December 1998 • NREL/SR-540-25114

Subcontractor Report

Cummins Engine Company B5.9 Propane Engine Development, Certification, and Demonstration Project

February 1997 — June 1998

The ADEPT Group, Inc.
Los Angeles, California

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National Renewable Energy Laboratory

1617 Cole Boulevard
Golden, Colorado 80401-3393

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Contract No. DE-AC36-98-GO10337

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Southwest Research Institute:	Kent Spreen
U.S. Department of Energy:	Steve Goguen

Many other parties, not identified above, were involved in various project phases beyond the scope of this report, but contributed to the project's success (such as the field test sites, Cummins' distributors, LPG/dealers, and marketers).

Acronyms and Abbreviations

AFUP	Alternative Fuels Utilization Program
AFV	Alternative fuel vehicle
bhp	brake horsepower
BTDC	below top dead center
CARB	California Air Resources Board
CC	Clean Cities
CCVS	closed crankcase ventilation system
CFFV	Clean Fuel Fleet Vehicle
CFR	Consolidated Fuel Research
CNG	compressed natural gas
CO	carbon monoxide
CR	compression ratio
CTC	Cummins Technical Center
CVS	constant volume sampling
dBA	decibel attenuated
DF	deterioration factor
DOE	U.S. Department of Energy
ECM	engine control module
EPA	U.S. Environmental Protection Agency
ETS	Engineering Test Services Facility (Cummins)
ft	feet
g/bhp/hr	grams per brake horsepower per hour
GVW	gross vehicle weight
HC	hydrocarbons
HD	heavy-duty
hp	horsepower
ICM	ignition control module
lb	pounds
LEV	low-emission vehicle
LNG	liquefied natural gas
LPG	liquefied petroleum gas
NAA	nonattainment area
NMHC	non-methane hydrocarbons
NO_x	oxides of nitrogen
NRCan	Natural Resources Canada
NREL	National Renewable Energy Laboratory
OEM	original equipment manufacturer
0_2	oxygen
PC	personal computer
PM	particulate matter
psig	pounds per square inch gauge

Acronyms and Abbreviations (concluded)

PTO	power take-off
PVC	Propane Vehicle Council
rpm	revolutions per minute
SCAQMD	South Coast Air Quality Management District
SwRI	Southwest Research Institute
THC	total hydrocarbons
ULEV	ultra-low emission vehicle
WOT	wide-open throttle

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Executive Summary

In late 1994, the Cummins B5.9 Propane (LPG)[1] Engine Development, Certification, and Demonstration Project was organized by Cummins Engine Company, the propane industry, and The ADEPT Group. Cummins began engine development in 1995 and continued through 1997, building on its extensive experience with natural gas engines, specifically the B5.9G[2]. The objective of this project was to successfully develop and certify an LPG dedicated medium-duty original equipment manufacturer (OEM) engine that could be put into production (see Figure 1). This project was co-funded by Cummins, the National Renewable Energy Laboratory (NREL), Natural Resources Canada (NRCan), the Propane Vehicle Council (PVC), the South Coast Air Quality Management District (SCAQMD), and Superior Propane. Several field-test sites provided vehicles and staff to help demonstrate "field-test" and "market-seed" engines.[3]

The foundation for the B5.9LPG project was the B5.9G engine. The B5.9G development and certification program began in 1991. It was launched into production in 1994. More than 800 B5.9G engines are now in service in the United States and abroad. This engine is offered by more than 30 bus and truck OEMs. The B5.9 diesel version is used worldwide with millions sold since its introduction.

NREL funded two specific project tasks: (1) Task 1–Pre-Certification Testing and Engine Optimization and (2) Task 2–California Air Resources Board (CARB) and U.S. Environmental Protection Agency (EPA) Engine Certification. This report describes the conduct and completion of these two tasks.

The following personnel at the below locations conducted all testing and engine optimization activities:

- Cummins Alternative Fuel Division Engineering staff in the Cummins Technical Center (CTC) in Columbus, Indiana: Vinod Duggal, Jim Branner, Jr., Mostafa Kamel, Madison Rye, Mike Haub, Dave Dunnuck, and Jeff Mahon.
- Engineering Test Services (ETS) facility in Charleston, South Carolina: Joel Evans.
- Southwest Research Institute (SwRI) staff (lower tier subcontractor) in San Antonio, Texas: Kent Spreen.

ADEPT served as project manager and administrator of the NREL, PVC, and SCAQMD funds and as coordinator for one field-test site. ADEPT support personnel included: Alex Spataru, Alina Kulikowski-Tan, James Hendersen, Jeff Thayer, and Tracy Wilcox.

[1] Also known as liquefied petroleum gases (LPG).

[2] Natural Gas

[3] "Field-test" engines were the first prototype engines put into demonstration. "Market-seed" engines were a pre-production engine where a chassis OEM was involved.

Data for engine optimization were collected from laboratory facilities and from the field. During the project, Cummins logged more than 9,000 hours on 48 engines in various lab-testing activities and more than 300,000 miles in the field at 11 sites. In September 1997, Cummins launched the B5.9LPG into limited production. In May 1998, the engine was put into full production.

Background

NREL is the field manager for the U.S. Department of Energy (DOE) Alternative Fuels Utilization Program (AFUP), which sponsored the B5.9LPG engine project. AFUP's goal is to develop and advance technology that allows optimum use of alternative transportation fuels, while complying with modern constraints such as reduced vehicle emissions. For alternative fuels to be viable candidates to replace petroleum-based counterparts, it must be demonstrated that their impact on air quality will be no worse than that of existing fuels and preferably show characteristics that will improve air quality.

Because of the nation's continuing concern about air pollution, Congress enacted the Clean Air Act Amendments of 1990. The act's provisions have forced broad changes in fuels and vehicles. For example, reformulated gasolines, clean diesels, and alternative fuels are receiving wide attention as industry struggles to comply with the act. Also, to meet their air quality standards, many of the nonattainment areas (NAAs) across the country will need to increase their use of alternative fuels. Of the major transportation sectors, the medium-duty vehicle sector (e.g. package delivery vans, large pick-ups, and shuttle buses) may offer a good opportunity for urban emissions reduction because many of these vehicles are operated in urban environments. Therefore, additional research and development of alternative fuel, medium-duty engines and vehicles is important to DOE and NREL.

DOE projected that there were about 381,000 alternative fuel vehicles (AFVs) in use at the end of 1997. Out of these 271,000 operate on propane. This represents more than 71% of all the AFVs in the United States. In 1997 (in total gasoline equivalent gallons) LPG accounted for about 77% of all alternative transportation fuels used in the United States.

In light of federal and California emission reduction goals, the 1997 B5.9LPG engine certification target was the EPA Clean Fuel Fleet Vehicle (CFFV) ultra-low-emission vehicle (ULEV) certification and CARB Optional Low NO_x (see Table 1). The EPA CFFV program applies to fleets of 10 or more vehicles, which are centrally fueled or capable of being centrally fueled, in the 22 NAAs. For heavy-duty vehicles (8,500-26,000 lb gross vehicle weight [GVW]), the requirement is 50% of new vehicles purchased starting in 1999. A low-emission vehicle (LEV) counts as 1.0 credit, whereas an ULEV vehicle counts as 1.87 credits. Heavy-duty (HD) vehicles greater than 26,000 lb GVW for these NAA fleets can generate credits; though not required to as part of this program.

Note that CARB LEV and ULEV emission standards do not apply to the B5.9LPG engine because it is not used in applications of less than 14,000 lb GVW. The CARB Optional Low NO_x emissions levels refer to vehicle applications of 14,000 lb GVW or higher. For 1997 the standard could be from 0-3.5 grams per horsepower-hour (g/bhp-hr) in 0.5 increments (1.5 g/bhp-hr below the current-year NO_x emissions limit). For 1998, the standard is 4.0 g/bhp-hr; thus, the maximum optional low NO_x is 2.5 g/bhp-hr. Table 1 gives further details.

Table 1. CARB/EPA Transient Heavy-Duty Vehicle Emissions Standards

Emissions	Emissions Standards			Emissions Certification[4]	
(g/bhp-hr)	EPA CFFV LEV	EPA CFFV ULEV	CARB HD[5]	1997 B5.9LPG	1998 B5.9LPG[6]
NO_x			5.0[7]	2.2	2.3
THC			1.3	0.9	0.8
NO_x+THC	3.8	2.5		3.1	3.1
PM	0.10	0.05	0.10	0.02	0.01
CO	15.5	7.2	15.5	3.6	1.0
HCHO		0.025			
EPA CFFV				LEV	LEV
CARB Low NO_x				2.5	2.5

Introduction

The B5.9G is a six-cylinder, in-line configuration, four-cycle engine with 150 to 230 hp. The overall B5.9 LPG engine development strategy was to:

- Build on the B5.9G engine experience, which uses a base diesel platform.
- Maximize sub-system commonality with the B5.9 diesel and natural gas models (ignition, controls and air/fuel management).
- Optimize LPG sub-systems: (a) fuel delivery, (b) power cylinder, (c) combustion performance, and (d) emissions.
- Obtain 1997 CARB/EPA certification.

The engine optimization and precertification testing process included the following elements:

- Complete engine functional specification.
- Refine and complete natural gas engine components modification for LPG and LPG-specific components.
- Refine and complete engine software calibration modifications (e.g., O_2 sensor).
- Select and optimize LPG specific items (i.e., oxidation catalyst and integral vaporizer/regulator.)

4 96 inches maximum distance from the turbocharger exhaust outlet to the catalyst inlet.
5 EPA (>8,500 lbs GVW), CARB (>14,000 lbs GVW)
6 Closed crankcase ventilation system required by 1998 EPA Certification
7 Optional low NO_x (0-3.5 in 0.5 increments for 1997; 0-2.5 for 1998)

- Pre-certification testing and analysis:
  - Establish certification-testing parameters.
  - Test for performance ranges with HD-5 specification LPG fuel.
  - Test for mechanical development (including vibration, leakage, hydrostatic, and deformation) and durability (including 500 and 1,000 hours, and precertification transient emissions).

Figure 1 illustrates the B5.9 LPG engine.

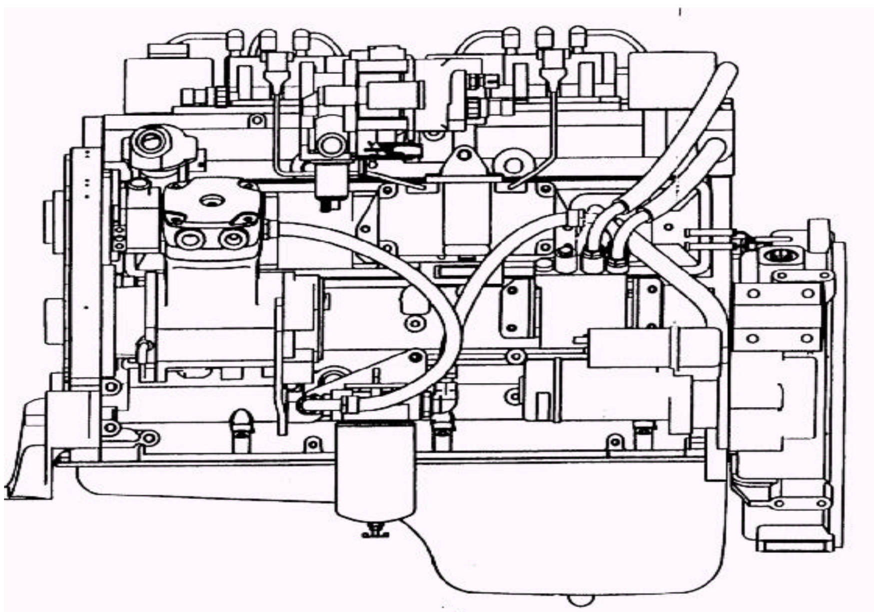


Figure 1. B5.9 LPG Engine

This engine was designed for use with HD-5 LPG specification fuel. Certification with and without an oxidation catalyst was planned, though Cummins expected (based on previous work) that a catalyst would be required to meet the total hydrocarbons (THC)[8] requirement for CARB/EPA. Certification deterioration factor (DF) tests were not required because Cummins had an approved DF for a spark-ignited, lean-burn natural gas engine—the B5.9 natural gas, upon which the B5.9LPG was designed. The DF is the same for a spark-ignited engine family (i.e., B5.9) independent of fuel type (compressed natural gas [CNG], liquefied natural gas [LNG], and LPG). This DF was based on a 1,200-hour engine test conducted at Cummins in 1994. The CARB/EPA (40 Consolidated Fuel Research [CFR] 86) certification requirements are as follows:

- One cold cycle (1/7 weighted)
- One hot cycle (6/7 weighted)
- Composite average result
- Established DF factor.

