Health and Safety Code Division 26, Part 5, Chapter 2; and pursuant to the authority vested in the undersigned by Health and Safety Code Sections 39515 and 39516 and Executive Order G-02-003;

IT IS ORDERED AND RESOLVED: The engine and emission control systems produced by the manufacturer are certified as described below for use in on-road motor vehicles with a manufacturer's GVWR over 14,000 pounds. Production engines shall be in all material respects the same as those for which certification is granted.

MODEL YEAR	ENGINE FAMILY	ENGINE SIZES (L)	FUEL TYPE [1]	STANDARDS & TEST PROCEDURE	INTENDED SERVICE CLASS [2]	ECS & SPECIAL FEATURES [3]	DIAGNOSTIC [6]
2009	9CEXH0540LBC	8.9	CNG/LNG	Diesel	MHDD	TBI, TC, CAC, ECM, EGR, TWC, HO2S	N/A

PRIMARY ENGINE'S IDLE EMISSIONS CONTROL [5]	ADDITIONAL IDLE EMISSIONS CONTROL [5]
EXEMPT	N/A

ENGINE (L)	ENGINE MODELS / CODES (rated power, in hp)
8.9	ISL G 320 / 0887;FR92424 (320), ISL G 300 / 0887;FR92104 (300)
8.9	ISL G 280 / 0887;FR92738 (280), ISL G 260 / 0887;FR92739 (260), ISL G 250 / 0887;FR92847 (250)
*	*
*	*

* =not applicable; GVWR=gross vehicle weight rating; 13 CCR xyz=Title 13, California Code of Regulations, Section xyz; 40 CFR 86.abc=Title 40, Code of Federal Regulations, Section 86.abc; L=liter; hp=horsepower; kw=kilowatt; hr=hour;

[1] CNG/LNG=compressed/liquefied natural gas; LPG=liquefied petroleum gas; E85=85% ethanol fuel; MF=multi fuel a.k.a. BF=bi fuel; DF=dual fuel; FF=flexible fuel;

[2] L/M/H HDD=light/medium/heavy heavy-duty diesel; UB=urban bus; HDO=heavy duty Otto;

[3] ECS=emission control system; TWC/OC=three-way/oxidizing catalyst; NAC=NOx adsorption catalyst; SCR-U / SCR-N=selective catalytic reduction – urea / – ammonia; WU (prefix) =warm-up catalyst; DPF=diesel particulate filter; PTOX=periodic trap oxidizer; HO2S/O2S=heated/oxygen sensor; HAFS/AFS=heated/air-fuel-ratio sensor (a.k.a., universal or linear oxygen sensor); TBI=throttle body fuel injection; SFI/MFI=sequential/multi port fuel injection; DGI=direct gasoline injection; GCARB=gaseous carburetor; IDI/DDI=indirect/direct diesel injection; TC/SC=turbo/super charger; CAC=charge air cooler; EGR / EGR-C=exhaust gas recirculation / cooled EGR; PAIR/AIR=pulsed/secondary air injection; SPL=smoke puff limiter; ECM/PCM=engine/powertrain control module; EM=engine modification; 2 (prefix)=parallel; (2) (suffix)=in series;

[5] ESS=engine shutdown system (per 13 CCR 1956.8(a)(6)(A)(1)); 30g=30 g/hr NOx (per 13 CCR 1956.8(a)(6)(C)); APS =internal combustion auxiliary power system; ALT=alternative method (per 13 CCR 1956.8(a)(6)(D)); Exempt=exempted per 13 CCR 1956.8(a)(6)(B) or for CNG/LNG fuel systems; N/A=not applicable (e.g., Otto engines and vehicles);

[6] EMD=engine manufacturer diagnostic system (13 CCR 1971); OBD=on-board diagnostic system (13 CCR 1971.1);