[8] This is an LPG-specific issue because of the chemical structure and hydrocarbon (HC) content of LPG.

In 1997 Cummins conducted formal certification testing on B5.9LPG engines three times with engine analysis and data optimization between and after each test series:

- February 1997 at SwRI: Initial testing did not achieve desired emissions targets.
- August 1997 at SwRI: 1997 EPA LEV and CARB Optional Low NO_x certifications were achieved with an oxidation catalyst.
- November 1997: 1998 EPA CFFV LEV and CARB Optional Low NO_x certification were successful.

The Task Discussion reviews the work conducted in the following sections: Engine Optimization to LPG, Optimization Refinements Resulting from Field Experience, Precertification Testing, and Certification Testing.

Engine Optimization to LPG[9]

Completion of Functional Specification for B5.9 LPG Engine

The B5.9 LPG is a lean-burn, spark-ignited engine with electronic management. The engine's design targets for the B5.9 LPG operating on HD-5 LPG were:

- 195 rated hp at 2,800 rpm and 420 ft-lb peak torque at 1,600 revolutions per minute (rpm)
- 285 ft-lb at 800 rpm at wide open throttle
- ULEV targets (g/bhp-hr) with a catalyst:[10] with NO_x + THC 2.5; CO 7.2; and particulate matter (PM) 0.05 (zee Table 1)
- Integrated fuel handling and ignition subsystems (see Figures 2 and 3)
- Engine protection and PC-based diagnostics (see Figure 5)
- Engine-mounted controllers
- Compression ratio (CR) of 9:1
- Maximize parts commonality with B5.9G engine (only 10 new LPG-specific parts)

These targets were met with the exception of emissions (LEV, instead of ULEV) and rated horsepower speed (achieved at a lower speed of 2,600 rpm).

---

[9] There are several references to suppliers throughout the report. ADEPT and Cummins are not presently authorized to identify them in this report. For further inquiries, please contact Cummins Alternative Fuels Group.

[10] A catalyst is required for the B5.9LPG to meet the heavy-duty THC standard.

Refinements and Completion of Modified Natural Gas Engine Components for LPG, LPG Specific Components, and Engine Software Calibration

The B5.9 engine components listed below were added, modified, or optimized (or all three) to the LPG application.

- Pistons
- Integral vaporizer/regulator/shut-off valve
- Vaporizer coolant hoses
- Fuel hoses
- Fuel assembly housing
- Mass flow sensor
- Fuel metering valve
- Engine control module (ECM) software
- Engine wiring harness
- Catalyst

Two new B5.9G family enhancements were incorporated in the B5.9 LPG engine to maintain parts commonality: (1) a high-temperature exhaust manifold[11] and (2) a revised fuel-metering valve.[12] Figure 2 illustrates the B5.9 LPG subsystem engine integration, including those items specifically added for the LPG application.

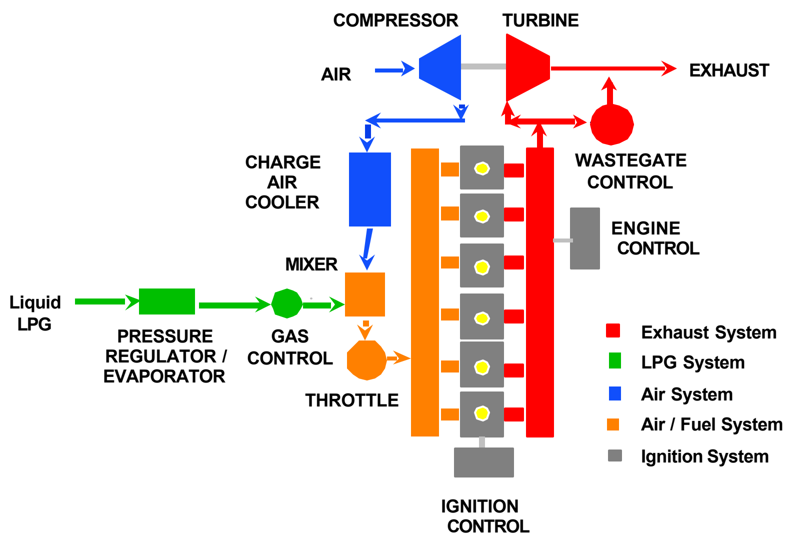


Figure 2. B5.9 LPG Engine Integration

Piston/Combustion Chamber Design

Cummins' evaluation of the engine operating margins (detonation) indicated a need for increased knock margin at rated power [195 hp at 2,800 rpm]. This optimization process led to rated horsepower

[11] Initially released on the B5.9 diesel engine platform.

[12] Initially released on the B5.9G engine platform.

speed change from 2,800 to 2,600 rpm while governed speed was maintained at 2,800 rpm. The LPG-specific piston was also redesigned to lower the CR from 9.5:1 to 9:1 (the B5.9G CR is 10.5:1).

Cummins modified the piston compression ratio because of the lower octane rating of LPG compared to that of natural gas. The piston bowl geometry was modified to achieve a CR of 9:1 while meeting internal piston design standards. This modification also expanded the knock margin. The new piston was implemented for durability and field-test engine evaluation. Operating margin evaluation work continued throughout the certification period.

Engine-Mounted Vaporizer/Regulator - LPG Specific Item[13]

The combination vaporizer/pressure regulator design for performance and durability continued to be optimized with the supplier. Although the supplier produces vaporizer/regulators for other LPG engine applications, this effort is B5.9 LPG engine specific because of the engine's operating requirements (i.e., turbocharged and engine-mounted). This component was the primary reliability concern during performance and field tests. Figure 3 illustrates the sequence of fuel handling from the vehicle tank to the engine.

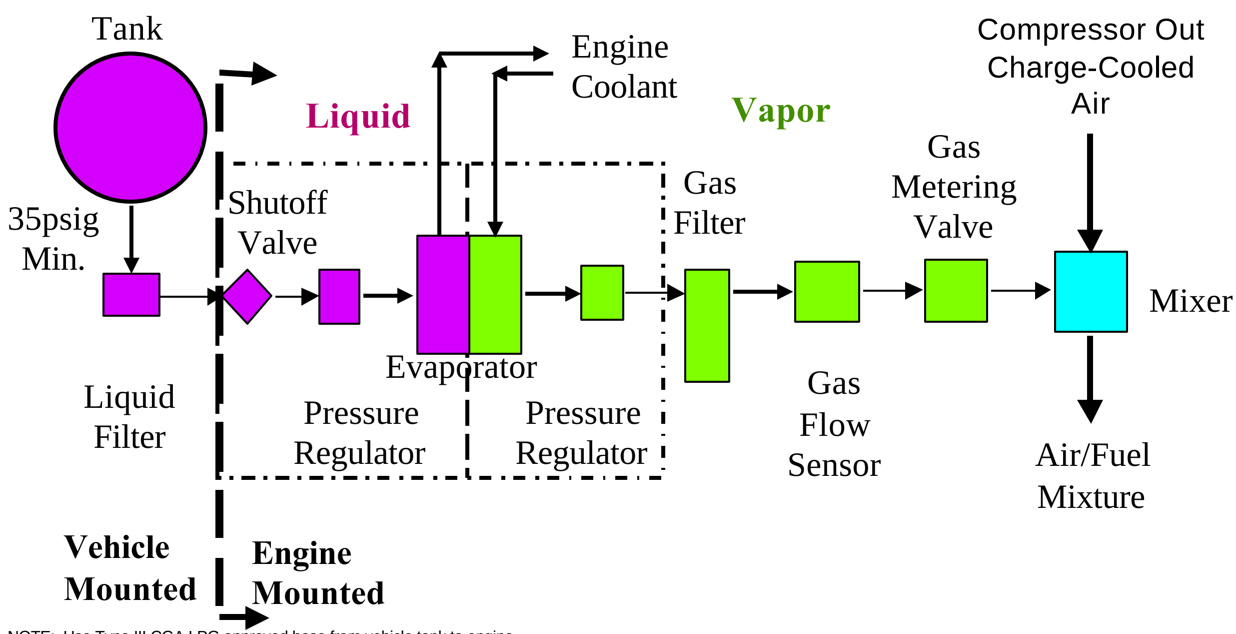


Figure 3. B5.9 LPG Engine - Fuel Delivery Sub-System

Catalyst - LPG Specific Item

Initially Cummins applied the B5.9G catalyst to the B5.9 LPG engine. This catalyst did not meet emissions reduction targets in the first phase of certification testing. Subsequently, Cummins selected an oxidation catalyst for the B5.9 LPG engine from its current supplier for the C8.3G engine that provided

[13] This item was added to the engine for the LPG application rather than a modification of an existing engine part.

higher THC reduction efficiency than the B5.9G catalyst. See further discussion in the section entitled "Certification."

Cummins demonstrated the capability to meet EPA CFFV/ULEV emission levels (see Table 1) for the B5.9 LPG engine with an oxidation catalyst through preliminary steady-state and transient precertification emissions tests at CTC.

Fuel-Metering Valve Technologies (Vapor Side-Fuel Plumbing)

As a turbocharged spark-ignited engine with single-point gaseous fuel injection, the B5.9 LPG engine requires a minimum fuel supply pressure to the engine to reach rated performance. The minimum fuel supply pressure, with margin, was set at 35 pounds per square inch gauge (psig) to the upstream side of the shut off valve prior to the vaporizer/regulator. This 35-psig requirement was derived from an evaluation of LPG characteristics at low temperatures, flow-pressure losses through the engine's fuel system, and the need to overcome maximum turbocharger boost pressure rated horsepower for single-point fuel injection.

For a vehicle fuel system, saturated LPG tank pressure is a function of temperature. In cold-weather operation, a temperature could be reached where the fuel supply pressure to the engine cannot meet the 35-psig requirement (see Figure 4). At such temperatures, delivery of liquefied LPG in the engine affects the engine fuel supply and, therefore, engine performance. Because engine block water is used to vaporize the fuel, cold weather operation required special equipment such as heating blankets or a vehicle fuel system with a pump. [14] The shaded region in Figure 4 highlights the region between minimum pressure supplied by the pump (35 psig line) and the LPG saturated pressure/temperature curve.

Vehicle and laboratory cold-weather startability tests[15] at CTC demonstrated the capability of providing 35-psig minimum LPG supply to the engine. In March 1997, the engine started successfully at

- 32°F minimum ambient temperature, with an unpressurized vehicle fuel system
- 10°F ambient temperature, with an engine block heater and an unpressurized vehicle fuel system
- -10°F ambient temperature, with a pressurized vehicle fuel system.

In April 1997, further vehicle and laboratory cold weather startability tests demonstrated the capability of successfully providing 35-psig minimum LPG supply at

- 32°F minimum ambient temperature, with an unpressurized vehicle fuel system
- 5°F ambient temperature, with engine block and oil pan heaters and an unpressurized vehicle fuel system

[14] For the B5.9LPG, the LPG must be sustained in a gaseous phase. As illustrated in Figure 4, cold weather conditions can cause a bi-phase fuel condition that would affect engine performance. This is a propane specific issue.

[15] The CTC facility uses dedicated refrigerated test cells for cold temperature startability and performance tests.

- -17°F ambient temperature, with a pressurized vehicle fuel system; engine warm up at idle was required to assure full rated power capability.

There were two reasons for the expansion in the test temperatures threshold: (1) the addition of an oil sump heater allowed a cold start of the engine at even lower temperatures, and (2) the discovery that the engine would start at ambient temperatures between -17°F to 10°F, but could not operate at full rated power. Additional cold-weather tests, which confirmed these test results, were conducted in June 1997.

Cummins held a meeting with a propane vehicle fuel system supplier to discuss the cold-weather requirements for the lean-burn, turbocharged B5.9 LPG engine. This supplier manufactured a pressurized vehicular fuel tank system that would meet the 35-psig liquid fuel supply requirement to the engine. A prototype of this system was used for Cummins cold-weather testing for a pressurized vehicle fuel storage system.

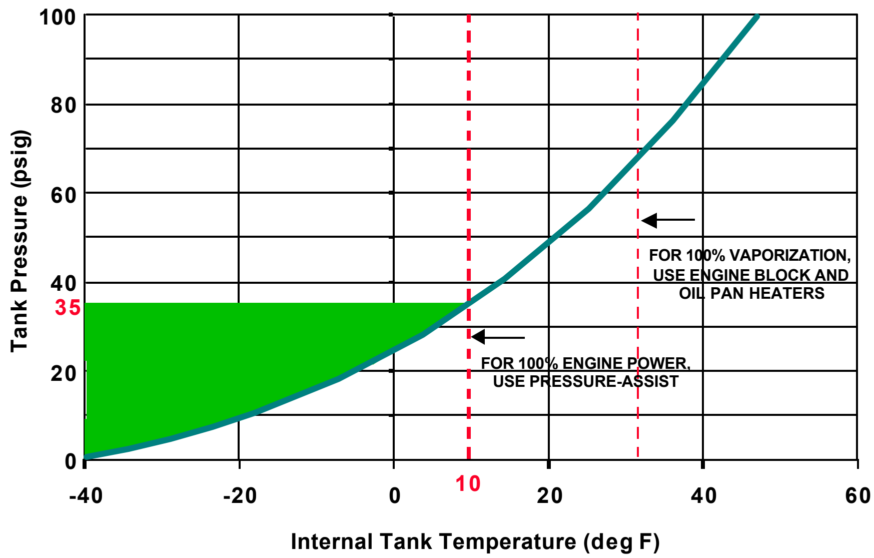


Figure 4. Vehicle LPG Tank -- Cold Ambients Effect[17]

ECM Software Recalibration

Engine operating margins evaluation work resulted in a requirement to lower peak rated horsepower speed (2,600 rpm) while maintaining governed speed at 2,800 rpm. The ECM software calibration was revised to tailor to optimum LPG operation. Components that required software table modifications were

- Air/fuel ratio
- Ignition timing

[16] For the B5.9LPG, the LPG must be sustained in a gaseous phase. As illustrated in Figure 4, cold weather conditions can cause a bi-phase fuel condition that would affect engine performance. This is a propane specific issue. Previously used strategies to address this issue include on-board heating of the fuel.

[17] Pressure assist refers to the use of a pump to deliver fuel versus an unpressurized fuel system.

- Rated speed
- Turbocharger boost pressure
- Gas flow sensor.

The tasks for ECM software development included

- Concept engine controls
- Development engine controls
- Optimization of performance and emissions
- Production engine controls.

Figure 5 shows the ECM/ignition control module (ICM) interface and the various functions and sub-system controls.

This rated horsepower speed change and the piston revision implemented last spring provided the required detonation margin at rated power (based on validation tests conducted at CTC). The software calibration revision was downloaded into the ECM of all field-test and market-seed units, with no problems reported to date.

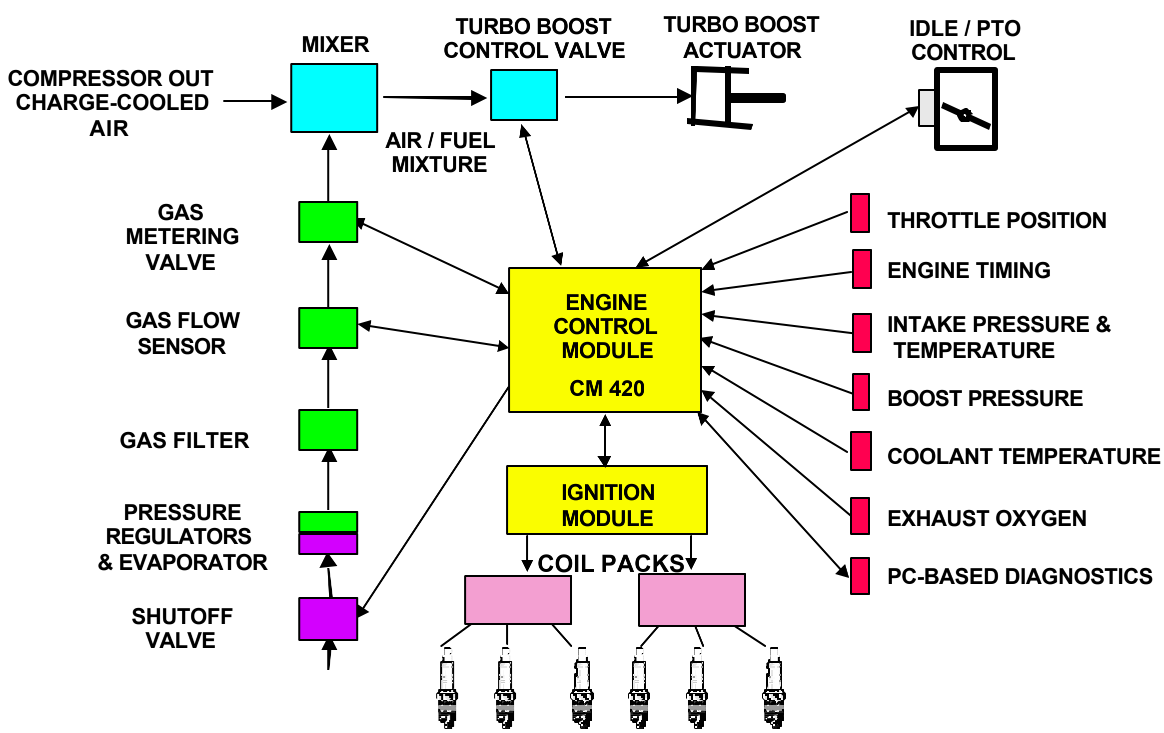


Figure 5. B5.9 LPG Engine Electronic Control Sub-System

Engine Optimization and Refinements Resulting from Field Experience

Engine Software Algorithm

In March 1997, one field-test issue required software algorithm testing to validate a solution. All five LPG bobtail trucks' engines stalled occasionally in the field after completing power take-off (PTO) operation for off-loading LPG fuel while the engine was at 1,000 rpm. A temporary fix was provided during engine operation (modified driver procedures before and after PTO operation). The modified drivers' procedures included pressing the accelerator to increase the engine speed above idle speed before engaging in PTO.

Subsequently, an ECM software revision was validated in the laboratory and provided a permanent solution to engine stalling. The revision was downloaded into the engines' ECM in LPG bobtail applications.

Other Data Collected from the Field

Oil consumption data and analysis for the field-test vehicles showed equal results to fleets operating the B5.9G 195-hp engine. Cummins anticipated this outcome because the hardware affecting oil consumption is identical for both engine versions. No problems were found with wear metals, contaminant metals, additive metals, non-metallic components, or lube fluids.

B5.9 LPG engine shutdowns were observed in the field. These shutdowns were correlated with the following conditions: voltage drops in the ECM/ICM, failure of the regulator vaporizer, and front-cover and rear-cover gasket failure. Analysis of these occurrences is ongoing. Detail at a later date may be obtained from the Alternative Fuels Division of Cummins Engine Company. In the ECM/ICM voltage drop incidences there appear to be electric system instabilities and faulty wiring. Also, voltage swings are experienced in the transit shuttle application itself.[18]

Pre-Certification Testing

From July 1997 to August 1997 two preproduction B5.9 LPG engines were subjected to pre-certification tests (steady-state emissions), performance and emissions optimization, and constant volume sampling (CVS) transient emissions analysis. These tests, in addition to field-test vehicle performance (driveability) tests, served to optimize the engine for limited production, scheduled for the third quarter of 1997. All precertification tests were conducted at CTC.

Performance, durability, and field-test engine data were used to develop an optimum performance and emissions baseline for optimization based on both steady-state and CVS transient emissions tests. Enhancements were validated in the laboratory on the performance and durability of the engines, as well as in vehicles via field test engines.

[18] For further detail please contact the Alternative Fuels Group of Cummins Engine Co.

All testing was conducted on HD-5 specific LPG. The LPG had the following component percentages: 94.6-95.8% propane, 0.3-0.8% propene 0.4-1.6% iso-butane, and 0.1-0.2% n-butane. A contract propane marketer that supplies LPG fuel for Cummins CTC forklifts supplied the HD-5 specification fuel. Cummins qualified the contents of the fuel in a CTC laboratory analysis. The HD-5 fuel specification is shown in Table 2.

Table 2. Propane Gas (HD-5) Fuel Specification

Constituents	Requirement	Test Method
Propane, volume %	90.0 Minimum	ASTM D 2163
Propylene, volume %	5.0 Maximum	ASTM D 2163
Butane & Heavier, volume %	2.5 Maximum	ASTM D 2163
Hydrogen Sulfide	Pass	ASTM D 2420
Total Sulfur, ppmw	123	ASTM D 2784
Oxygen, weight %	0.5 Maximum	ASTM D 1945
$CO_2 + N_2$	3.0 Maximum	ASTM D 1945

(Note: California specification for propane is 85% min. by volume)

An area of focus was the evaluation of combustion operating margins for rated power of 195 hp. Adequate knock margin was not initially achieved. Engine performance and combustion optimization work increased the detonation margin at rated power while preserving engine performance targets. (See Figure 6 and the Piston/Combustion Chamber Design discussion.)

As part of preparing for certification testing Cummins conducted the following tests:

1. Mechanical development testing included

   - Vibration
   - Leak
   - Hydrostatic.

2. Performance development tests included

   - 500-hour "hot box" (elevated system temperatures)
   - 500-hour thermal cycle
   - 500-hour hot endurance.

3. Additional development tests conducted

- 1,000-hour peak power overload
- 250-hour overload
- 250-hour idle speed.