Following are: 1) the FTP exhaust emission standards, or family emission limit(s) as applicable, under 13 CCR 1956.8; 2) the EURO and NTE limits under the applicable California exhaust emission standards and test procedures for heavy-duty diesel engines and vehicles (Test Procedures); and 3) the corresponding certification levels, for this engine family. "Diesel" CO, EURO and NTE certification compliance may have been demonstrated by the manufacturer as provided under the applicable Test Procedures in lieu of testing. (For flexible- and dual-fueled engines, the CERT values in brackets [ ] are those when tested on conventional test fuel. For multi-fueled engines, the STD and CERT values for default operation permitted in 13 CCR 1956.8 are in parentheses.).[4]

in g/bhp-hr	NMHC		NOx		NMHC+NOx		CO		PM		HCHO	
	FTP	EURO	FTP	EURO	FTP	EURO	FTP	EURO	FTP	EURO	FTP	EURO
STD	0.14	0.14	0.20	0.20	*	*	15.5	15.5	0.01	0.01	*	*
FEL	*	*			*	*	*	*	*	*	*	*
CERT	0.13	0.04	0.10	0.01	*	*	1.2	0.4	0.009	0.001	*	*
NTE	0.21		0.30		*		19.4		0.02		*	

[4] g/bhp-hr=grams per brake horsepower-hour; FTP=Federal Test Procedure; EURO=Euro III European Steady-State Cycle, including RMCSET=ramp mode cycle supplemental emissions testing; NTE=Not-to-Exceed; STD=standard or emission test cap; FEL=family emission limit; CERT=certification level; NMHC/HC=non-methane/hydrocarbon; NOx=oxides of nitrogen; CO=carbon monoxide; PM=particulate matter; HCHO=formaldehyde; (Rev.: 2007-02-26)

BE IT FURTHER RESOLVED: Certification to the FEL(s) listed above, as applicable, is subject to the following terms, limitations and conditions. The FEL(s) is the emission level declared by the manufacturer and serves in lieu of an emission standard for certification purposes in any averaging, banking, or trading (ABT) programs. It will be used for determining compliance of any engine in this family and compliance with such ABT programs.

BE IT FURTHER RESOLVED: For the listed engine models the manufacturer has submitted the materials to demonstrate certification compliance with 13 CCR 1965 (emission control labels) and 13 CCR 2035 et seq. (emission control warranty).

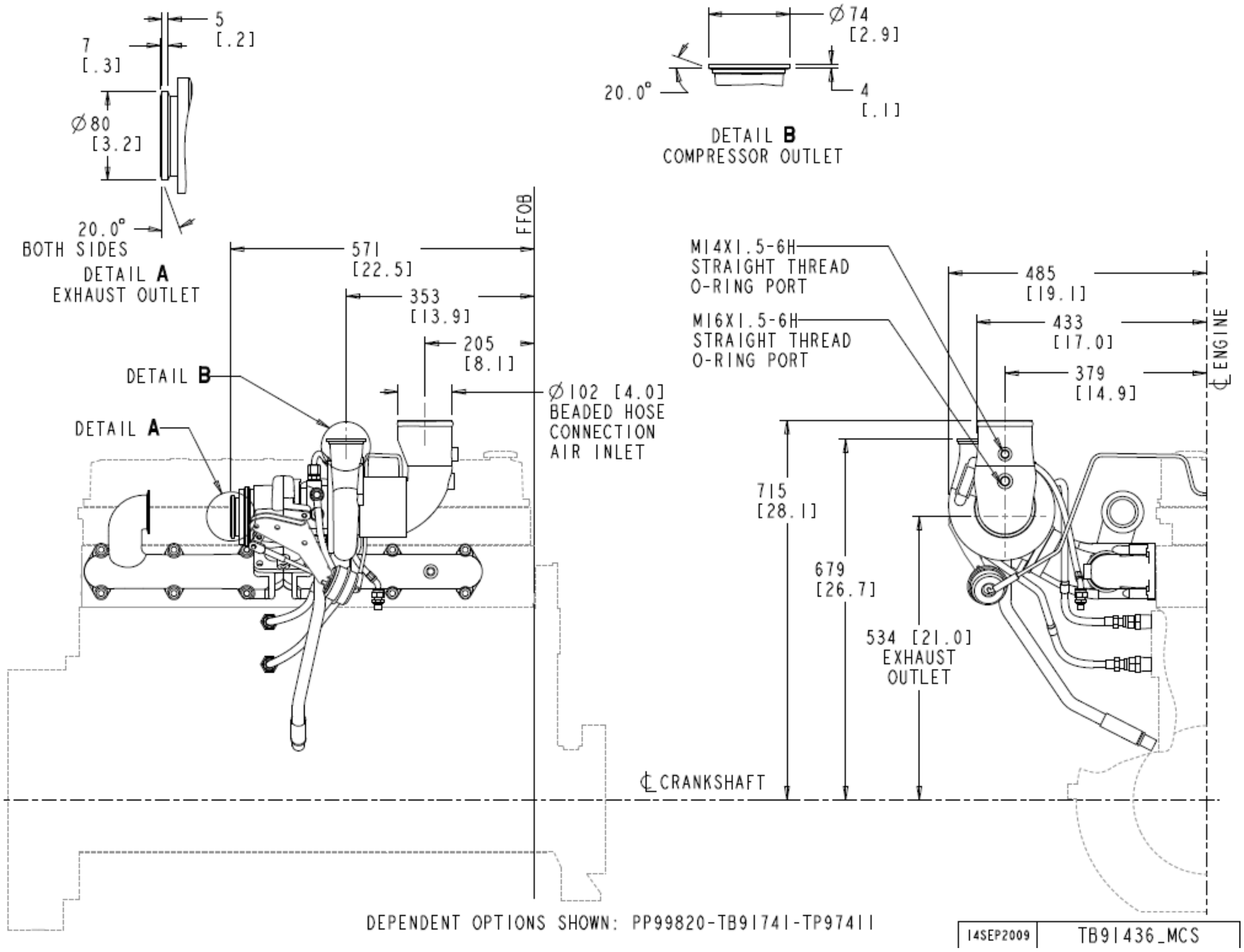
Engines certified under this Executive Order must conform to all applicable California emission regulations.

The Bureau of Automotive Repair will be notified by copy of this Executive Order.

Executed at El Monte, California on this 3 day of February 2009.

Annette Hebert, Chief
Mobile Source Operations Division

APPENDIX C
Turbo-Charger Option Graphics

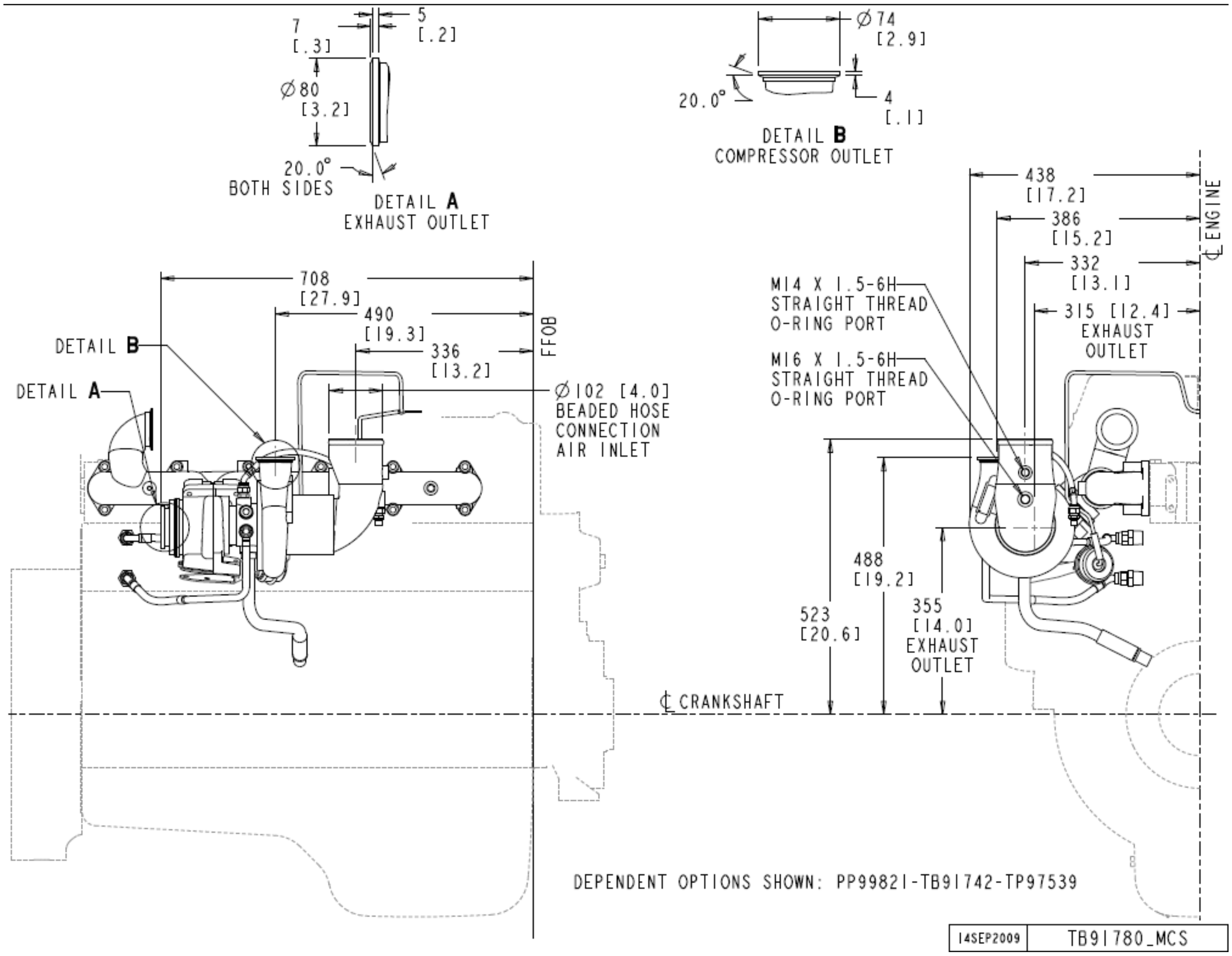


Elevation & Frontal Views of High Mount Turbocharger Option (TB91436)

The attached option graphic illustrates the content and geometry of the standard, high-mount turbocharger option available with ISL G prior to the ICAT project. The dashed lines illustrate a simplified engine outline in order to provide a spatial reference for the exhaust manifold and turbocharger hardware. Other engine options are intentionally excluded from this view.