For performance development tests, the cylinder head was instrumented for dynamic in-cylinder #1 pressure measurement for some of the performance and development engines. The engine was also instrumented for the following parameters:

-Engine speed	-Fuel temp	-Fuel pressure
-Torque	-Intake temp.	-Intake pressure
-Throttle position	-Exhaust gas oxygen	-Turbine inlet temp.
-Fuel flow	-Air flow	-Turbine inlet pressure
-Blowby pressure	-Exhaust port temp.	-Exhaust port pressure
-Compressor out-pressure		-Compressor outlet temp.

A Cummins proprietary high-speed data acquisition system was used in conjunction with the in-cylinder pressure transducer to analyze:

-Combustion duration	-Coefficient of variance
-Rate of combustion	-Start of combustion.

The tendency for knock and misfire and the engine heat release were evaluated using this engine data and to calculate:

-Air/fuel ratio	-Power
-Brake specific fuel consumption (bsfc)	-Thermal efficiency.

Cummins inspected the test engines for pitting, scuffing, abrasion, and excessive wear through visual inspection and micromeasurement and found no problems. Areas under inspection for wear were found to be within base engine specifications. In these development areas a variety of data-based analyses were compared to results for the B5.9G and diesel engines using Cummins' internal standards. No major issues were raised during these tests. Some of the major components analyzed for reliability and durability were:

-Cylinder head and overhead	-Spark plugs
-Fuel handling sub-system	-Turbocharger
-Crankshaft and bearings	-Camshaft and bearings
-Ignition subsystem	-Other base diesel/natural gas components.
-Power cylinder	

Figure 6 illustrates the final performance curve resulting from the above testing and optimization. The dash line denotes stoichiometric gasoline LPG conversions torque peak capability of similar rated HP.

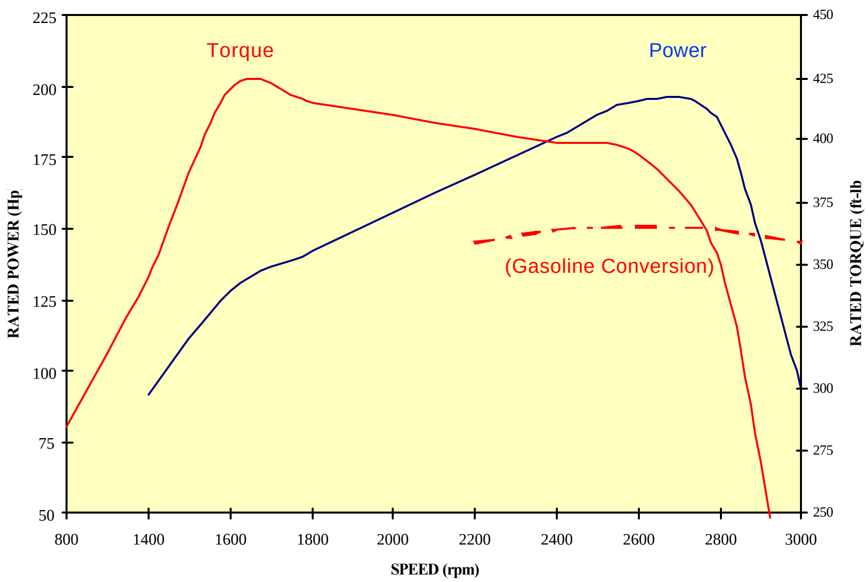


Figure 6. B5.9 LPG Final Engine Performance

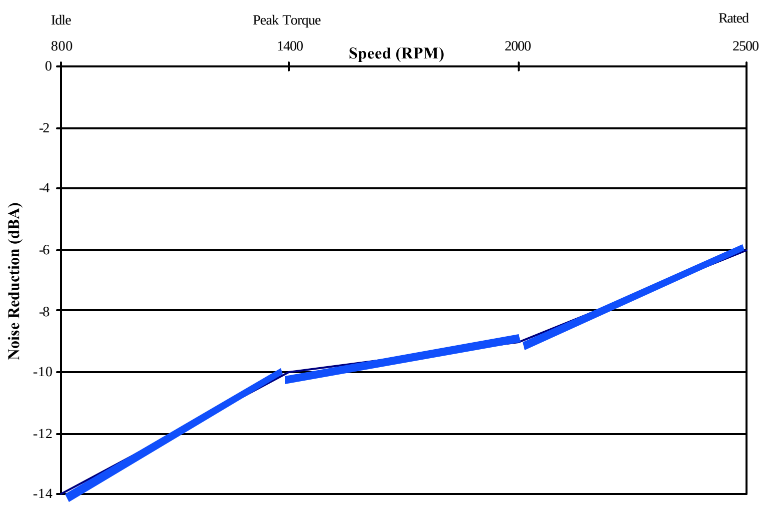


Figure 7. Noise Analysis – Baseline B5.9 Diesel Engine

Noise Testing

As part of its engine development program (but not part of the NREL project contract) Cummins conducted engine noise testing. A one-meter free-field noise measurement, per SAEJ1074, showed a significant noise reduction along the full-load torque curve in comparison to a B5.9 diesel (see Figure 7).

Certification Testing

The three certification tests will be described as Phases I-III.

Cummins selected SwRI as the testing subcontractor based on an established and successful history with SwRI and because the CTC test facilities are not EPA-certified for testing spark-ignition engines. The team that conducted and completed the certification program included the following members:

- Cummins: Vinod Duggal, Jim Branner Jr., Mostafa Kamel, Jeff Mahon, and Dave Dunnuck.
- SwRI: Kent Spreen.

Tests conducted at SwRI were completed in a test cell equipped and calibrated to perform the EPA Heavy-Duty Engine Transient Federal Test Procedure CFR 40 No. 86. The LPG test fuel had the following components: 94.3% propane, 3.8% propene, and 1.9% n-butane.[19] No testing was conducted without a catalyst.

Cummins did not conduct a DF test on the B5.9 LPG engine because there was an approved DF for the B5.9G. The premise for DF testing is to determine how various hardware and controls will deteriorate over a period of useful emissions life. The natural gas engine DF can be applied to the B5.9 LPG engine because the combustion processes, hardware design, and control principles are the same for both engines. The engines differ in the amount of fuel used, timing of combustion, and compression ratio or burn rates. The natural gas and LPG engines share the same ignition systems, fuel handling, air/fuel ratio control hardware, logic and control subsystems. The catalytic converters both include the same wash coat (catalytic surface), although the LPG engine catalyst is larger for the greater surface area needed for total HC control instead of only NMHC required for natural gas engines. This DF was based on a 1,200-hour engine test. The DF for the B5.9LPG engine is shown in Table 3.

[19] For information about test fuel sources contact the Alternative Fuels Group of Cummins Engine Co.

Table 3. B5.9 LPG Engine Deterioration Factor

Pollutant	EPA DF	CARB DF
NO_x	1.007	1.007
THC	1.000	1.000
CO	13.935	13.935
PM	1.000	1.000

The DF for carbon monoxide (CO) is relatively large because the CO emissions out of the oxidation catalyst are extremely low. At such low CO levels, measurement variability is high, and small changes in emission levels created a steep slope for the DF analysis. DFs are based on the slope of catalyst deterioration over time which, in the case of CO, resulted in a relatively high DF.

Phase I

The certification B5.9 LPG engine was built at the Cummins Rocky Mount, North Carolina, plant to utilize the manufacturing process system prototyping (e.g., customer order entry, engine assembly, software download, and engine test). The 120-hour certification-conditioning test of the engine and oxidation catalyst was completed at CTC. Subsequently, the engine was shipped to SwRI where an engine control problem (i.e., excessive vibration of the fuel control valve) occurred during preparation for emission certification testing. The engine was shipped back to Cummins for further troubleshooting.

The certification test was rescheduled after successful testing at Cummins. The engine control problem reoccurred at SwRI. Further trouble-shooting by Cummins staff at SwRI revealed that a solid-engine test cell mounting arrangement at SwRI caused excessive vibrations, which induced the fuel-system control problem. Soft-mounting of the engine in the SwRI test cell resolved the excessive engine vibration of the fuel control valve. The certification test was rescheduled and completed in February 1997. The results indicated that the B5.9 LPG engine with the catalyst failed to meet CARB/EPA heavy-duty certification because of THC emissions (1.3 g/bhp/hr).

Cummins rescheduled a second certification test for July 1997 once they completed a thorough emissions failure analysis; combustion operating margins evaluation, and performance/emissions optimization at CTC. Data analysis to understand certification test failure was conducted from March to June 1997. It revealed that:

- The engine was out of the rated power production specification (>5% limit), thus producing higher than expected THC.
- The engine catalyst was located too far from the engine exhaust outlet, resulting in reduced catalyst THC effectiveness.
- LPG fuel caused higher THC emissions than natural gas.

A CARB/EPA emissions certification plan for the second series of certification testing was prepared in April 1997 (see Appendix 1).

Cummins continued to optimize emissions and performance to assure NO_x and THC emissions met EPA CFFV targets. Because of SwRI test-cell availability constraints, certification testing was delayed until August 1997.

Phase II

In July 1997, transient emissions tests conducted at CTC showed capability of meeting EPA CFFV and CARB Optional Low-NO_x emission levels with the latest production version of the B5.9 LPG. Cummins reduced the maximum catalyst distance from the turbocharger outlet from 155 inches to 96 inches for cold start HC reduction. The second certification test with a production B5.9 LPG engine was scheduled for August 1997 at SwRI. Two changes were applied to the B.9 LPG engine: (1) the CR was changed from 9.5:1 to 9.0:1, and (2) the B5.9G catalyst was replaced with the C8.3G catalyst.

In August 1997, the 120-hour engine and catalytic converter conditioning test for certification was completed at ETS. Subsequently, the second engine CARB/EPA emissions certification tests were completed at SwRI. These tests were conducted on a production B5.9LPG engine, which included ECM software calibration revision, described earlier. Cummins submitted its applications for 1997 CARB and EPA emissions certificates. The certification data, with deterioration factors and the regulated EPA CFFV emission standards, are described in Table 1.

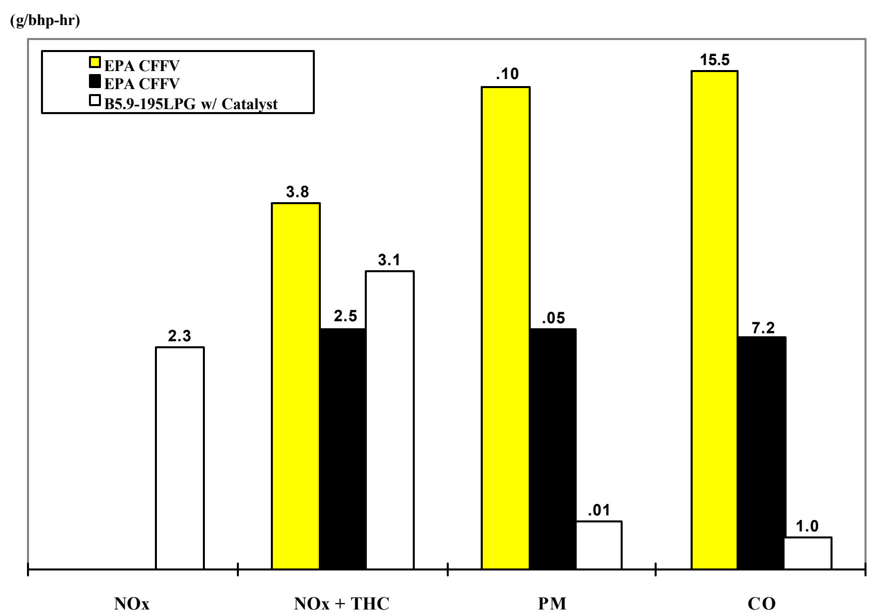


Figure 8. 1998 B5.9 LPG EPA CFFV Certified Emissions

In September 1997, Cummins received the EPA CFFV LEV certificate for the B5.9 LPG engine with a catalytic converter (see Appendix 2 for documentation). The B5.9 LPG was the first dedicated heavy-duty spark-ignited LPG engine to receive EPA CFFV LEV certification. Cummins' target for this program was the EPA CFFV ULEV standard. A LPG engine must certify to a total hydrocarbon (THC) emission level while a natural gas engine has the advantage of certifying to a non-methane hydrocarbon (NMHC) emission level.

In October 1997, Cummins received the CARB Optional Low NO_x (2.5 g/bhp-hr) certificate for the B5.9 LPG engine with a catalytic converter (see Appendices for documentation). The B5.9 LPG was the first dedicated heavy-duty spark-ignited propane engine to receive the CARB Optional Low NO_x certification. Cummins planned to recertify the B5.9 LPG engine with close crankcase ventilation system (CCVS) to 1998 EPA CFFV and CARB Optional Low NO_x standards in 1997.

Phase III

In November 1997, Cummins completed the emission certification 120-hour conditioning tests at ETS on the B5.9 LPG engine with a production CCVS catalyst. This is an EPA requirement for 1998 certification for heavy-duty spark ignited engines and was not part of the NREL funded contract. Subsequently Cummins completed the 1998 EPA and CARB emissions certification tests at SwRI for the B5.9 LPG engine with CCVS. Cummins received emission certification from EPA and CARB for 1998 in December 1997. These results are shown in Figure 8 in comparison to the EPA CFFV ULEV and LEV standards, and in Figure 9 in comparison to the diesel engine. See Table 1 for the test results with DF.

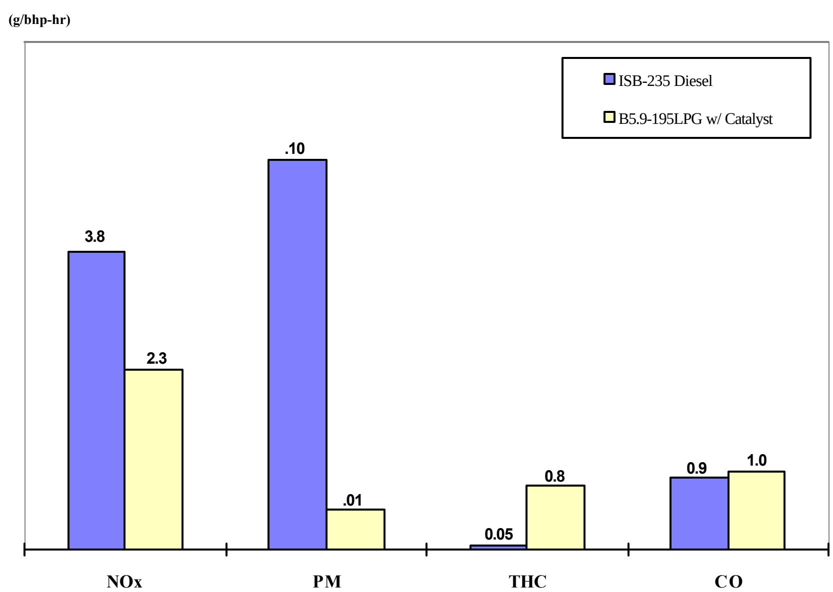


Figure 9. 1998 B5.9 EPA HD Certified Emissions

Project Promotions

Throughout the project, ADEPT and Cummins promoted the project on various fronts. Below is a list of media articles about the project (See Appendix 3 for full text of articles.)

- *Passenger Transport* article entitled: "San Antonio System to Add 283 New Vehicles by 2002," March 1998.
- *Butane Propane News* article, re: City of Pasadena field site, June 1997.
- *School Transportation News*, article "Propane Gas Bus Popularity Increasing in Texas," August 1997.
- Cummins B5.9LPG engine press release (November 1997).
- Excerpt from AQMD Annual Report 1997.

Cummins and PVC jointly sponsored a campaign to display the B5.9 LPG engine at various events around North America. The events are listed in chronological order

- Technical presentation and engine display at the Propane Vehicle Magazine Conference (Orlando, FL) February 2-4, 1997.
- Engine display at the Midwest LPGA Trade Show (Indianapolis, IN) March 8-10, 1997.
- Ottawa Truck Commando 30-yard spotter with engine display at the Truck Maintenance Council Show, March 1997, then transferred to a Los Angeles dealer for customer demonstrations.
- Engine display at the Southeast National Propane Gas Association Trade Show (Atlanta, GA), April 6-8, 1997.
- Engine and Suburban FL70 B5.9LPG field-test truck display at the Western LPG Trade Show (San Diego, CA), April 24-26, 1997.
- Technical presentation and B5.9LPG engine display at the Windsor Alternate Fuels Conference (Windsor, Ontario, Canada), June 8-10, 1997.
- Engine display at the Oklahoma Pupil Transportation Conference (Oklahoma City, OK), June 8-11, 1997.
- Engine and demonstration vehicle display at the DOE Clean Cities (CC) Conference (Long Beach, CA), June 25-26, 1997.
- Engine display at the DOE CC Regional Conference (St. Louis, Missouri), July 30, 1997.
- Engine display at Southwest Propane Gas Trade Show and Convention (Dallas, TX), August 19-20, 1997.
- Engine display at the DOE Regional CC Conference (Atlanta, GA), September 4, 1997.
- Engine display at the NPGA Trade Show and Convention (Providence, RI), September 26-28, 1997.
- Engine display at the National Association of Pupil Transportation (school bus) Conference (Indianapolis, IN), November 4-5, 1997.
- Technical presentation at the SCAQMD Technology Advancement Office Conference, December 4, 1997.
- Technical presentation and engine display at the Propane Vehicle Magazine Conference, February 11, 1998.

- Engine display at the Southeast[21] LPG Conference (Atlanta, GA), April 5-7, 1998.
- Engine display at the Midwest LPG Conference (Indianapolis, IN), April 25-27, 1998.
- Engine display for the Southwest LPG Conference (Dallas, TX), May 11-12 1998.
- Technical presentation and engine display for the DOE CC Conference (Washington, D.C.), May 31-June 3, 1998.

ADEPT and Cummins worked jointly to promote the use of the engine at additional sites. In Texas three sites are in development. Many more have started throughout the United States, Australia, and Mexico as a result of Cummins promotions. Table 4 shows the sites that have B5.9 LPG engines in use or on order.

Project Conclusions

This project was successful in that it resulted in an alternative fuel engine product that has the following attributes:

- Competitive fuel economy[22]
- PC based diagnostics (INSITE software)
- Minimum engine life to overhaul of 300,000 miles[23]
- Two year warranty with unlimited mileage
- CARB/EPA emissions warranty for five years or 100,000 miles with and without a catalyst. (LEV levels with catalyst only).
- B5.9 LPG offered by the following OEMs: Champion, El Dorado, Freightliner, Hoist, Ottawa, Spartan, and United Tractor.

The engine optimization and precertification tests for the B5.9LPG project were completed and met the EPA LEV and CARB Optional Low NO_x certification standards. As illustrated in Tables 1 and 3 and Figures 8 and 9, the PM and CO emissions are very low, with NO_x emissions substantially low. The ULEV emissions target was not met due to the challenges of higher levels of total HC. In addition to HC content, LPG's high heat of combustion may yield higher emissions. Oxidizing catalysts will continue to be required to meet increasingly stringent emission standards. A heavy-duty LPG spark-ignited engine must meet a THC requirement whereas the natural gas engine is required to meet a NMHC standard. Cummins met the other B5.9LPG program deliverablesB5.9LPG engine shutdowns were observed in the field. These shutdowns were correlated with the following conditions: voltage drops in the ECM/ICM, failure

[21] Both ADEPT and Cummins conducted the presentation.

[22] Per Cummins' comparisons to light-duty gasoline engine LPG conversions. Field test data, from Suburban Propane, shows 1.75-2.0:1 fuel consumption advantage of B5.9LPG vehicles versus LPG conversion vehicles in similar duty cycles.

[23] Engine life to overhaul is based on the expected life of the bottom-end components – crankshaft, camshaft, bearings, etc. for which 300,000 miles is the expectation. Although B5.9LPG engine experience is limited, Cummins L10G engine life experience lends to their expectation that B5.9LPG engine life will be longer than with diesel. This is predominantly due to the lack of soot or fuel in oil and lower thermal cycling of the engine over the operating range.

Table 4. Sites with Cummins B5.9 LPG Engines in Use or On Order

OEM/User Field Tests

Customer	Location	OEM	Application	Qty	Status (Miles)
Suburban Propane	Sacramento Area	Freightliner FL 70, Repowers	LPG Bobtail	4	38,200 - Unit #1 53,200 - Unit #2 45,500 - Unit #3 36,400 - Unit #4
Superior Propane	Toronto, Canada	FL 80 – Repower	LPG Bobtail	1	33,300
Western Transit	Pinole, CA	Thomas, Repowers	Shuttle Bus	2 Total:7	56,700 - Unit #1 63,000 - Unit #2

OEM/User Market Tests

Customer	Location	OEM	Application	Qty	Status (Miles)
Delta Liquid Energy	Paso Robles, CA	Freightliner FL 70	LPG Bobtail	1	9,700
City of Pasadena	California	Bluebird Q Bus, Repowers	Shuttle Bus	2	27,100 - Unit #1 12,300 - Unit #2
UPS	Minneapolis, MN	Ottawa Truck	Yard Spotter	1	In Service
Ranger Die Casting	Lynwood, CA	Freightliner FL 70	LPG Bobtail	1 Total:5	9,000

Limited Production

Customer	Location	OEM	Application	Qty	Status (Miles)
Allegheny Steel	New Castle, IN	Hoist Lifttruck	MD Forklift	1	In Service
Allied Signal	Albuquerque, NM	Ottawa Truck	Yard Spotter	1	In Service
Automotriz Uribe	Mexico City	Freightliner FL70	Regional Delivery	1	In Service
City of Santa Rosa	California	Freightliner FL70	Regional Delivery	1	In Service
CC Ind. School Dist.	Corpus Christi, TX	Blue Bird, Repower	School Bus	1	Planned
CC Regional Transit	Corpus Christi, TX	Champion/Spartan	Shuttle Bus	6	On Order
CC Regional Transit	Corpus Christi, TX	Repowers	Shuttle Bus	3	1 On Order
Delta Liquid Energy	Paso Robles, CA	Freightliner FL70	LPG Bobtail Deliv.	1	Operational
Elgas	Australia	Freightliner FL80	Regional Delivery	1	Operational
FEMSA (Coca Cola)	Mexico City	Freightliner FL70	Regional Delivery	1	In Service
Garber Post	Montgomery, IN	Ottawa Truck	Yard Spotter	1	In Service
Kleenheat Gas	Australia	Freightliner FL80	Regional Delivery	1	Operational
LA DoT	Los Angeles, CA	El Dorado	Shuttle Bus	30	30 In Service
LA DoT	Los Angeles, CA	El Dorado	Shuttle Bus	17	On Order
L.A. Murphy	Australia	Freightliner FL80	Regional Delivery	1	Operational
Northwest Trek Tram	Tacoma, WA	AAI-ACL/Spartan	Shuttle Bus	2	Engines Installed
Oneil Gas	Choudrant, LA	Freightliner FL70	LPG Bobtail Deliv.	4	Planned
Paratransit	Sacramento, CA	Thomas Repowers	Shuttle Bus	2	Planned
Solar Turbines	San Diego, CA	United Tractor	Yard Tug	1	In Service
UPS	Minneapolis, MN	Ottawa Truck	Yard Spotter	4	In Service
Various Customers	Not Available	Ottowa Truck	Yard Spotter	8	2 Engines Shipped
Various Customers	Not Available	Freightliner FL70	Not Available	3	On Order
VIA Transit	San Antonio, TX	Trolley	Shuttle Bus	15	Planned
VIA Transit	San Antonio, TX	Champion/Spartan	Shuttle Bus	66	On Order
VIA Transit	San Antonio, TX	Chance Coach	Trolley	5	Planned
Western Propane	Santa Maria, CA	Freightliner FL70	LPG Bobtail	1	Operational
Western Transit	Pinole, CA	Thomas, Repowers	Shuttle Bus	2	In Service
White River Dist.	TBD	Freightliner FL70	LPG Bobtail Deliv.	1	Planned
			Total:	**181**	

of the regulator vaporizer, and a front-cover and rear-cover gasket failure. Analysis of these occurrences is ongoing. Detail at a later date may be obtained from the Alternative Fuels Division of Cummins Engine Company.

In light of the HD-5 fuel specification, regular fuel testing by fleet operators is critical. Maintenance of HD-5 fuel quality is a requirement of B5.9 LPG warranty service. Even though all the LPG suppliers involved in this project made efforts to ensure HD-5 compliance, field-testing indicated a wider range of fuel quality was supplied.

Additional research and development are recommended in the following areas:

- EPA CFFV ULEV capability
- Wider range fuel capability for combustion, performance, and emissions
- Parts supplier research and development to increase performance and durability of LPG specific parts
- Regulator vaporizer issues remain to be completely resolved
- An octane sensor could help further LPG engine design. Such a sensor, as part of ECM control, can advise actual fuel quality of the charge about to be introduced in the combustion chamber (an engine with known octane value input to its ECM allows for the option to adjust certain combustion control parameters like air/fuel ratio or ignition timing, or both). Thus the engine can be more tolerant of a broader range of LPG fuel.
- On-board fuel supply sub-systems and components require further research and development. For instance, an accurate LPG fuel level gauge is needed.

Additional marketing/promotion activities are recommended to:

- Increase the number of OEMs offering the engine.
- Increase awareness of this engine's availability on international markets.

In summary, this project was a success in that it fostered an engine that met engine performance targets while significantly reducing emissions. The engine development program illuminated critical design differences between natural gas and LPG engines. Further research and development is needed for LPG-specific components provided by outside suppliers.

In its first year of production, Cummins has received almost 200 orders. Warranty service experience for this engine will not be known for some time but is expected to be similar to the B5.9G engine.

Nrel092att. pdf

Appendix 1 - CARB/EPA Emissions Certification Plan

Cummins 6B Propane Engine Development, Certification & Demonstraton Project

ARB / EPA EMISSION CERTIFICATION PLAN

Below is the proposed emissions certification plan for the Cummins 6B Propane Engine Development, Certification & Demonstration Project. The technically accurate name of the 6B LPG engine is the B5.9L LPG engine. For brevity and to reflect common usage, the 6B LPG name is used. Propane, or liquefied petroleum gases, is referred to as LPG. Please note that the timeframe is fluid and that there may changes based on the actual progress of certification testing and approval.

PARAMETERS:

Proposed Certification: Certification tests of the 6BLPG engine are planned per the requirements specified by the California Air Resources Board (ARB) and U.S. Environmental Protection Agency (EPA) for testing and application.

Fuel Specification: This engine is designed to use LPG that complies with the HD-5 LPG vehicular fuel specification. This specification requires a minimum of 95% LPG content within the fuel.

Catalyst: As initially proposed, certification with, and without, a catalytic converter was anticipated. However, based on previous work, it is expected that an oxidation catalyst will be required to meet the total hydrocarbons (THC) requirement for ARB / EPA requirements.

Deterioration Factor: Certification deterioration factor (DF) tests will not be required as Cummins already has an approved DF for a spark ignited lean-burn engine. This DF was based on a 1,200 hour engine test.

Emissions Targets: The 6B LPG engine certification targets are the EPA Clean Fuel Fleet Vehicle (CFFV) ultra low emission vehicle (ULEV) and proposed 2004 ARB / EPA Heavy Duty emission levels. Please refer to the following table.

The EPA CFFV program applies for fleets of 10 more vehicles which are centrally fueled, in the 22 non-attainment areas (NAA). For heavy-duty vehicles (8,500-26,000 gross vehicular weight [GVWR]), the requirement is 50% of the new vehicles purchased starting in 1998. A low emission vehicle (LEV) vehicle counts as 1.0 credits and a ULEV vehicle counts as 1.87 credits. Heavy-duty vehicles (over 26,000 GVWR) for these NAA fleets can generate credits though there are not required to as part of this program. Note that ARB LEV and ULEV emission standards do not apply to this engine since it is used in applications over 14,000 GVWR.

Cummins 6B Propane Engine Development, Certification & Demonstraton Project

ARB / EPA Emission Certification Plan

ARB / EPA Transient Heavy-Duty Engine Emissions Standard Table g/bhp-hr (g/kW-hr)

	1996 ARB / 1998 EPA Urban Bus	1998 ARB / EPA Heavy-Duty	1998 EPA ^ Heavy-Duty CFFV LEV	1998 EPA Heavy-Duty CFFV ILEV	1998 EPA Heavy-Duty CFFV ULEV	2004 ARB / EPA Heavy Duty
NOx	4.0 (5.36)	4.0 (5.36)	4.0 (5.36)	4.0 (5.36)	4.0 (5.36)	2.0 (2.7)
THC	1.3 (1.74)	1.3 (1.74)	1.3 (1.74)	1.3 (1.74)	1.3 (1.74)	0.54 (0.7)[1]
PM	0.05 (0.07)	0.10 (0.13)	0.10 (0.13)	0.10 (0.13)	0.05 (0.07)	0.10 (0.13)
CO	15.5 (20.8)	.15.5 (20.8)	15.5 (20.8)	14.4 (19.3)	7.2 (9.7)	15.5 (20.8)
HCHO	-	-	-	0.050	0.025	-

[1] Assumed THC limit is about 90% on NMHC limit.

TIMEFRAME:

Item	Target
Performance and Emission Optimization:	
- performance engine builds	10/96-3/97
- test cell R&D engine work	
- vehicle drivability evaluation	
- steady- state emissions testing baseline	
- CVS transient emissions testing baseline	
- repeat above procedure as required	
- test pre-certification limited production engine builds	
Plant Build/ Test of Certification Engine:	4/97 - 5/97
- certification limited production engine build	
- 120 Hour Conditioning Cycle Test at Cummins ETS Facility	
Engine Emissions Certification Test:	5/97
- per ARB / EPA (40 CFR 86) certification requirements; in general, this involves:	
- one cold cycle (1/7 weighted)	
- one hot cycle (6/7 weighted)	
- composite average result, and	
- apply established DF factor	

Cummins 6B Propane Engine Development, Certification & Demonstraton Project

ARB / EPA Emission Certification Plan

Submit 1997 Certification Requests to ARB / EPA:	6/97
Award of Certification from ARB/EPA:	7/97

Appendix 2 - Emissions Certification Documentation

State of California
AIR RESOURCES BOARD

EXECUTIVE ORDER C-86-75
Relating to Experimental Permits
For Vehicle Emission Control Devices

CUMMINS ENGINE COMPANY, INC.

Pursuant to the authority vested in the Air Resources Board by Section 43014 of the Health and Safety Code which allows it to issue permits for the testing of experimental motor vehicle pollution control devices installed in used motor vehicles, or for the testing of experimental and prototype motor vehicles which appear to have very low emission characteristics; and

Pursuant to the authority vested in the undersigned by Section 39515 and Section 39516 of the Health and Safety Code and Executive Order G-45-9(3)(k);

IT IS ORDERED AND RESOLVED: That Cummins Engine Company, Inc. having applied for a permit for experimental testing be granted this permit for emission and performance testing of one (1) propane gas bus engine.

Cummins Engine Company, Inc. shall keep a copy of this permit in the glove compartment of the following vehicle:

Vehicle MY	Make/VIN	Engine MY	Model	ESN
1993	Bluebird Q Bus 1BAGEBSA8RF061098	1998	B5.9-230G	45265227

Cummins Engine Company, Inc. shall maintain a record of the vehicle including the specific test program. This record shall be maintained for the duration of the test program and made available at reasonable times to the Air Resources Board.

This permit is valid for one year from the date of signature. At the expiration of this permit, the vehicle must be rebuilt to California-certified configuration or be shipped out of California.

Executed at El Monte, California this 9th day of December 1996.

John Kowalski

John Kowalski, Chief
Certification Branch
Mobile Source Operations Division

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

1997 MODEL YEAR
HEAVY-DUTY LOW EMISSION VEHICLE
CERTIFICATE OF CONFORMITY
WITH THE CLEAN AIR ACT OF 1970 ISSUED TO:

CUMMINS ENGINE COMPANY, INC	CUMMINS-NGE (MHDD)-97-34
MANUFACTURER	CERTIFICATE NUMBER
Chester J. France, Director, EPCD	September 5, 1997
OFFICE OF MOBILE SOURCES	EFFECTIVE DATE

DATE ISSUED: September 8, 1997

Pursuant to Section 206 of the Clean Air Act (42 U.S.C. 7525) and 40 CFR Parts 86 and 88, this certificate of conformity is hereby issued with respect to the test engines which have been found to conform the requirements of these regulations on Control of Air Pollution from New Motor Vehicles and New Motor Engines (40 CFR Parts 86 and 88)and which represent the following motor vehicle engines, by engine family, more fully described in the application of the above named manufacturer:

HEAVY DUTY (MEDIUM-HEAVY) NATURAL GAS FAMILY:VCE359D1CAAC (493F)

This certificate of conformity covers only those new motor vehicle light heavy-duty natural gas engines which conform, in all material respects, to the design specifications that applied to those engines described in the documentation required by 40 CFR Parts 86 and 88 and which are produced during the model year production period stated on this certificate of the said manufacturer, as defined in 40 CFR Parts 86 and 88. This certificate of conformity does not cover vehicles imported prior to the effective date of the certificate.

It is a term of this certificate that the manufacturer shall consent to all inspections described in 40 CFR 86.096-7, 86.606, and 86.1006 and authorized in a warrant or court order. Failure to comply with requirements of such a warrant or court order may lead to revocation or suspension of this certificate for reasons specified in 40 CFR Part 86 including 40 CFR 86.095-30, or render the certificate void ab initio as specified in 86.096-7. It is also a term of this certificate that this certificate may be revoked or suspended or rendered void ab initio for other reasons specified in 40 CFR Part 86, including 40 CFR 86.095-30, 86.612, 86.096-7, and 86.1012.

This certificate does not cover vehicles or engines sold, offered for sale, or introduced, or delivered for introduction, into commerce in the U.S. prior to the effective date of the certificate.

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

1998 MODEL YEAR
HEAVY-DUTY LOW EMISSION VEHICLE
CERTIFICATE OF CONFORMITY
WITH THE CLEAN AIR ACT OF 1970 ISSUED TO:

CUMMINS ENGINE COMPANY, INC
MANUFACTURER

CEX-NGE (MHDD)-98-12
CERTIFICATE NUMBER

Chester J. France, Director, EPCD
OFFICE OF MOBILE SOURCES

December 3, 1997
EFFECTIVE DATE

DATE ISSUED: December 3, 1997

Pursuant to Section 206 of the Clean Air Act (42 U.S.C. 7525) and 40 CFR Parts 86 and 88, this certificate of conformity is hereby issued with respect to the test engines which represent the following motor vehicle engines, by engine family, more fully described in the application of the above named manufacturer:

HEAVY DUTY (MEDIUM-HEAVY) NATURAL GAS FAMILY:WCEXH0359BAL (493F)

This certificate of conformity covers only those new motor vehicle heavy-duty natural gas engines which conform, in all material respects, to the design specifications that applied to those engines described in the documentation required by 40 CFR Parts 86 and 88 and which are produced during the model year production period stated on this certificate of the said manufacturer, as defined in 40 CFR Parts 86 and 88. This certificate of conformity does not cover vehicles imported prior to the effective date of the certificate.

It is a term of this certificate that the manufacturer shall consent to all inspections described in 40 CFR 86.096-7, 86.606, and 86.1006 and authorized in a warrant or court order. Failure to comply with requirements of such a warrant or court order may lead to revocation or suspension of this certificate for reasons specified in 40 CFR Part 86 including 40 CFR 86.095-30, or render the certificate void ab initio as specified in 86.096-7. It is also a term of this certificate that this certificate may be revoked or suspended or rendered void ab initio for other reasons specified in 40 CFR Part 86, including 40 CFR 86.095-30, 86.512, 86.096-7, and 86.1012.

This certificate does not cover vehicles or engines sold, offered for sale, or introduced, or delivered for introduction, into commerce in the U.S. prior to the effective date of the certificate.

State of California
AIR RESOURCES BOARD

EXECUTIVE ORDER A-21-201

Relating to Certification of New Heavy-Duty Motor Vehicle Engines

CUMMINS ENGINE COMPANY, INC.

Pursuant to the authority vested in the Air Resources Board by Sections 43100, 43102 and 43103 of the Health and Safety Code; and

Pursuant to the authority vested in the undersigned by Sections 39515 and 39516 of the Health and Safety Code and Executive Order G-45-9;

IT IS ORDERED AND RESOLVED: That the following Cummins Engine Company, Inc. 1998 model diesel engines are certified for use in motor vehicles with a manufacturer's gross vehicle weight rating (GVWR) over 14,000 pounds:

Fuel Type: Liquefied Petroleum Gas (LPG)

Engine Family	Liters	(Cubic Inches)	Exhaust Emission Control Systems and Special Features
WCEXH0359BAL (493F)	5.9	(359)	Charge Air Cooler Turbocharger Powertrain Control Module Heated Oxygen Sensor Oxidation Catalytic Converter

Engine models and codes are listed on attachments.

The following are the certification exhaust emission standards for this engine family in grams per brake-horsepower-hour:

Total Hydrocarbons	Carbon Monoxide	Nitrogen Oxides	Particulates
1.3	15.5	2.5	0.10

The following are the certification exhaust emission values for this engine family in grams per brake-horsepower-hour:

Total Hydrocarbons	Carbon Monoxide	Nitrogen Oxides	Particulates
0.8	1.0	2.3	0.01

BE IT FURTHER RESOLVED: That for the listed engine models, the manufacturer has submitted the materials to demonstrate certification compliance with the Board's emission control system warranty provisions (Title 13, California Code of Regulations, Section 2035 et seq.).

BE IT FURTHER RESOLVED: That the listed engine models are certified to the optional lower-emission NOx standards pursuant to the California Code of Regulations, Title 13, Section 1956.8(a)(1) and th incorporated "California Exhaust Emission Standards and Test Procedures for 1985 and Subsequent Model Heavy-Duty Diesel Engines ar Vehicles", adopted April 8, 1985, as last amended June 29, 1995.

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

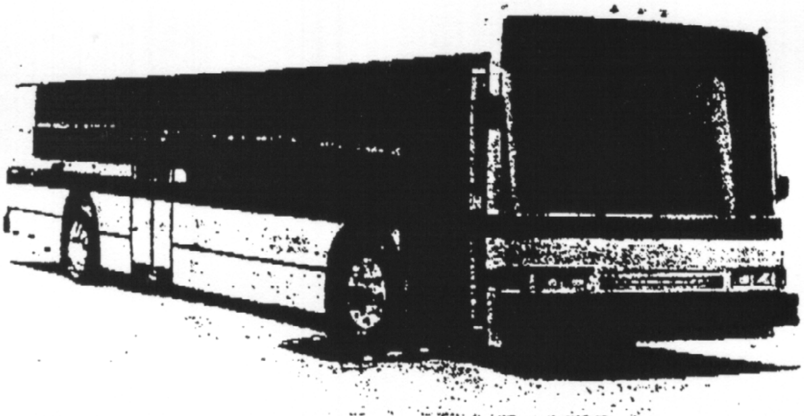
The Bureau of Automotive Repair will be notified by copy of this orde and attachments.

Executed at El Monte, California this 17th day of February 1998.

R B Summerfield

R. B. Summerfield, Chief
Mobile Source Operations Division

Appendix 3 - Cummins B5.9LPG Engine Articles



MORE THAN 200 ... low floor buses from North American Bus Industries are being added to VIA Metropolitan Transit's fleet in San Antonio, Texas.

San ... nio System To Add 283 New Vehicles by 2002

SAN ANTONIO, TEXAS—VIA Metropolitan Transit has approved the purchase of 283 new accessible low floor buses to be delivered between 1999 and 2002: 66 propane-powered 30-foot buses from Champion Motor Coach and 217 diesel-powered 40-foot buses from North American Bus Industries.

Of the $69.1 million total cost for the two bus contracts, federal grants will provide $55.3 million. The purchase, the largest bus procurement since VIA was established in 1978, was made to help make the system more accessible and to modernize the fleet.

Once all the new buses are delivered, 60 percent of VIA's fleet will be accessible—a substantial improvement from the current 6 percent.

Low floor buses do not need steps at the door because the floor is at approximately the same height as the street curb; the buses will be equipped with a ramp at the front door to allow wheelchair access. Together, these features are expected to make boarding the bus much quicker and easier for wheelchair users and other riders who have trouble climbing steps.

Doug Peck, VIA's director of vehicle maintenance, said both ergonomics and economics were factors in the choice of low floor vehicles. "Customers from other transit companies have really liked the low floor feature, which also happens to be much more economical than other styles," he said.

Because of the proximity to the curb level, low floor buses eliminate the need for a lift to accommodate some passengers. The hydraulic ramp and its controls are conveniently positioned in the front, allowing the operator to have a good view of the boarding process and assist passengers when necessary.

The bus acquisitions will complement VIA's other efforts to build an accessible system for all passengers, including persons with disabilities.

The system is developing a new fixed route bus ridership training program to provide persons with disabilities and the elderly with the skills necessary to ride the bus. The program will include hands-on instruction on how to ride the bus to work, medical facilities, or other destinations. In addition, VIA will have specially trained "Transit Ambassadors" available to work one-on-one with people to help them overcome obstacles that might have discouraged them from riding the bus.

While VIA currently operates paratransit service to provide transportation for persons with disabilities, riding the regular bus routes offers more flexibility and convenience for passengers. The new buses will allow the system to increase the number of accessible bus routes.

"Through these innovative programs and with these new buses, we will be able to offer people with disabilities more options," said VIA General Manager John Milam.

Modernizing the aging fleet was another priority for VIA; 107 of the system's buses have been in operation since the late 1970s. The new buses will replace part of VIA's older fleet. In fact, VIA plans to retire 329 older buses, vans, and streetcars by the year 2002. By the end of 2002, the average age of the fleet will be reduced from 14.86 years in 1998 to 7.99 years.

"The fact that we've been operating some of these vehicles for so long is certainly a tribute to the manufacturers and our employees in maintenance and operations," Peck said. "But now it's time to upgrade our fleet with the latest technology and advanced accessibility solutions."

The new vehicles also are expected to improve VIA's impact on the environment and further demonstrate the agency's commitment to the use of alternative fuels. The new 30-foot buses, equipped with the Cummins B5.9LPG low emissions vehicle propane engine, will join the 209 propane-powered vehicles currently in VIA's fleet. In addition, the system plans to convert all 20 of its downtown streetcars to propane by 1999.

While the Cummins ISC8.3 liter diesel engine on the new 40-foot buses is not LEV-certified, it is required to meet the 1998 Environmental Protection Agency urban transit bus emissions standards.

VIA is scheduled to receive all 66 of the 30-foot buses and the first 80 of the 40-foot buses in 1999. Eighty of the 40-foot buses will be delivered between 2000 and 2001, with the remaining 57 buses slated for delivery in 2002. At that time, the agency is expected to have a total of 502 buses and 20 streetcars in operation.

El Niño Doesn't Sink Ca... Thanks to Advance Pla...

Working with Amtrak

SAN CARLOS, CALIF.—Caltrain reports that advance planning has helped to keep service on the commuter railroad on track despite this winter's El Niño-related storms.

When talk of El Niño escalated last summer, Caltrain and its contract operator, Amtrak, closely inspected the entire Caltrain-owned right of way, 51 miles from San Francisco to San Jose.

Rail staff determined a little prevention would go a long way in maintaining the commuter rail service, on which 27,000 riders depend each weekday.

"Good drainage is the key to a successful railroad," said Caltrain Maintenance of Way Manager Mark Hennessy. To keep the rails flood- and debris-free, ... additional portable pum... problem areas. Caltrain ... generators, to operate the ... event of a power outage.

During last year's sto... right of way fell across ... passengers. This year, ra... trimmed trees between ... wood City and removed ... lyptus trees in Burlinga... branches could damage ... lines required for safe m...

Rail crews continue da... tracks and surrounding r... foot.

"By preparing for the ... vented it," said Hennessy...

Passenger Transport

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Propane Gas Bus Popularity Increasing in Texas

AUSTIN, Texas — As the drive to clean the air, lower maintenance costs and increase gas mileage continues, certain alternative fuels are enjoying a resurgence of sorts.

And this despite the legislature's 1995 decision to enact Senate Bill 1, removing mandates requiring public schools to convert their buses to cleaner burning fuels.

Propane, or liquefied petroleum gas (LPG), appears to be the most popular of the alternative fuels at this point with 1,764 Texas school buses in active service running on propane or a combination of the gas and diesel fuel. There are approximately 30,000 school buses currently on the road statewide, according to Sam Dixon, Texas's director of School Transportation.

The Railroad Commission of Texas, a longtime supporter and financial beneficiary of the propane industry, said the 1,764 school buses operating with the gas is up 389 buses from 1,375 in June 1995. An estimated 131 additional LPG bus conversions are planned, according to the commission.

"It's a very clean burning fuel, the oil stays cleaner and the spark plugs last longer," said E.L. Washington, transportation director at Dimmitt Independent School District about 70 miles south of Amarillo. "You can look at the engine and even if it's run 100,000 miles, it looks like a new engine."

Fourteen of Dimmitt's 17 school buses either run on LPG alone or with a combination of LPG and diesel.

Cheaper Fuel

Of course the main push behind converting to LPG is its ability to reduce air pollution and lower maintenance costs.

Propane is also cheaper at the pump with prices ranging from 60 cents to 65 cents per gallon compared to 89 cents or 90 cents per gallon for diesel or gasoline. School districts with their own fueling stations can take advantage of even cheaper LPG prices, according to Rhoda Elovitz at the Texas Railroad Commission.

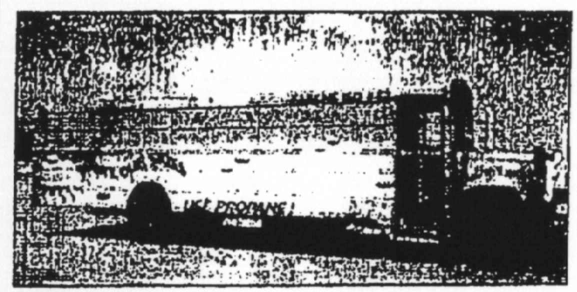
Reluctance to Change

So why aren't all school districts rushing to convert their buses to LPG?

A couple of reasons: gas mileage and there is currently only one major manufacturer of gasoline buses that can be successfully converted to use propane.

Washington said his 72-passenger buses get only five or six miles per gallon, compared to diesel buses that average between nine and 11 miles per gallon. The nineteen-passenger buses average about eight miles per gallon using propane gas. So while the purchase price may be cheaper, gas mileage is lower and in essence the cost is about the same.

In addition, Blue Bird Corporation is the only company offering the suitable General Motors-Chevrolet bus chassis that can be converted, according to Tom Turner, an engineer with the company's Fort Valley plant in Georgia.



Propane gas buses, similar to this one used by the Fabens Independent School District approximately 50 miles south of El Paso, are helping to clean the air and lower transportation costs for school districts across Texas.

Given the relatively low gas mileage of LPG buses, Dixon said there is often little incentive for school districts to convert from standard gasoline. New equipment must also be fitted to LPG buses which further increase the conversion price tag, he added.

According to Northwest Butane in Dallas, school districts operating without a fuel contract are required to pay $1,949 per bus to complete the conversion process. Those with a contract to purchase from Northwest Butane currently pay $1,250 per bus. Rates vary depending on the company providing fuel, Elovitz said.

More Benefits

Gene Holloway, director of Transportation for Denton Independent School District about 35 miles north of Dallas, said his district began converting some of its 103 buses to propane in fall 1995. Courtesy of an 80 percent funding grant from the state's Alternative Fuels Council, 60 of the district's buses are now operating on propane. The remaining buses operate on either diesel fuel of unleaded gasoline.

Even though the district was required to pay 20 percent of the conversion cost, Halloway said the move was a good one and it is resulting in lower maintenance and overall fuel costs. His department in the midst of determining the savings they have achieved by utilizing the buses but he feels it will be a substantial amount over previous years.

"As technology improves, gas mileage of propane buses will continue to improve," Halloway said. "And with the wave of movement to alternative fuels, more districts are going to realize that it is smart move both financially and environmentally."

New Pasadena Bus Drives Rose Parade Route Every Day

Some lucky bus drivers in Pasadena, Calif. get to drive a propane-fueled bus up and down much of the parade route for the "Grandaddy" of all parades, the Rose Parade. On parade every day as part of the city's transportation services, the propane-fueled Bluebird bus with a Cummins B5.9 LPG engine is one of several buses used on two routes, to provide free bus transportation.

The artistically decorated buses are part of the city's efforts to help get citizens out of their cars and reduce the number of vehicles on city streets. Students in the city's schools entered a contest to design the decoration for the buses. The designs that were chosen were then enlarged and placed on the buses. Most of the bus fleet currently runs on diesel. Two propane-fueled models are part of an 18-month demonstration project to determine if the alternative fuel is cost effective and works efficiently.

The first bus was converted at the end of 1996. Cummins changed the diesel engine to its propane model at the manufacturer's Southern California facility. The new fuel tanks were also installed at that time. The bus, which is called "the Rose Parade bus" by the city's transit office, experienced a few minor operation problems in the beginning. Since then, according to the city transit office, it has been operating consistently and smoothly along the 15-mile route. The other route is 6 miles long. A second bus was to be converted at the end of May and be in operation shortly afterward.

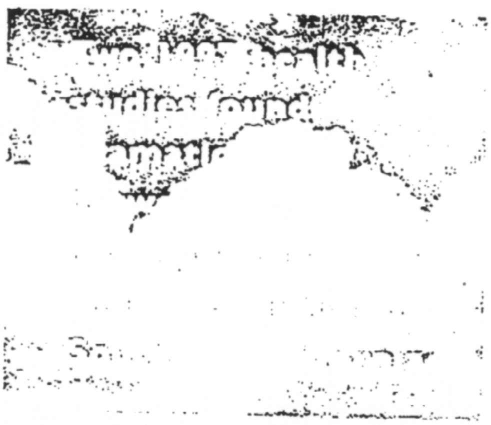
The "Peace Bus"

According to Steve Moore of Mutual Propane (Gardena, Calif.), the first bus was taken to the nearby Cummins facility to change the engine, add the two Manchester propane tanks, and make sure the vehicle was working properly. The bus has a manifolded fuel supply, an 80-gal. tank and a 35-gal. tank. For the second bus, Cummins was expected to replace the diesel engine at its facilities and Mutual would then add the tanks at its Gardena plant. The second bus is called "the Peace bus" and is decorated with numerous symbols representing peace to different cultures.

When not in operation, the buses are stored at the Laidlaw bus facility in Pasadena with the other city transit vehicles. Laidlaw, a company that offers bus and transit services to cities and other organizations, is managing the fleet for the city. Mutual installed an 1150-gal. tank and refueling equipment for the buses at a city storage site near the Laidlaw facility and close to their routes. The buses can be filled at about 12-15 gpm. Mutual said installation of the refueling site was one of the more difficult aspects of the project because the city required a lot of paperwork to be filled out as part of the permit process. Luckily, the city's transit department was helpful in handling much of the paperwork.

According to Diane Kotto of the city transit office, one of the propane-fueled models will be on display at this year's Clean Cities Conference, which will be held in Long Beach, Calif., June 24-27. ■

The $5 million Southern California Ozone Study (SCOS97) conducted during the summer of 1997 will help with those planning efforts. AQMD was a major participant in the effort, which used laser light beams, aircraft and balloons to gather data. The study provided a wealth of information to determine how smog travels from one region to another and will help predict when the region will achieve clean air.



Health News

Two health studies sponsored by AQMD and reported in 1997 found dramatic links between ozone and particulate pollution in Southern California and hospitalizations, emergency room visits and premature deaths. The studies are significant because they paired detailed daily air quality data in the Southland with local hospital records.

One study surveyed hospital records of more than 1.6 million Kaiser Permanente patients. The results suggest that each 10 microgram increase in the coarse fraction of PM_{10} is associated with a 7% increase in hospital admissions for chronic respiratory disease -- twice the rate reported in other areas of the country.

A second study found that a 10 microgram increase in PM_{10} in the Coachella Valley was associated with a 2.5% increase in emergency room visits for pneumonia and a 1% increase in deaths.

Clean Fuel Technologies

AQMD launched its Technology Advancement Office in 1988 to promote the development of advanced clean fuel technologies.

Clean fuel technologies took a giant leap forward in 1997 with major automakers pledging nearly $1 billion toward research and development of fuel cell-powered electric automobiles.

Fuel cells combine hydrogen and oxygen to produce electricity, emitting only water vapor. AQMD's Technology Advancement Office (TAO) has been a major proponent and contributor in the development of fuel cells since the late 1980s.

In 1997, the Governing Board approved 42 contracts for fuel cells and other clean fuel technologies totaling $5 million. Cost-sharing from other agencies and private firms will boost the value of the projects to $17.1 million.

Milestones of TAO-sponsored projects in 1997 include:

- Completion of three fuel cell-powered utility vehicles -- the only ones in daily use in the world -- in the City of Palm Desert;
- Building of an affordable electric car prototype with detailed plans on how it could be mass-produced in California;
- Completion of a one-year study demonstrating that professional "wet cleaning" of garments with soap and water is a viable substitute for dry cleaning, which uses the toxic chemical perchloroethylene;
- Development of a new locomotive engine design using liquid natural gas fuel that cuts nitrogen oxide emissions by 75% and virtually eliminates soot. The technology will be demonstrated in the near future in a Metrolink train; and

AQMD co-sponsored several significant clean fuel projects in 1997, including the Pasadena Art Bus, a shuttle in that city's downtown area powered by a soot-free propane engine.

■ Production of the first medium-duty propane engine certified to meet low emission standards by the California Air Resources Board.

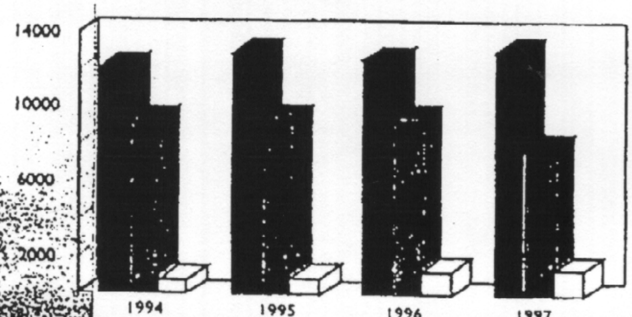
Mobile Source Air Pollution Reduction Review Committee

Two year (FY97-98 and FY 98-99) program budget:	$29,500,000
Contracts awarded/funds committed in calendar year 1997:	$13,001,680

MSRC Programs

In 1997, the Mobile Source Air Pollution Reduction Review Committee (MSRC) awarded $13 million in contracts to co-fund zero- and ultra-low-emission vehicles, transportation management and local government air quality programs. MSRC is an independent entity whose projects are approved by AQMD's Governing Board. Since 1995, MSRC's "Quick Charge" program has been instrumental in putting more than 300 electric vehicles on Southland streets and installing more than 400 electric vehicle charging stations.

Permitting Activity



■ Permits Processed* ■ Permits to Operate □ Permits to Construct

*Includes applications canceled, expired and denied

Permit Streamlining

AQMD staff took several steps in 1997 to streamline permit processing, including:

■ Simplifying permit applications, resulting in 50% fewer filing errors;

■ Streamlining applications for major sources in Title V, the new federal operating permit program; and

■ Maintaining detailed permit application instructions and downloadable forms on AQMD's Website. Businesses can even submit applications for some commonly used equipment over the Internet.

But the region's rebounding economy, more complex federal permitting requirements and a smaller AQMD workforce caused a small but worrisome increase in the permit backlog by year's end. AQMD plans to reallocate staff to permit processing and pursue additional permit streamlining in 1998 to reduce that backlog.

Business Assistance

During 1997, AQMD's Office of Public Affairs Business Assistance Group engaged in several activities to help firms comply with air quality regulations, including:

■ Assisting officials at an Entenmann's Bakery facility in Montebello, who were contemplating a cost-saving move to Central California, to instead modernize their

Speakers Bureau Presentations:	216
Outreach events and conferences:	153
Community and business outreach meetings:	145
Foreign dignitaries hosted: 94 visitors in 32 delegations representing 20 countries	
Small business assistance customers assisted:	1,922

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13. ABSTRACT *(Maximum 200 words)* The objective of this project was to successfuly develop and certify an LPG-dedicated medium-duty original equipment manufacturer (OEM) engine that could be put into production. The engine was launched into production in 1994, and more than 800 B5.9G engines are now in service in the United States and abroad. This engine is now offered by more than 30 bus and truck OEMs.

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Alternative transportation fuels, liquefied petroleum gas, propane, engine development

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