To quantify the location differences between the high mount and low mount turbocharger options, consider the turbo-compressor outlet flange as a reference point (see Detail B above). The spatial location of the turbo-compressor outlet flange is:

- 679 mm above the crankshaft centerline
- 433 mm outboard of the engine centerline
- 353 mm rearward from the front face of the engine block (FFOB)



Elevation & Frontal Views of Low Mount Turbocharger Option (TB91780)

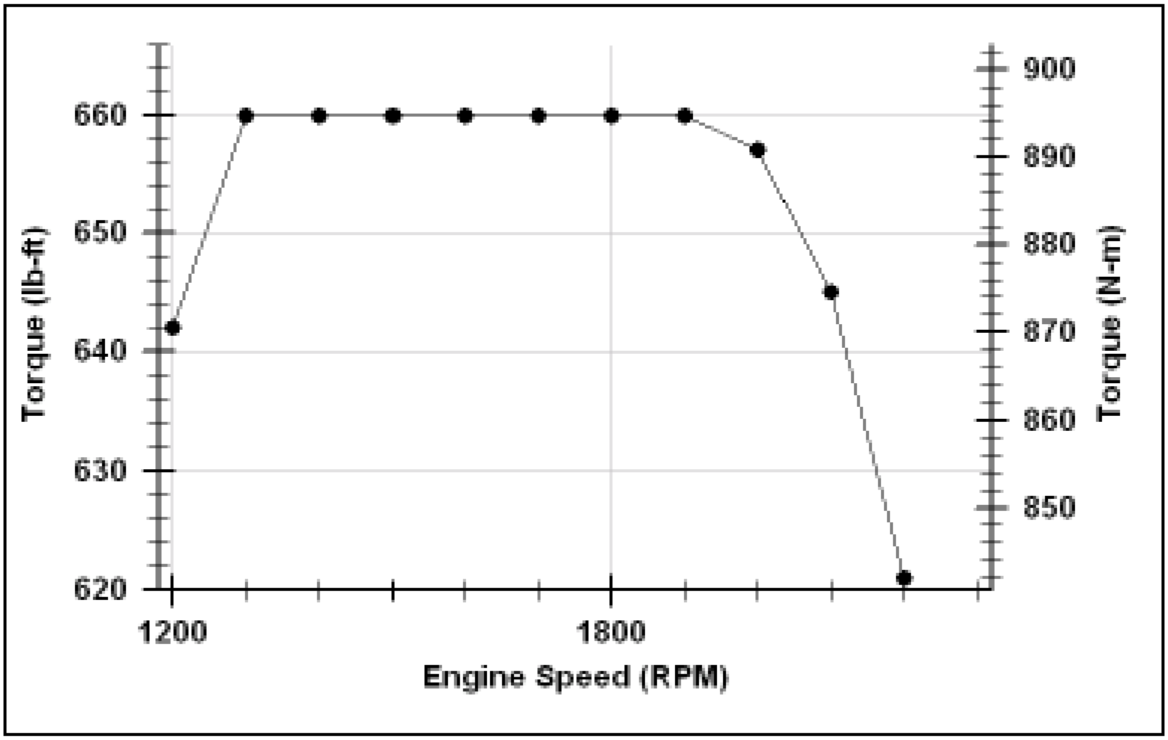
The spatial coordinates of the turbo-compressor outlet flange in the new, low mount turbocharger are as follows:

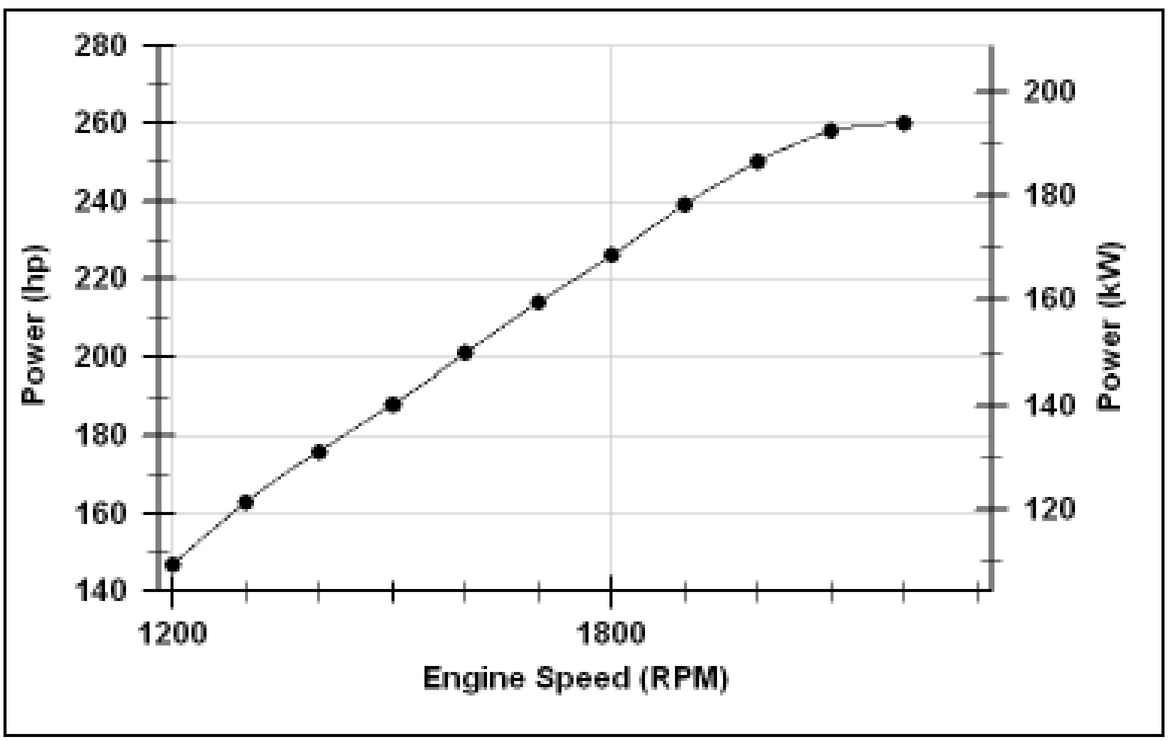
- 488 mm above the crankshaft centerline
- 386 mm outboard of the engine centerline
- 490 mm rearward from FFOB

Therefore, the new low mount turbocharger is located 191 mm lower, 47 mm inboard, and 137 mm rearward relative to the high mount turbocharger option.

APPENDIX D
POWER & TORQUE CURVES FOR NEW PERFORMANCE RATINGS

260 hp / 660 lb-ft:





250 hp / 730 lb-ft: