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AUTHOR	Lyons, John Kim; McCoy, Gilbert A.
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ABSTRACT

This document presents findings of a study that evaluated the use of both propane and compressed natural gas as alternative fuels for Washington State school buses. It discusses air quality improvement actions by state- and federal-level regulators and summarizes vehicle design, development, and commercialization activities by all major engine, automotive, and school bus manufacturers. It also examines Washington's school bus fleet and recommends actions to ensure the emissions-reduction benefits gained from purchasing and operating clean-burning vehicles. It is recommended that the state: (1) establish safety standards controlling the use of alternative fuels; (2) support the office of Superintendent of Public Instruction's (SPI) current development of minimum gaseous fuel specifications for school buses; (3) monitor original equipment manufacturers' activities; (4) support after-market conversions under specific conditions; and (5) establish a framework for future alternative fuel use. Contains 13 tables and 21 figures. (LMI)

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Alternative Fuels for Washington's School Buses

A Report to the Washington State Legislature

WSEO
Washington State Energy Office

Alternative Fuels for Washington's School Buses

A Report to the Washington State Legislature

December 1991

Prepared for:
The House Appropriations Committee
The House Environmental Affairs Committee
The Senate Ways and Means Committee
The Senate Environment and Natural Resources Committee

Prepared by
John Kim Lyons
Gilbert A. McCoy

Washington State Energy Office
809 Legion Way SE
PO Box 43165
Olympia, WA 98504-3165

WSEO
Washington State Energy Office

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The Honorable George Orr
The Honorable Bob Oke
The Honorable Adam Smith
The Honorable Sarah Casada
Michael McSorley, WSEO
Norman Lowrey, Tumwater School District
Don Carnahan, Office of the Superintendent of Public Instruction
Larry Berdan, Washington Natural Gas
Teddy Le, Department of Ecology
Alvey Erskin, Riverside School District

Findings and Recommendations

The Alternative Fuel School Bus Advisory Committee has been evaluating the use of both propane and compressed natural gas (CNG) as a motor vehicle fuel for school buses. The following findings and recommendations summarize the major issues effecting the use of alternative fuels, and identify actions that can be taken by the State to help foster the development of an alternative fuels program for Washington's school bus fleet.

Findings

- Washington's school districts operate a combined fleet of 7,111 buses. Sixty-four percent (4450 buses) of the fleet consists of diesel-powered units, while gasoline-fueled buses account for 31.9 percent (2273 buses) of the total. Approximately 30 percent (2128 units) consists of aging 1977 and earlier model year buses.

- Alternative fuels—compressed natural gas and propane—are already being used by 3.9 percent (284 buses) of the state's fleet.

- Because of fuel economy advantages, engine availability, and safety concerns, the state's school districts have been preferentially purchasing diesel buses since 1984. The majority of the alternative-fueled buses are older, pre-1985 models because only gasoline-powered engines have been converted to operate with alternative fuels.

- Bus safety standards have changed significantly since 1977. Improvements include escape doors on both sides of the bus, roof escape hatches, minimum aisle width and seat space requirements, seat material combustibility standards, and fuel tank crash guards.

- Various authorities conclude that both compressed natural gas (CNG) and propane, when used as a vehicle fuel, are as safe or safer than gasoline provided that proper safety standards are followed. While there is no federal standard currently regulating the use of gaseous fuels for vehicle operations, there are a number of industry-sponsored standards that have been adopted by the state and appear to adequately address gaseous fuel safety and performance issues.

- From a safety standpoint, it is detrimental to extend the operating life of antiquated buses by rebuilding them and converting them to operate on alternative fuels. Emissions reductions and safety benefits are best obtained by procuring new crash-tested, dedicated alternative-fueled buses.

- Factory-built buses, with original equipment manufacturer dedicated-CNG engines, are now available at prices that are competitive with those for diesel buses. Additional engine and body offerings will be available soon. No factory-built propane-fueled buses are currently being produced, however, both General Motors and Ford have begun to manufacture dedicated propane engines.

- The dedicated CNG engines available are in their prototype, demonstration, and early production stages. The first factory-built dedicated CNG-fueled buses "hit the streets" in the spring of 1991. Refinements and reductions in emissions are expected as engine, carburetion, fuel injection, and pollution control technologies mature. Of particular interest is the incorporation of closed loop, micro-processor-based alternative fuel electronic fuel injection system equipment into the factory-built buses. Two such systems became commercially available in the fall of 1991.

- Limited emissions testing results indicate that the currently available CNG-powered engines are capable of meeting EPA's strict 1994 emission requirements. This is not unexpected, however, as the 1994 standard is focused on reducing particulate emissions. CNG-powered engines are, by nature, low particulate emitters.

- Conventional liquid-fueled heavy-duty engines sold after 1994 also must meet EPA requirements. The next generation of diesel engines is now in the design, prototype testing, and pre-production stage. It is, therefore, impossible to predict overall emissions reduction benefits due to procuring and operating alternative-fueled buses as compared to the next generation of conventionally fuelled buses.

- Likewise, little information is currently available on the fuel economy of advanced electronic-diesel or of dedicated alternative-fueled engine designs.

- The emissions benefits resulting from after-market conversion of vehicles to gaseous fuel operations is unpredictable and varies from excellent to poor. Retrofit vehicle performance depends on the make, model, and condition of the vehicle converted; the type of conversion equipment specified; the quality of the installation; how well and how often the equipment is calibrated; and the type and condition of the vehicle's emissions control equipment.

- Both Colorado and California require manufacturers of propane and CNG conversion systems to obtain state approval prior to the systems being sold or installed in vehicles. The certification is based on emissions compliance for a given class of vehicle.

- The cost-effectiveness of an alternative fuels program depends on many variables, including bus size, usage, engine option, fuel economy (for both the conventional and alternative-fueled units), fuel price differential, federal and state fuel taxing policies, and refueling station costs.

- While no "rules of thumb" are available, experience with previous alternative fuel retrofit programs indicates that for heavy usage vehicles, simple paybacks on investment of 4 years or less are attainable.

Recommendations

The engine, automotive, and school bus manufacturing industries are in a state of rapid transition as ever more restrictive air quality regulations are being imposed. With continued advances in combustion, fuel-injection, and post-combustion treatment technologies, factory-built CNG and propane fuel buses offer the promise of significant reductions in vehicle emissions while simultaneously providing equal or lower operating costs. Given this environment, the potential benefits from alternative fuel bus operations can not be ignored. While a headlong rush is not warranted at this time, steps supporting alternative fuel use in Washington's school bus fleet are needed.

First and foremost, safety standards controlling the use of alternative fuels need to be established. Until federal standards are in-place, the State should adopt and enforce relevant industry standards including NFPA 52, NFPA 58, and D.O.T. cylinder specifications. Currently, the NFPA Standards are followed by the state Fire Marshal, however, formal recognition of these standards by the State would help to strengthen their use. The State should also consider adopting the AGA 1-85 conversion kit certification requirements and the California Air Resources Board's (CARB) list of approved liquified petroleum gas (LPG) and CNG conversion systems. Further, the State should institute an inspection program to make sure fuel cylinders are being recertified using D.O.T. specifications. This latter activity could be done by the State Patrol during their regularly scheduled school bus safety inspections.

The State should also support SPI's current development of minimum gaseous fuel specifications for school buses. This will assist school districts currently considering the purchase of alternative fueled buses as well as establish bottom line safety and performance standards for alternative fuel use. Standardization of CNG refueling nozzles and refilling station pressures should also be considered here.

Because dedicated alternative fueled buses offer the greatest potential for both air quality benefits and safety improvements, their procurement should be encouraged. However, until the market settles, an all out investment in factory-built alternative fuel buses would not be in the State's best interest. Instead, original equipment manufacturers (OEM) activities should be monitored, as should developments within California's and Texas' alternative fuel school bus programs. This information can then be used to help develop alternative fuel bus procurement specifications.

With respect to after-market conversions, the State should support these activities provided that all relevant safety and code requirements are enforced; that the conversion equipment used be CARB approved; and that the bus to be converted is within its useful operating life as defined by the Superintendent of Public Instruction. This final condition is needed to ensure that conversions do not extend the operating life of a bus beyond what is considered safe.

Finally, the State should establish a solid framework for future alternative fuel use. To this end, a series of demonstrations of commercially available technologies should be conducted. Monies from the State Clean Fuels Fund could be allocated to school districts interested in purchasing, testing, and operating alternative clean fuel vehicle technologies. The State should also seek co-funding opportunities with natural gas utilities and/or the propane industry. Fuel economy, vehicle performance, and emissions data would be collected and the results used to help structure additional alternative fuel activities.

Table of Contents

8

Tables

Figures

Chapter 1
Introduction

Background

A natural gas working group, comprised of seven gas utilities, prepared *An Alternative Vehicle Fuels Program for the Commonwealth of Virginia*. The group stated that:

> Natural gas, like no other alternative fuel, has the ability to simultaneously reduce, in an across the board fashion and in significant quantities, all the major vehicular pollutants.[1]

The U.S. Environmental Protection Agency (EPA), in their recent report *Analysis of the Economic and Environmental Effects of Compressed Natural Gas as a Vehicle Fuel* states that "optimized dedicated CNG (*compressed natural gas*) vehicles are projected to emit 80-93 percent less reactive hydrocarbon emissions than future in-use gasoline vehicles." EPA also states that "future advanced technology CNG vehicles will likely be able to provide reductions of over 90 percent for CO emissions." When the emissions and potency are considered together, "the exhaust emissions from CNG-fueled cars can be more than 90 percent lower in toxic impact compared to gasoline-fueled vehicles."[2]

The key words in the above paragraphs are "optimized dedicated" and "future advanced technologies." Much work remains to be done to fully capture the emissions reductions benefits of gaseous powered vehicles.

The Natural Gas Vehicle Coalition lists a number of supporting actions that are required for the design, commercialization, and widespread use of low-emission natural gas vehicles in the United States. These actions could also be applied to propane-powered vehicles and include:[3]

- Establishing a technically sound legal and regulatory environment
- Developing engines and vehicles optimized for natural gas use
- Developing needed component technologies for use in advanced CNG-fueled engines
- Convincing vehicle manufacturers to produce and sell natural gas vehicles
- Securing public and user acceptance

Recent state and local government activity, aimed at creating markets for clean-fuel vehicles and at increasing the use of domestically produced fuel, has spurred the development and demonstration of gaseous-fueled vehicles. Advances in technologies such as on-board fuel storage and microprocessor-based fuel injection systems, oxygen sensors, lean-burn engine concepts, and optimized catalytic converters, are occurring at a rapid rate. Virtually all engine and vehicle manufacturers are now in the process of designing or building dedicated gaseous fueled units. Institutional issues such as mechanic training, conversion center certification, equipment and mounting specifications, conversion kit emissions performance, and fire safety and code enforcement are also beginning to be addressed.

Currently, over 3.8 million vehicles have been converted to operate with liquified petroleum gas (LPG) worldwide with 370,000 propane-fired commercial vehicles in the U.S. An additional 440,000 vehicles have been converted to operate on natural gas worldwide, with 30,000 CNG-fueled vehicles in the United States and 26,000 in Canada. Italy reports the largest number of natural gas powered vehicles in use. Because of this, Italy is a predominate source of supply for all types of vehicle conversion and refueling station equipment.[4]

The converted vehicles are, however, mainly driven by light-duty gasoline automotive engines that have been retrofitted to allow the use of natural gas or propane. Heavy-duty diesel engine conversions are rare, with only 560 reported worldwide. Buses are the most commonly converted heavy-duty vehicle. Numbers of natural gas converted vehicles and refueling stations by country are given in Table 1.[4]

Table 1
Natural Gas Vehicles by Country

Country	Number of Vehicles Converted			Refueling Stations
	Total	Diesel	Gasoline	
Italy	235,000	20	234,980	240
Argentina	100,000	10	99,990	125
New Zealand	50,000	65	49,935	350
US	30,000	unknown	unknown	328
Canada	26,100	25	26,075	173
Brazil	700	300	400	7
Australia	626	112	514	10
Bangladesh	65	13	52	1
Thailand	31	11	20	2
Belgium	24	0	24	1
Japan	22	1	21	4
UK	16	0	16	2
Sweden	6	5	1	3
Totals	**442,590**	**560**	**442,030**	**1,246**

What This Report Covers

This report discusses air quality improvement actions by regulators—both at the state and federal levels—and summarizes vehicle design, development, and commercialization activities by all major engine, automotive, and school bus manufacturers. The report also examines Washington's school bus fleet and recommends actions that can be taken to ensure that the emissions reduction benefits from purchasing and operating clean-burning vehicles can be captured.

Chapter 2
Washington's School Buses

Fleet Overview

Washington's school bus fleet is constantly changing as new buses are purchased and older units are retired. At best, we can onlyexamine this fleet at a single point in time. The "snapshot" used for this study is a mid-1991 version of the school bus database maintained by the Pupil Transportation Section of the office of Superintendent of Public Instruction (SPI).

The SPI database indicates that in mid-1991, 289 Washington School Districts operated a total of 7111 buses. A breakout of buses classified by fuel type is shown in Figure 1. Sixty-four percent (4559 buses) of the fleet consists of diesel-powered units while gasoline-fueled buses account for 31.9 percent (2273 buses) of the total.

Fourteen Districts provide for student transportation with 863 buses leased from private carriers. Five of these Districts, Seattle, Tacoma, Spokane, Everett, and Battleground, account for 772 or almost 84 percent of the leased bus total.

Approximately 3.9 percent (279 buses) of the state's fleet is currently comprised of alternative fueled units. Twenty-four school districts operate a total of 226 propane-powered buses while the Tumwater, Yelm, and Tacoma school districts now operate 53 dual-fueled and 5 dedicated fuel CNG buses. Dual fuel capability means that the bus is equipped with a selector switch that enables the driver to choose to operate on either CNG or gasoline fuel.

The number of buses purchased by model year is given in Figure 2. Annual purchases, depending upon funding sources, range between 100 to 500 buses. Figure 2 also indicates that the post 1984 purchases are comprised mainly of diesel-powered buses. The majority of pre-1984 purchases consist of gasoline-fueled units. Figure 2 also indicates the number of alternative-fueled buses in the state fleet by model year. The majority of the alternative-fueled buses are older, pre-1985 units, as only gasoline-powered engines have been converted to operate on alternative fuels.

The age distribution for Washington's buses is given in Figure 3. Approximately 30 percent (2128 units) of Washington's fleet consists of 1977 and earlier model year buses. The bulk of these pre-1978 buses, as shown in Figure 4, are gasoline-powered. These buses are not built to current safety standards and are considered to be near the end of their useful operating lives. From a safety as well as emissions standpoint, it would not be in the interest of the State to repower these buses with alternative fueled engines or to rebuild/convert the existing engines to an alternative fuel. Replacement with newer buses, either using electronic diesel or original equipment manufacturer-supplied natural-gas-fired engines, will yield safety, fuel economy, and emissions reductions benefits.

School Bus Characteristics

Washington's school buses have seating capacities ranging from 8 to 97 students. The total number of buses is shown by passenger carrying capacity in Figure 5. Only size increments with more than 100 buses are shown. Approximately 51 percent (3622) of all Washington school buses are sized for carrying 65, 66, 73, or 78 passengers. When evaluating factory-built, alternative-fueled equipment it is obviously important to consider the availability of buses in these size ranges and/or of engines with the torque and horsepower capabilities necessary to power buses in these size ranges.

Figure 1

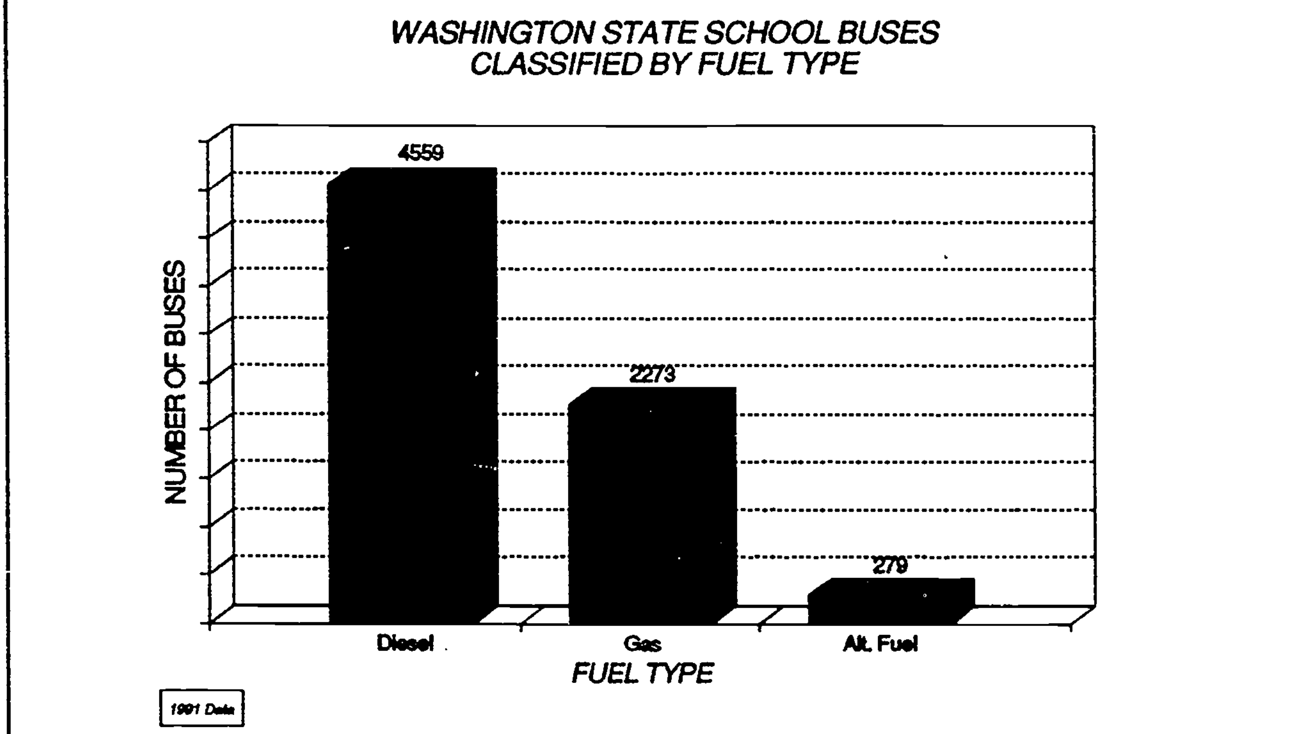


Figure 2

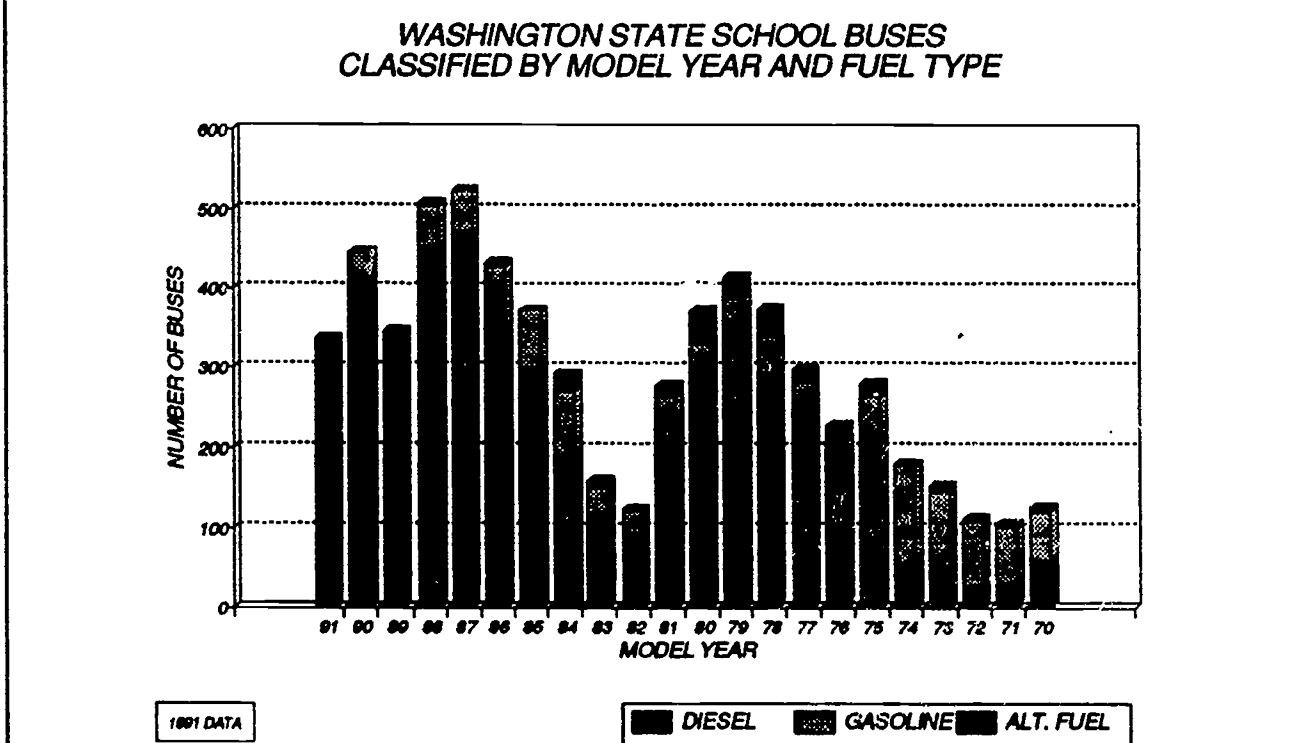


Figure 3

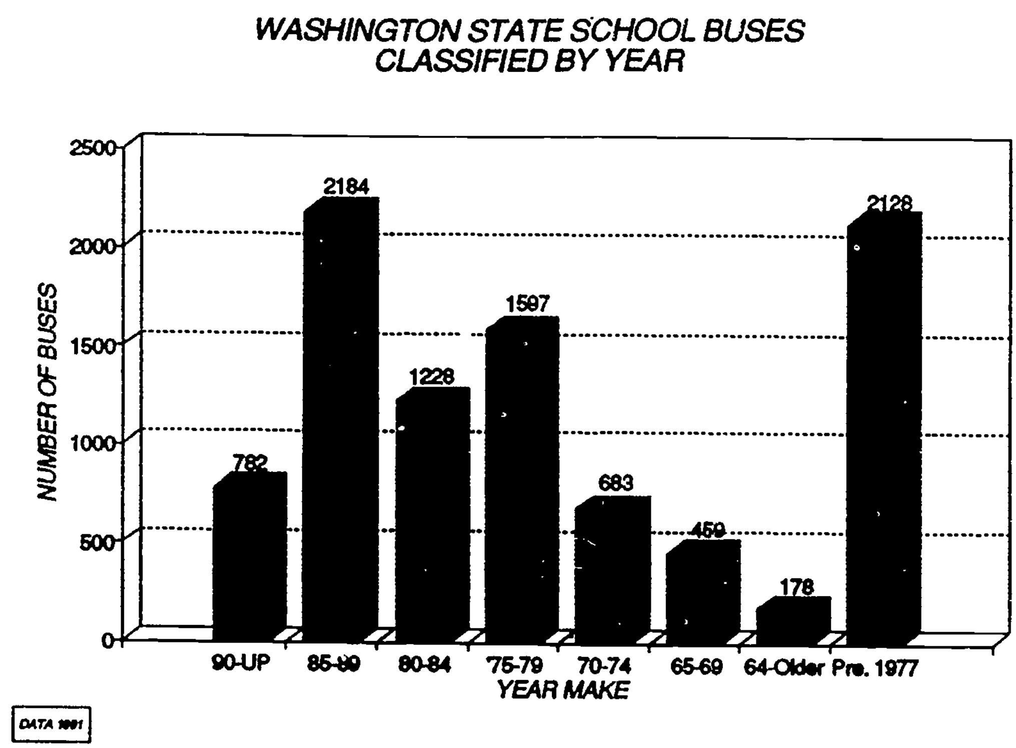


Figure 4

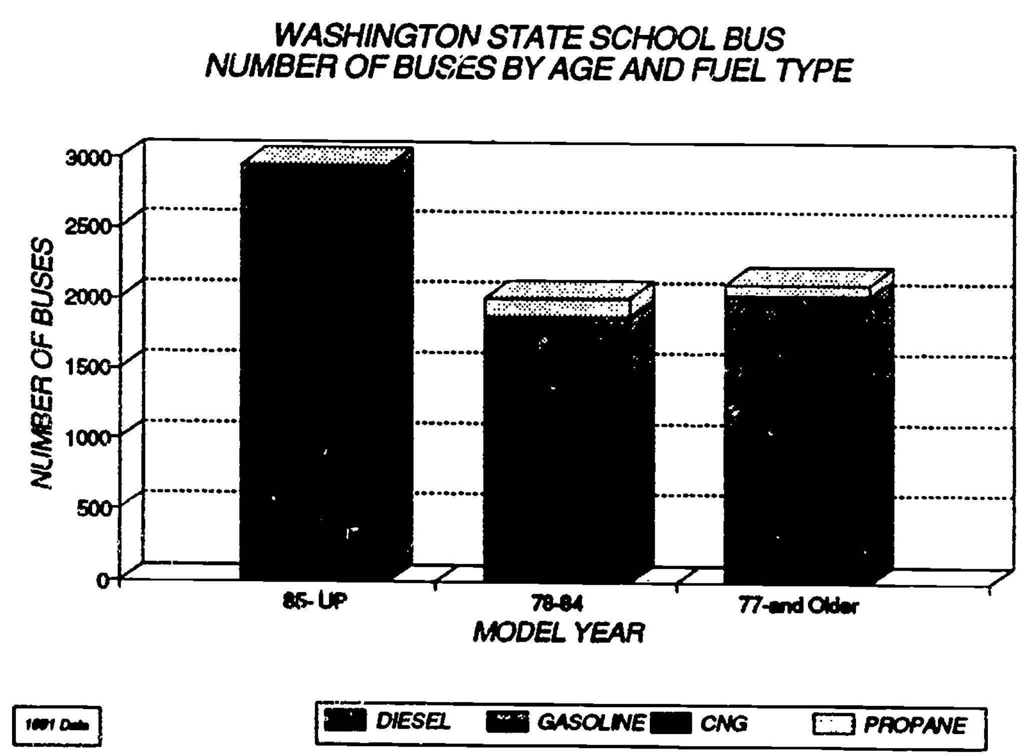
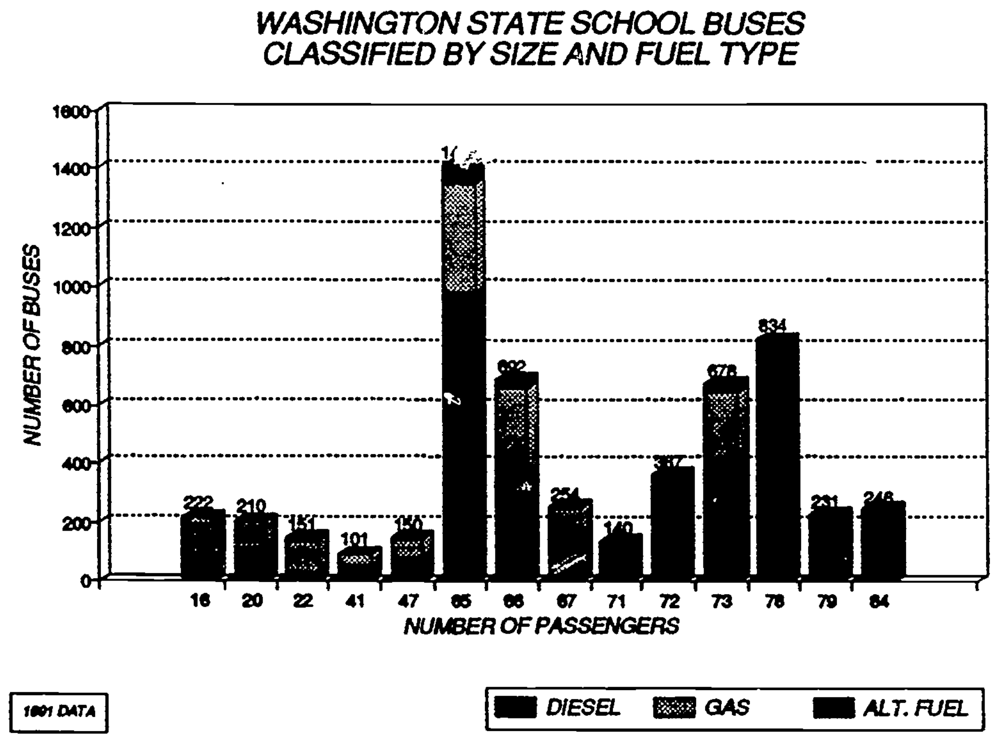


Figure 5



The distribution of school district fleet sizes is also of interest. At least 15 buses, using approximately 2000 gallons of fuel per year, and returning to a single base would be necessary to justify the expense of installing an on-site CNG refueling station. Figure 6 indicates the number of school districts operating fleets within given size ranges. One hundred twenty-nine Washington districts operate fleets of greater than 15 buses. When natural gas service is available, these fleets represent prime candidates for future alternative fuel projects. Figure 7 indicates the total number of buses as a function of fleet size. Districts with fleets exceeding 15 units operate 5,902 buses or approximately 83 percent of the entire state's total.

Engine Selection

The SPI school bus database lists engine make, model, and displacement for 1982 model year and newer buses. A breakout of the number of buses by engine manufacturer and fuel type is given in Figure 8. Caterpillar and International account for the bulk of the engines purchased and used within Washington. The number of buses by engine model is indicated in Figure 9. The Caterpillar 3208, International DT 466, and Cummins 5.9L diesel engines represent approximately 53 percent of the engines currently listed in the database.

There is no "standard" engine that is typically specified for a bus of a given passenger-carrying capacity or gross vehicle weight. As many as 25 different engines might be available and ordered for a 65-passenger bus. The most commonly used engines for buses of various sizes are indicated in Table 2.

The variation in engine capability is illustrated by examining the Detroit Diesel 6-71, which is available at 300 hp, and the Cummins 5.9L engine, which is available at 160, 190, 210, and 230 hp. Both are used to power 78-passenger buses.

Figure 6

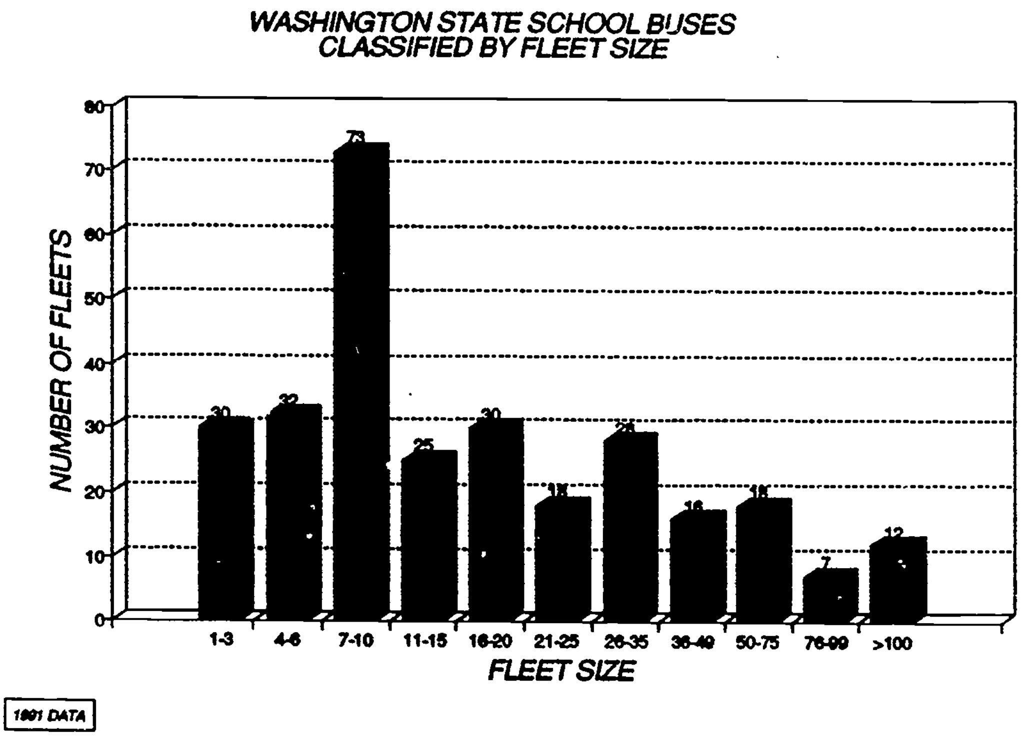


Figure 7

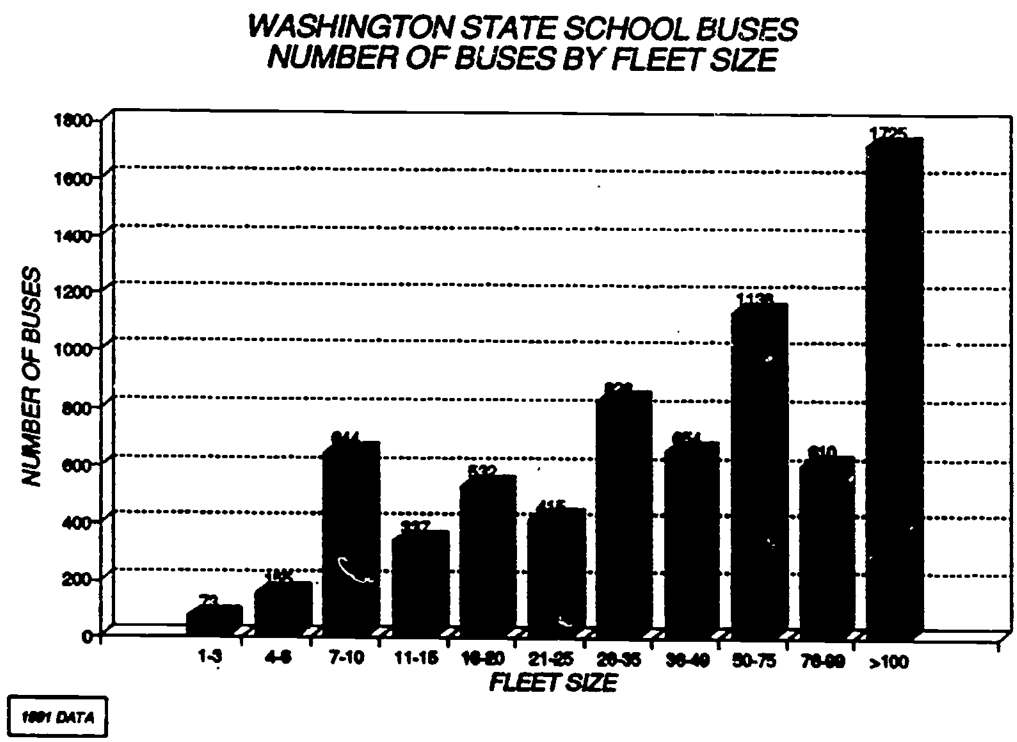


Figure 8

WASHINGTON STATE SCHOOL BUSES CLASSIFIED BY ENGINE MAKE AND FUEL TYPE

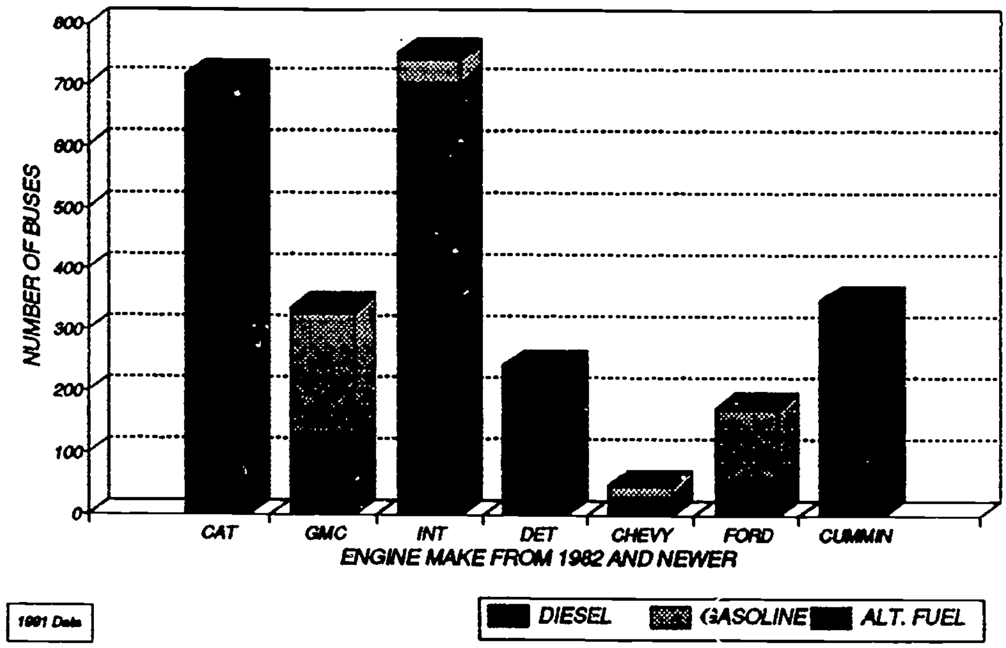
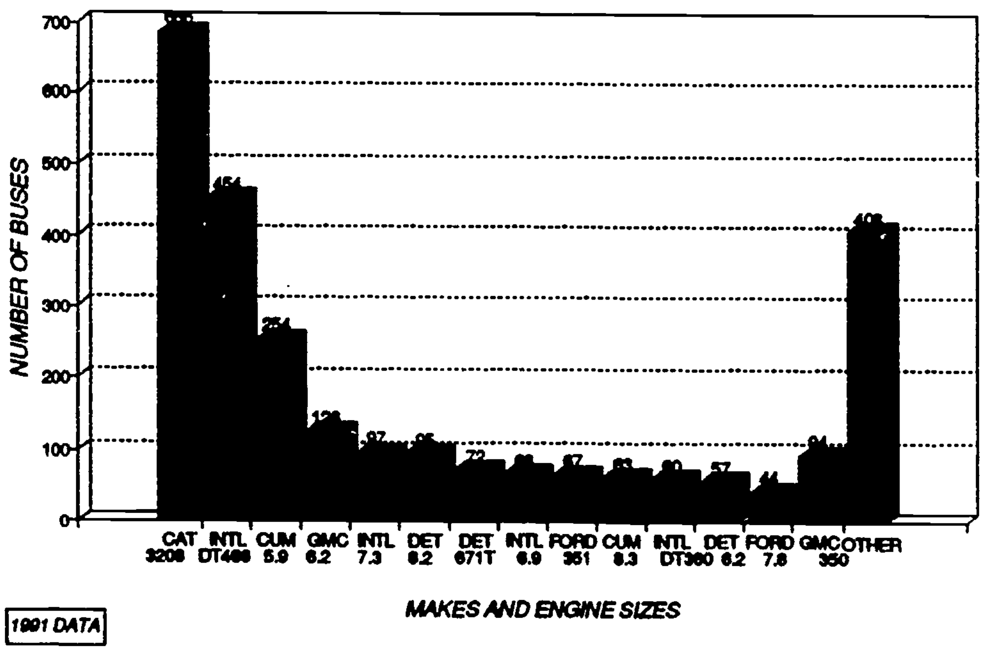


Figure 9

WASHINGTON STATE SCHOOL BUSES ENGINE SELECTION FROM 1982 AND NEWER



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Power output for engines that are typically found in school buses are indicated in Figure 10. The commonly used CAT 3208 engine has been superseded by the 6.6L CAT 3116 in-line, 6-cylinder diesel engine. This engine comes in 170, 185, 215, and 250 horsepower models.

Table 2
Commonly Specified Engines for School Buses of Various Capacities

Engine Manufacturer/ Model	Bus Passenger-Carrying Capacity				
	16	20	47	65	78
CAT 3208			4	8	347
DET 6-71T					70
Cummins 5.9L				2	33
Intl DT 466			25	287	6
Cummins 8.3L					8
GMC 427					3
DET 8.2L			4	37	
Ford 7.8L				23	
GMC 366				20	
Intl 6.9L	4	12	13		
DT 360			6		
Ford 351	4	38			
Ford 4.9L	4	10			
Intl 7.3L	7	30			
DET 6.2	2	10			

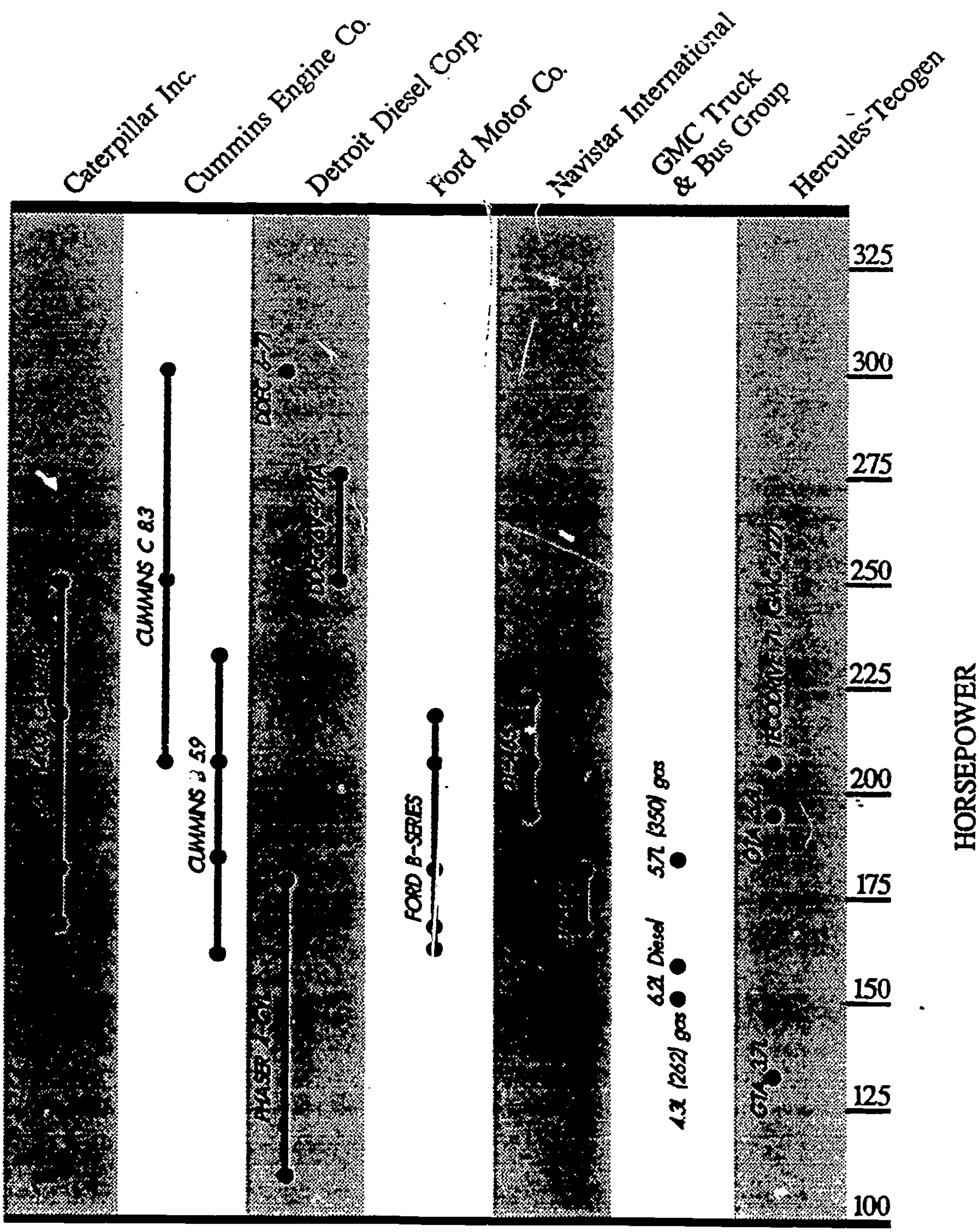
Three manufacturers now produce factory-built dedicated CNG-fueled engines. Two original equipment manufacturers produce a propane-powered engine. The available natural gas engines include a turbocharged and air-to-air charge cooled Hercules GTA 3.7L (226 cu in) 4-cylinder model producing up to 130 hp with 280 ft-lbs of torque and the GTA 6-cylinder 5.6L (339 cu in) model capable of providing 190 hp and 415 ft-lbs of torque. Hercules intends to develop a 7.8L natural-gas-fired engine with the goal of providing a family of engines for school buses and vans, to class 6 or 7 trucks. The optimized fast-burn/lean burn Hercules engines are derived from diesel engine carcasses, are suitable for all chassis mounting arrangements (rear engine, forward control, conventional), and are compatible with all transmissions. The engines are covered with a Hercules factory warranty. An extended warranty can be purchased for a minimal cost.

Tecogen, Inc. produces the TecoDrive 7000 7.0L (427 cu in) natural-gas-powered engine. This engine is capable of producing 195 hp with a torque of 318 ft-lbs. The TecoDrive engine consists of a modified GM 427 gasoline-powered engine. From Figure 10, it is apparent that the power output of the available alternative-fueled engines overlaps with the performance characteristics of the GMC 5.7L and DT 360, and smaller hp offerings of the Ford B-series diesel, Cummins B 5.9L, and CAT 3116. These engines are commonly employed on 65-, 66-, and 68-passenger buses. The alternative fueled engines may be suitable for buses carrying up to 78 passengers; however, some loss in performance would be expected. Buses carrying up to 84 passengers could be alternative-fueled with no loss in performance/driveability when the Hercules 7.8L engine is available.

Dedicated propane-powered engines are being manufactured by the Ford Motor Co. and General Motors. The Ford Motor Co. is producing a 429 cubic inch engine, while GM has begun production of 350 and 427 cubic inch engines. To date, neither the Ford or GM engines have been placed in school buses.

Figure 10

School Bus Engine Characteristics



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Chapter 3
School Bus Manufacturers

In 1990, Washington Districts purchased 336 school buses. Two hundred buses were purchased from the Blue Bird Body Company. The remainder were ordered from such suppliers as Thomas Built Buses, Wayne Corporation, AmTran Ward, Crown Coach, Carpenter Manufacturing, GM, and Collins Bus Corporation. The number of buses purchased by manufacturer is given in Table 3; percentages are shown in Figure 11.

Table 3
Washington School Bus Purchases by Manufacturer
1991 Model Year

Manufacturer	No. of Buses Purchased
Blue Bird	200
Thomas Built	85
Wayne	30
Collins	8
Ward	6
Crown	4
GM	2
Carpenter	1
Total	336

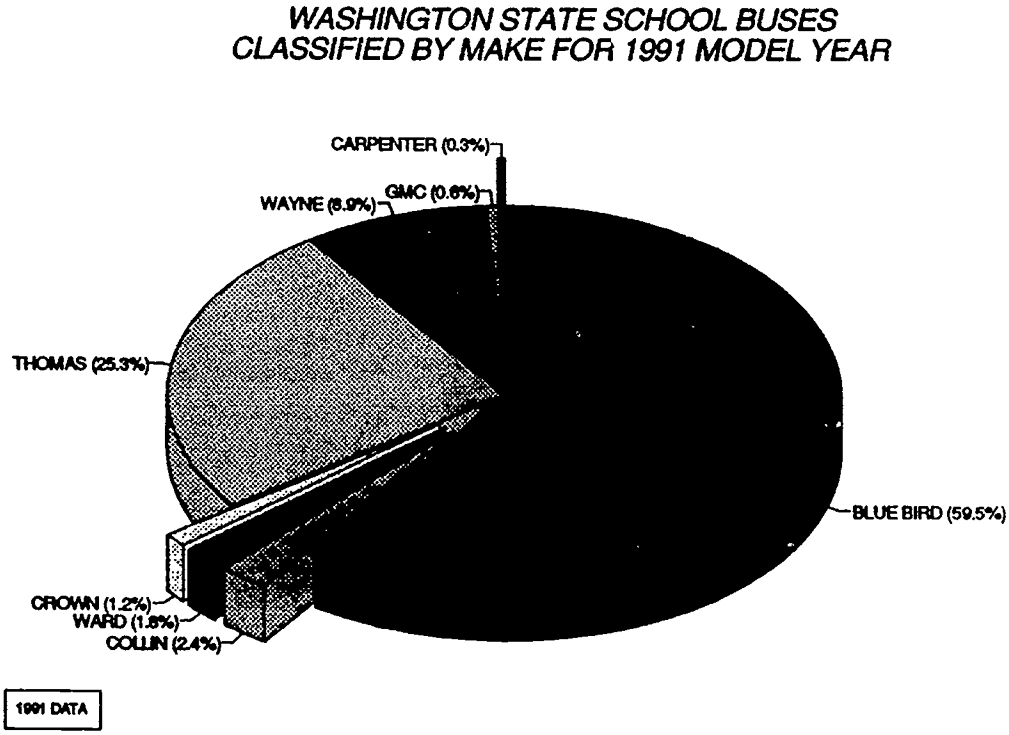
The school bus manufacturing industry is very competitive, with a broad cast of participants including body manufacturers, chassis suppliers, and engine companies. A single bus manufacturer might purchase their chassis from one or more suppliers. Three or more engine options might be offered for a single bus model. For instance, the Type D Carpenter Counselor can be ordered with either a standard Cummins 5.9L or Caterpillar 3116 diesel engine. The Hercules GTA 5.6L dedicated natural-gas-fired engine is available as an option.

School Buses are classified as Type A through D, with the letter designation varying based upon carrying capacity, gross vehicle weight, and engine location. Bus Type definitions and manufacturer offerings are summarized in Figure 12.[5]

A national trend is to move away from the conventional cowl chassis school bus toward the Type D or transit style bus. The flat frontal design of the Type D bus improves visibility for the driver, which subsequently improves student safety. Type D buses also have a larger capacity than conventional buses. This means that the same number of students can be transported in fewer buses.[5]

Several bus manufacturers now offer factory-built dedicated compressed natural gas engines in Type C or Type D configurations.

Figure 11



AmTran Ward offers a forward control Type D version of its Senator body equipped with a Hercules GTA 5.6L engine mounted on a Crane-Carrier chassis. This configuration can be designed for 54 to 84 passenger carrying capacities. Tumwater school district purchased five 68-passenger Ward buses in the Fall of 1991. These natural-gas-fueled buses are now in route service.

The Type D Carpenter Counselor is also available with the optional Hercules GTA 5.6L engine mounted on a chassis supplied by Crane-Carrier. Carpenter hopes to have a rear engine model available soon. Carpenter also recently purchased the assets of Crown and offers a rear engine methanol-powered coach equipped with a modified Detroit Diesel 6V-92 engine.

Blue Bird offers a Type C bus equipped with a TecoDrive 7000 engine mounted on a General Motors Corporation chassis. Blue Bird Body Company supplies the body and is the final vehicle manufacturer. This monofuel bus will be certified to CARB standards, will meet all Federal Motor Vehicle Safety Standards, and is fully covered by Blue Bird parts and service warranties.[6,7]

Finally, Thomas Built Buses is installing the Hercules GTA 5.6L engine in a rear engine mounted Type D coach. Thomas Built "builds both ways." They can self produce an integral chassis with body or mount a Thomas Built body on a chassis supplied by Ford, Navistar, or Crane-Carrier. Manufacturers that offer factory-built alternative fueled buses are summarized in Table 4.

Figure 12

School Bus Type Designations

COMPANY				
	TYPE A	TYPE B	TYPE C	TYPE D
AmTran				
Volunteer			•	
Patriot			•	
Vanguard	•			
Senator Fwr'd Control				•
Blue Bird Body Co.				
Micro Bird	• (Dual)			
Mini Bird		•		
Conventional			•	
TC/2000				•
TC/2000 Rear Engine				•
All American Rear Engine				•
All American Frw'd Pwr'd				•
Carpenter Mfg.				
Classmate	• (Dual)			
Cadet		•		
Classic			•	
Corsair, Rear Engine				•
Counselor Fwr'd Control				•
Collins Bus Corp.				
Super Bantam	•			
Bantam	•			
Crown Coach Int'l				
Supercoach				•
Gillig Corp.				
Advanced Design Bus				•
Girardin				
Minibus	•			
GMC				
Vandura	•			

15

Figure 12 (continued)

School Bus Type Designations

COMPANY				
	TYPE A	TYPE B	TYPE C	TYPE D
Midbus				
Superior 63 + 68	•			
Busette	• (Dual)			
Mid Bus Guide	• (Dual)			
Superior Coach Int'l				
Partner	•			
TAM-USA				
252A121				•
Thomas Built Buses				
Minotour	• (Dual)			
Mighty Mite		•		
Vista		•		
Conventional			•	
Saf-T-Liner				•
Westcoast-er				•
MVP				•
STURICORP.				
Sturdivan	•			
Super-Sturdivan	•			
Sturdibus	• (Dual)			
Van-Con Inc.				
16-20 Passenger	•			
Wayne Corp.				
Lifestar				•
Lifeguard			•	
Chaperone	• (Dual)			
Busette	• (Dual)			
Chaperone XL	• (Dual)			

TYPE A: Type "A" school bus is a conversion or body constructed upon a van-type compact truck or a front-section vehicle, with a gross vehicle weight rating of 10,000 pounds or less, designed for carrying more than 10 persons.

TYPE B: A Type "B" school bus is a conversion or body constructed and installed upon a van or front-section vehicle chassis, or stripped chassis, with a gross vehicle weight rating of more than 10,000 pounds, designed for carrying more than 10 persons. Part of the engine is beneath and/or behind the windshield and beside the driver's seat. The entrance door is behind the front wheels.

TYPE C: A Type "C" school bus is a body installed upon a flat back cowl chassis with a gross vehicle weight rating of more than 10,000 pounds, designed for carrying more than 10 persons. All of the engine is in front of the windshield and the entrance door is behind the front wheels.

TYPE D: A Type "D" school bus is a body installed upon a chassis, with the engine mounted in the front, midship, or rear, with a gross vehicle weight rating of more than 10,000 pounds designed for carrying more than 10 persons. The engine may be behind the windshield and beside the driver's seat; it may be at the rear of the bus, behind the rear wheels, or midship between the front and rear axles. The entrance door is ahead of the front wheels.

MPV: A vehicle with less than 10 passenger capacity including the driver that cannot be certified as a school bus. The MPV is a federal vehicle classification that was adopted by the school bus industry at the 10th National Standards Conference in 1985

Table 4
Factory-Built Alternative Fuel Bus Availability

	Fuel Type	
	CNG	Methanol
Blue Bird	•	–
Amtran Ward	•	–
Carpenter	•	–
Crown	–	•
Thomas Built	•	–
Wayne	–	–
TAM—USA	–	–

Alternative-fueled Ward, Carpenter, and Thomas-Built buses all come equipped with the Hercules GTA 5.6L engine mounted on a Crane-Carrier Chassis. Both Hercules and Crane-Carrier are newcomers to the school bus industry. Hercules has a long history of producing diesel engines for stationary, marine, and military transport applications, while Crane-Carrier is a major producer of chassis for refuse and heavy-duty dump trucks. These two major companies combined to provide an early entry into what they see as an emerging and significant market.

Navistar currently holds 60 percent of the chassis market for school buses. Their chassis are typically sold to bus body companies or to dealers. The Navistor chassis can currently be purchased with an International diesel turbocharged DT-360 or DT-466 engine.

International is now working on clean diesel concepts and diesel catalytic converter approaches. Navistar is dedicated towards coming out with products that meet their customers' needs, and expects to have optimized dedicated CNG prototype engines in the field in 1992.

In general, the bus manufacturers agree that the factor limiting dedicated alternative fueled bus availability today is the powerplant. The Hercules and Tecogen dedicated CNG school bus engines currently available produce up to 190 or 195 hp. In contrast, school districts often seek to purchase buses with engines that deliver from 210 to 250 hp, such as the Caterpillar 3116, Cummins 5.9, Ford B-series diesel, or International DT-466. Cummins does offer a 240 hp transit style dedicated CNG L-10 engine, but it is heavy, expensive, and only appropriate for school buses carrying 100 passengers, such as those employed in California.

Dedicated CNG engine performance limitations are expected to soon be lifted as Hercules moves towards development of a natural-gas-fired version of its 7.8L diesel engine, Cummins looks at natural gas firing for its B and C series diesel engines, and International moves into development of optimized CNG-fueled diesel powerplants.

Chapter 4
Engine Manufacturer Activity

Almost all manufacturers of diesel- and gasoline-powered medium and heavy duty engines are engaged in the development of "factory-built" natural-gas-fueled models. As development, testing, and refinement costs are significant, market entry generally consists of one or two engines targeted at a particular market niche. After an engine concept is proven with respect to reliability, durability, fuel economy, cost effectiveness, and emissions, the manufacturer generally expands its alternative fuels offering to other engines in its product line.

Cummins and Detroit Diesel have targeted large, urban transit bus engines while Hercules and Tecogen produce factory-built dedicated CNG engines that may to used to power school buses carrying fewer than 73 to 78 passengers. In contrast,General Motors is targeting the 3/4 ton pickup and medium-duty truck markets while Ford is aiming at the 1/2 ton pickup arena. Chrysler has focused its activities on the passenger and cargo van markets.

It must be emphasized that the available engines are in the prototype, demonstration, or early development stages. Not only engine designs, but electronic fuel injection and catalytic converter technologies are in a rapid state of transition. Fuel economy, price, and emissions data are, for the most part, almost non-existent. Even the limited information that is available often reflects yesterday's technology and not the "new and improved" versions that soon may be mass produced.

Engine manufacturers are particularly reluctant to release emissions data, even if it appears promising. Data gathered from an engine mounted on a test stand and operated under laboratory conditions may not be representative of how that engine performs when mounted in a vehicle. Manufacturers are concerned that federal or state regulators may rewrite standards based on preliminary information. the manufacturer would incur huge losses if the mass-produced vehicle-mounted engines could not replicate promising results indicated by laboratory prototypes.

The engine market is now regulatory driven. Uncertainty abounds as regulations are constantly changing. All that manufacturers will promise—for either alternative fueled or conventional fueled engines—is that their engines will meet all applicable EPA and CARB certification requirements and emissions standards.

The following sections summarize the CNG-fueled engine development activities and market plans for all major U.S. engine manufacturers.

Hercules Engines, Inc.
Canton, Ohio

Hercules is the process of designing a family of dedicated natural gas engines for light (over 8500 lbs GVW) and medium-duty trucks. A "fast burn/lean-burn" combustion concept is employed to achieve power requirements equivalent to diesel-fueled operation while meeting on-highway exhaust emission standards. Niches for these engines include delivery vans and trucks, commuter vans, shuttle buses, recycling trucks, school buses, and transit buses. Engines in limited production include a 3.7L (226 cu in) 4-cylinder unit delivering 130 hp at 2800 RPM, and a 5.6L (339 cu in) in-line 6-cylinder unit delivering 190 hp. These turbo-charged and after-cooled engines are optimized for operation with CNG. Design features include a diesel cylinder block and head, which are modified to incorporate spark plugs, plus diesel intake and exhaust manifolds. Hard faced valves and valve seat inserts are specified for durability and compatibility with CNG fuel. The lean burn engine operates at a 10:1 compression ratio.[8,9,10]

The Hercules engines induce complete burning and low emissions through promoting highly turbulent combustion with swirl ports in a compact combustion chamber. A centrally located high energy spark system compensates for the low flame speed characteristic of CNG fuel. Currently available and proven ignition and fuel injection systems are specified. Hercules currently mounts an IMPCO mixer on the air intake manifold. Future plans call for incorporation of an Ortech electronic air/fuel control and natural gas fuel metering system into the engine design.[8]

Hercules' goal is to achieve emissions objectives without requiring a catalyst on the engine exhaust system. Engine design parameters, such as compression ratio, valve timing, spark plug position, and air supply, plus combustion parameters such as fuel to air ratio and ignition timing must be optimized for all engine speed and load conditions. Lean burning—supplying excess air to the combustion process—promotes the complete combustion of CO and HC while reducing temperature buildup that favors NOx formation.

Hercules also is planning for the development of a 7.8L engine capable of delivering 230 to 240 hp. A target market for this engine is larger school buses.

Hercules expects market demonstration and introduction to be expedited by subsidized purchases and regulatory requirements. The Tulsa, Oklahoma school district has already purchased 45 Ward school buses with Hercules GTA 5.6L natural-gas-fired engines, while the Tumwater School District currently has 5 such buses in route service. Hercules has a California Air Resources Board permit to place 100 of each of its engines in service in California for demonstration purposes. Hercules is obligated to retrofit the California engines with electronic fuel injection systems when the technology is available. Hercules intends to first demonstrate that the engine concept works, then to demonstrate the emissions benefits attainable through dedicated CNG engines operating with electronic fuel injection systems.

Tecogen, Inc.
Walthan, Massachusetts

In concert with General Motors, Tecogen, Inc. developed the TecoDrive 7000 compressed-natural-gas-fueled engine. The Gas Research Institute provided funding for this conversion and optimization of a GM 7.0L (427 cu in) gasoline-powered engine for CNG service, a compatible engine fueling system, and a state-of-the-art engine control system.[11]

The TecoDrive 7000 delivers 195 hp at 4000 RPM, with a torque of 318 ft-lbs at 2,400 RPM. The TecoDrive engine is a heavy-duty automotive engine intended for use in t ks and buses. The spark ignited V-8 engine features a 10:5-to-1 compression ratio and contains modifications such as special high compression forged aluminum pistons, a long-life ring pack, and valve train modifications.[12]

Delco Electronics developed the engine controller while AC Rochester provided the electronic fuel injection system. Tests, conducted in accordance with the EPA's Federal Heavy Duty Gasoline Transient Test Procedure, indicate that the TecoDrive 7000 meets the CARB 1991 emission standards.[11]

The Blue Bird Body Company, under an exclusive agreement with General Motors and Tecogen, offers the TecoDrive 7000 in 66 to 72 passenger school bus configurations. In the spring/fall of 1991, 10 CNG Blue Bird buses equipped with TecoDrive engines were placed in service at three school districts in California.

Cummins Engine Company
Columbia, Indiana

The CNG-powered Cummins 10L (611 cu in) L10-240G engine develops 240 hp at 2100 RPM. The in-line, 6-cylinder turbocharged and after-cooled engine utilizes spark-ignited, lean burn combustion technology while operating at a compression ratio of 10.5:1.[13]

The Cummins natural gas-fueled powerplant is a derivative of its LTA-10, 6-cylinder diesel engine. When equipped with a catalytic converter, the L10-240G has demonstrated its ability, in the laboratory, to meet the stringent 1993 EPA Urban Bus Diesel Emission Standards. Cummins currently uses a Woodward electronic governor for engine speed control, an Altronic ignition system, and an IMPCO Mechanical carburetor.[13,14]

By mid-August of 1991, 34 CNG-fueled L-10 engines were operating in transit buses with one additional engine mounted in a refuse truck. A total of 440,000 operating miles had been accumulated. Cummins expects to place a total of 86 engines in operation by the end of 1991, with Pierce Transit of Tacoma putting 15 buses with Cummins L-10-240G engines in service by November of 1991.[15]

Detroit Diesel Company
Detroit, Michigan

Detroit Diesel has been actively working to modify its two-stroke 6V-92TA diesel engine to operate on natural gas. The 6V-92TA is commonly used in transit coaches or large dump trucks.

Early work focused on diesel pilot fuel ignition. In the conventional diesel engine cycle, the fuel automatically ignites when it is subjected to high temperature and pressure. As natural gas is compressible, a small quantity of diesel fuel is required to initiate combustion.

Urban transit buses have been singled out as a target for clean-burning heavy-duty engines. DDC's pilot injected natural-gas-fired engine was designed to meet EPA's 1991 urban bus emission standards. The first engine was installed on a Denver RTD bus in February of 1990. Denver has since procured four additional buses. Additional transit buses are in operation in Vancouver, Santa Barbara, and Colorado Springs. The City of Houston also has two dump trucks equipped with natural-gas-fueled 6V-92 engines in operation.[16]

Detroit Diesel now offers the dual fuel 6V-92TA as an original equipment manufacturer (OEM) option to transit companies wanting to purchase new buses with natural-gas-fired engines. At the same time, with Gas Research Institute support, DDC is actively working on a dedicated or mono-fuel natural-gas-fired version of the 6V-92TA. By eliminating the necessity for diesel pilot fuel, the mono-fueled version offers the promises of lower cost, less complexity, and emissions improvements. In particular, particulate emissions that form during diesel fuel combustion can be reduced.[16,17]

The mono-fuel engine uses a spark plug and a precombustion chamber to provide ignition. A stoichiometric fuel-to-air mixture is ignited in the precombustion chamber, which then serves as a high-energy source of ignition for a learner mixture in the main combustion chamber. This fast burn/lean burn concept minimizes NOx formation due to the small prechamber volume. Simultaneously, HC and CO emissions are minimized due to complete combustion with the excess air in the main chamber.

General Motors
Truck and Bus Group & Power Train Division
Pontiac, Michigan

General Motors and the Gas Research Institute are providing $40 million for the development of GM light and medium duty trucks powered by CNG. The program goal is to develop fuel management systems and optimized dedicated CNG-fueled medium- and light-duty vehicles that comply with EPA and California Low Emission Vehicle standards.

The medium-duty focus is on the GM Topkick/Kodiak truck. This truck usually operates in GVW classes 4 through 7. Powerplants being modified for medium duty CNG service include GM's spark-ignited 7.0 (427 cu in) and 7.4L V-8 (450 cu in) engines. The medium-duty program may also result in a school bus offering.[18]

GM's light- and medium-duty truck programs will follow a four-phase production plan designed to produce fully factory engineered and tested products. GM's approach ensures that all factors of product, market, and business development are considered in order to design the most economic and satisfactory approach to high-volume production.

The four technology development phases include:[18]

- Technology and concept development
- Product process development and prototype validation
- Process validation and product confirmation
- Production and product improvement

In the light-duty truck arena, GM is developing a dedicated CNG version of its 3/4 ton Sierra Pickup. This vehicle will feature an optimized closed loop, state-of-the-art, computer-controlled gaseous fuel injection system for GM's 5.7L (350 cu in) light-duty truck engine.

GM will also offer dedicated or dual-fuel versions of its Chevrolet Caprice and Buick Roadmaster. Both passenger cars are equipped with the 5.7L engine.

The 1992 model year dedicated CNG-powered Sierra is currently undergoing durability, crash, emissions, and fuel economy testing. A production run of 4500 units is scheduled to begin on April 1, 1992. The price premimum for the dedicated CNG Sierra pickup is expected to be $3200.

Chrysler Motors Corporation

Chrysler is developing and commercializing a factory produced, supported, and warranted natural-gas-powered version of its Dodge Ram 250 cargo/passenger van. This full-size van will contain a CNG optimized version of Chrysler's 5.2L (318 cu in) spark-ignited V-8 engine.

Chrysler is using a commercially available multi-port fuel injection system controlled by a Chrysler electronic engine controller programmed for natural gas operation. The current (1991) version of Chrysler's CNG-fueled 5.2L engine uses single port injection and produces 165 hp. A multi-port injection model, available in 1992, should provide 185 to 195 hp.[19]

Chrysler has produced a test run of 57 Ram vans; 50 are being demonstrated in public sector fleet applications. Chrysler intends to begin production of 2000 vehicles per year starting April 1, 1992. Press releases will accompany the offering of this van.

Chrysler foresees a factory incremental cost for the dedicated CNG van of $3,975. The sticker markup will likely be on the order of $5000. For comparison, the base price for a passenger van is $18,000 to $20,000. A cargo van costs much less.

Chrysler's next alternative fuels niche is likely to be its mini-van. Chrysler views CNG as attractive for fleet applications and intends to target vans used in service, delivery, and passenger moving applications.

Chrysler intends to meet all EPA and California gasoline-powered vehicle emission control requirements. The van will include either a heated or unheated catalytic converter. Chrysler is in the process of minimizing emissions through more precise natural gas pressure regulation, fuel-to-air ratio selection, and spark optimization.

Ford Motor Company
Truck Operations, Allen Park, Michigan

Ford intends to produce 100 demonstration units of a light-duty F-150 pickup powered by a dedicated CNG-fueled 4.9 or 5.0 L engine. Ford foresees a second demonstration run of 200 to 600 vehicles before going to full production. Factory-built CNG-powered vans will also be considered.

Ford is examining both the IMPCO and Ortech gaseous fuel injection systems. Alternatively, Ford could develop an in-house system. Ford is currently focused on the 8500 lb GVW market, while General Motors, with its 5.7, 7.0 and 7.4 L engines, is seeking niches in the 8500 lb GVW arena.

In the medium-duty truck arena, Ford has placed about a dozen 25,000 to 35,000 GVW CNG-powered units in operation. These trucks are powered by a 7.0L (429 cu in) gasoline carcass engine converted in the field for CNG operation. Ford historically has also produced 6.6 L and 7.8 L diesel engines. As Ford recently obtained an equity interest in the Cummins Engine Company, it is phasing out its diesel operations, and by March 1992 will offer the Cummins 5.9 L diesel engine.

Ford is focusing its demonstration efforts on light and medium-duty trucks and passenger cars and is planning to produce 100 production prototypes of a dedicated CNG CrownVictoria as well as begin work on a CNG-fueled Econoline van. Ford's policy is to not support experimental work on vehicle that carry people. Ford is thus not sponsoring alternative fuels research or developmental work on school bus chassis or bodies.

Caterpillar
Peoria, Illinois

Caterpillar is currently working on a spark-ignited CNG-fueled version of its 10L 3306 engine. Caterpillar has focused its CNG efforts on stationary engines. No research has been completed for the 3208 or 6.6L 3116 engines, which are often specified for school buses within Washington State.

To meet the 1994 EPA standards Caterpillar is seeking to improve engine-out emissions. Catalytic converters may be required for some ratings; however, Caterpillar believes that even engines operating with alternative fuels may require catalysts.

IMPCO Technologies, Inc.
Cerritos, California

IMPCO has developed a microprocessor-based Alternative Fuel Electronics System (AFE). This fuel management system can be integrated with an original equipment manufacturer's sensor feedback, computer, and engine control systems to promote optimized combustion with minimized emissions over the entire engine operating range.[21]

Specifically, AFE's computer takes engine speed, intake air flow density, engine oxygen sensor, and gaseous fuel mass flow sensor readings into account to determine the optimum fuel to air mixture. AFE then controls the valve position in the natural gas injection line to achieve desired results. Closed loop combustion control is thus maintained over all engine operating conditions.

AFE features Adaptive Learn Programming, where the AFE system software is automatically modified based upon the performance of the engine as indicated by the closed-loop air-fuel-ratio feedback system. This gives AFE the capability of adjusting for variations between engines, eliminate, changes in operating conditions, or degradation in the engine's performance. No adjustments are required after installation.[21]

IMPCO's AFE system can be used by original equipment manufacturers (OEMs) to produce "factory-built" alternative-fueled vehicles or it can be used in aftermarket conversion kits. AFE can be specified for conversions to either compressed natural gas or liquefied petroleum gas (LPG) fuels.

The AFE natural gas conversion kit has been tested and approved by the CARB for 1991 and older model year General Motors light-duty trucks and medium-duty vehicles equipped with a 5.7L (350 cu in) displacement closed-loop engine. The AFE system for both CNG and LPG applications entered production in the fall of 1991.[21]

Ortech International
Mississauga, Ontario

Ortech International has developed and tested a solid state electronic Gaseous Fuel Injection (GFI) system. The Ortech GFI hardware can be used to convert vehicles to operate with either natural gas or propane. For dual-fuel vehicles, operators may switch between gasoline and gaseous fuels, or diesel fuel only versus mixtures of diesel and gaseous fuels. The system may be used with light-, medium-, or heavy-duty engines.[22]

The GFI system can be installed on virtually any vehicle, either as a retrofit or as original equipment. The GFI system is compatible with 4- or 2-stroke diesel or gasoline engines in the 50 to 450 brake horsepower range. The engines can either be naturally aspirated or turbocharged. The system is flexible as it contains altitude and temperature compensation, and can be used with or without exhaust gas recirculation (EGR) systems, catalysts, secondary air pumps, or oxygen sensors. Either distributor-less or distributed ignition systems may be employed.[22,23]

Similar to the IMPCO's AFE, the GFI system computer monitors operating conditions and automatically adjusts to maintain peak performance over the engine's entire speed/load range. Efficient and complete combustion results in decreased CO and HC emissions. Mileage with the GFI system (on a Btu basis) should be as good or better than with gasoline or conventional fuels.[22]

The GFI system minimizes NOx formation through the use of demonstrated lean burn combustion techniques. Since no oxygen sensors are commercially available with linear feedback features, an open loop air-to-fuel ratio and spark timing control approach is used. Under this approach, engine "mapping" is required to establish a database of observed torque, emissions, and exhaust temperatures. Upon receiving such input variables as engine speed, charge temperature, and ignition timing, the GFI computer specifies the appropriate fuel-to-air ratio and spark advance to meet emissions, fuel economy, and performance requirements.

The GFI system became commercially available in November of 1991. Stewart & Stevenson of Houston and Commerce City, Colorado, holds the worldwide rights to market the GFI system.

Chapter 5
Federal and State Clean Air Regulations

The 1990 Amendments to the Federal Clean Air Act and changes in California's air quality regulations have significantly strengthened automobile exhaust emission standards and have cleared a path for the commercialization of alternative fuels for motor vehicle use.

Federal Clean Air Act Amendments of 1990

The 1990 Amendments to the Clean Air Act explicitly recognize that changes in motor fuel composition must play a role in reducing motor vehicle emissions. To this end, the Act established new tailpipe emissions standards, a reformulated and oxygenated fuel requirement, and a clean-fuel vehicles and fuels standard.

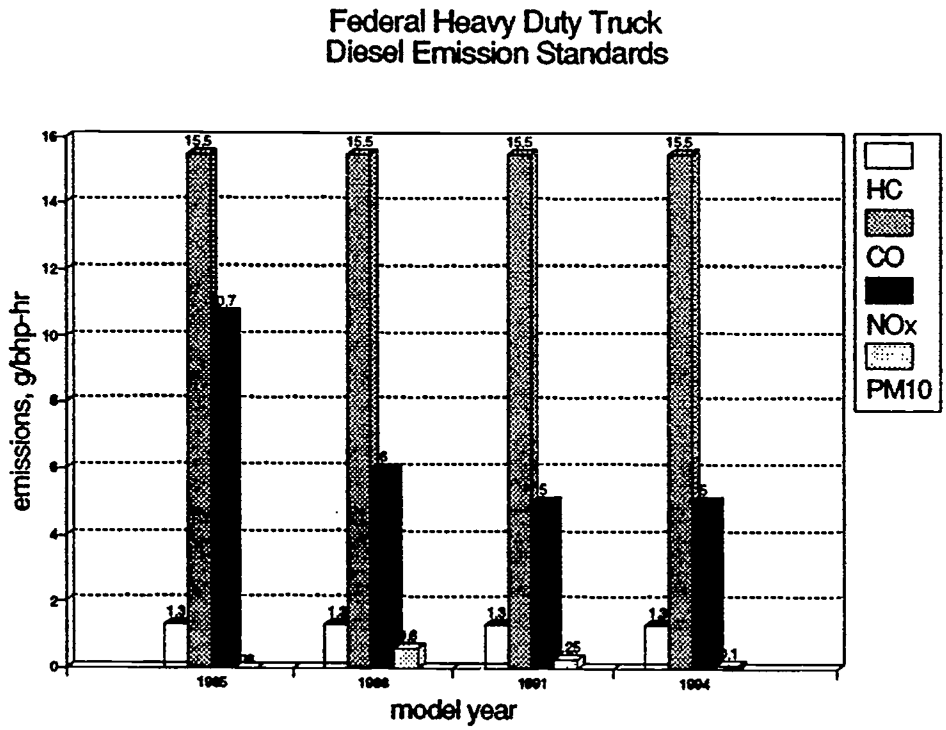
Both the clean-fuels program and the reformulated gas requirements are aimed at reducing urban ozone levels. The clean-fuel regulations will affect centrally-fuelled fleets of 10 or more vehicles. Beginning in model year 1998, 30 percent of all new vehicles purchased by these fleets will need to meet emission standards much lower than those which apply to vehicles in general. Purchase requirements increase to 70 percent by 2001. The program is mandatory for all 26 serious, severe, and extreme ozone non-attainment areas in the country and includes all vehicle types. Because there are no serious, severe, or extreme ozone non-attainment areas in Washington State, the State is not required to participate in the clean-fuels program at this time. The clean-fuel emission standards for heavy-duty vehicles are presented in Table 5 (page 27).

The reformulated gasoline mandate applies to the nine highest ozone areas in the country, with voluntary opt-in available to 87 other ozone non-attainment areas. Reformulated gas will be required for all vehicles in the affected areas beginning in 1995 and is expected to increase the price of gasoline by 3 to 15 cents per gallon. Although Washington State is not identified as one of the nine mandated areas in the country requiring reformulated gasoline use, the state may opt-in to the program at a later date. Washington State will need to participate in the federal oxygenated fuel program, however. The areas of the state listed as CO non-attainment areas include Spokane, Seattle-Tacoma, and Vancouver. The oxygenated fuel program begins in November 1992 and requires that gasoline sold during the winter contain 2.7 percent oxygen by weight.

Unlike the other provisions, the new federal tailpipe emission standards are unilateral and affect Washington State as well as the rest of the country. Although these standards are fuel neutral, their increasing strictness sends a signal to automakers that clean fuels may offer an alternative or complimentary design approach to reducing auto emissions. This is particularly true for manufacturers of heavy-duty vehicles, including school buses, where clean fuels may provide a least-cost approach to meeting the new emission standards.

Figure 13 presents a history of heavy-duty vehicle emission standards including the proposed 1994 federal standards.[24] As shown, the federal heavy-duty vehicle emissions standards for HC, CO, and NOx have changed very little over the last 10 years. What has changed, however, is the allowable particulate emissions, which have dropped more than 80 percent between the 1988 and 1994 standards. The development of engine technologies that can meet current and future particulate standards is currently driving OEM heavy-duty engine activities.

Figure 13



California Emission Standards

California is the only state permitted to establish its own emission standards. In addition, other states can adopt the California standards in place of the federal emission regulations. Because of deteriorating air quality, many of the large urbanized states are looking seriously at adopting the more stringent California standards. In October, 1991, eight eastern seaboard states including New York and New Jersey adopted the California standards. This could have profound effects on the regulatory and market environment for clean fuels, as the California standards and regulations effectively mandate the use of alternative fuels in motor vehicles.

The key to the California regulations is the establishment of increasingly stringent emission standards through the year 2000. The California regulations also create a tier of four vehicle emission levels that include transitional low emission vehicles (TLEV), low emission vehicles (LEV), ultra-low emission vehicles (ULEV), and zero emission vehicles (ZEV). The standards function in a similar manner to the Corporate Average Fuel Efficiency (CAFE) standards in that manufacturers may produce a mixed set of vehicles within these categories as long as the fleet average meets established emission limits for that year.

While concentrating on light- and medium-duty vehicles, California has also established a LEV and ULEV standard for medium-duty vehicles with a gross vehicle weight of 8500 to 14,000 pounds. The CARB is considering extending these or similar standards to heavy-duty engines. Until this occurs, heavy-duty vehicles must meet the 1994 California emission standards, which are similar to the federal standards except for hydrocarbon emissions. Recognizing the need to consider hydrocarbon reactivity, California measures non-methane hydrocarbons (NMHC) and has set a standard of 1.1 g/BHP-hr for NMHC. The California emission standards are summarized in Table 5.[3]

Table 5
Heavy-Duty Engine Emission Standards

	Emissions (g/Bhp-hr)				
	THC	NMHC	NOx	CO	PM
1994 Federal	1.3	NR	5.0	15.5	0.10
1994 California	NR	1.1	5.0	15.5	0.10
Cal. Light-Heavy		NMHC+NOx			
1995 Std	NR	3.9		14.4	0.10
LEV Std	NR	3.5		14.4	0.10
ULEV Std	NR	2.5		7.2	0.05
Fed Clean-Fuel Prog	NR	3.15		15.5	0.10

Clean Air Washington Act of 1991

The Clean Air Washington Act of 1991 also recognizes the role that alternative fuels must play in improving Washington's air quality. To this end, the Act directs a multi-agency effort, including the Department of Transportation, the General Administration, the Energy Office, and the Department of Ecology to evaluate the costs and benefits of clean fuels and clean fuels technology and to develop emission and performance specifications for vehicles powered by clean-fuels. It also mandates that 30 percent of new vehicles purchased by the State be clean fuel vehicles. In addition, the Act establishes financial assistance to support this effort.

Chapter 6
Propane and Natural Gas Engine Combustion and Emissions

Vehicle tailpipe emissions are dependent upon fuel type and composition, fuel injection system type and efficiency, combustion chamber design, and post combustion cleanup system performance (catalytic converter or particulate traps).

The emissions data of most significance, then, are not the "engine-out" emissions, but the "system," or overall vehicle emissions. Overall vehicle emissions are typically stated in grams per mile for light-duty vehicles and grams per brake-horsepower hour for heavy-duty vehicles.

Both conventional and alternative-fueled vehicles must meet increasingly stringent federal or California Air Resources Board emissions control requirements. A number of compliance paths are currently being explored singly or in combination, including the production and use of oxygenated gasoline additives, reformulated gasolines, and low sulfur diesel fuel; sequential, multi-port fuel injection systems; electronic or advanced diesel fuel-to-air control concepts; fast-burn/lean burn combustion with stoichiometric pre-combustion chambers; diesel particulate traps; and optimized three-way and/or heated catalytic converters.

Dramatic air quality improvements are expected and in fact, are required for vehicles operating with either conventional or alternative fuels. Therefore, the incremental emissions benefits associated with an alternative fuel are equal to the emissions expected from conventional fuel operations less the emissions obtained when operating on the alternative fuel.

State-of-the-art technology is rapidly changing. New technologies are rapidly emerging and old wisdom and antiquated approaches are falling by the wayside. Estimating emissions benefits due to alternative fuel use is extremely difficult as it involves examining two moving targets—the conventional fuel "base" case and the alternative.

In addition, tradeoffs are inevitable. Mobile sources emit four major EPA regulated "priority pollutants": particulates, carbon monoxide (CO), hydrocarbons (HC), and nitrogen oxides (NOx). Engine designs or combustion approaches that minimize the formation of one pollutant frequently increase the concentration of another. Rarely does an "across-the-board" winner emerge.

This chapter discusses the combustion and emissions tradeoff process, provides an overview of clean burning natural-gas-fired engine developments, and lists the emissions associated with the combustion of natural gas or propane in dual-fuel and dedicated mono-fuel engines.

Combustion Process Overview

The three Ts—time, temperature, and turbulence—are major design factors that can promote or prevent complete and efficient combustion. Complete combustion is encouraged by providing excess air, turbulence to promote fuel/air mixing, high temperature, and ample residence time in the combustion zone. Complete combustion yields a complete burnout of exhaust by-products with resulting low CO and HC emissions. Unfortunately, high temperatures associated with complete and efficient combustion favor NOx production.

In order to understand the combustion process, two concepts must be must be introduced: the stoichiometric air-to-fuel ratio and the equivalence ratio. The stoichiometric air-to-fuel ratio is that quantity of air required to support complete combustion under conditions of perfect mixing. In other words, it is the amount of air required to balance the chemical reactions in the fuel oxidation process.

Engines are said to burn "lean" when excess combustion air is supplied and "rich" as the stoichiometric fuel-to-air ratio is exceeded. "Smoke" or unburned combustion products result when insufficient combustion air is present.

The equivalence ratio is the stoichiometric air-to-fuel ratio divided by the actual air-to-fuel ratio. In other words:[25]

$$\textit{Equivalence Ratio} = \frac{\textit{Stoichiometric Air/Fuel Ratio}}{\textit{Actual Air/Fuel Ratio}}$$

A lean mixture has an equivalence ratio less than unity while a rich mixture has a ratio greater than unity. Different fuels, of course, have different chemical compositions and air-to-fuel ratios.

Exhaust emissions are found to be extremely sensitive to an engine's equivalence ratio. NOx emissions are reduced under lean burn conditions as the excess combustion air "quenches" or reduces the temperature rise in the cylinder. NOx emissions increase dramatically for engines running at an equivalence ratio of 0.8 to 1.0. Hydrocarbon and CO emissions are also minimized under lean burn conditions as the excess oxygen promotes complete combustion.

Limitations exist, however. If the air-fuel mixture is too lean, the combustion flame may fail to ignite or to propagate completely across the combustion chamber. The result is poor efficiency and excessive HC emissions.[26] The designer, then, must develop an engine that operates lean enough to minimize oxides of nitrogen (NOx) without, at the same time, increasing emissions of hydrocarbons. The air-to-fuel "operating window" for a dedicated natural-gas-fired engine is depicted in Figure 14.[8]

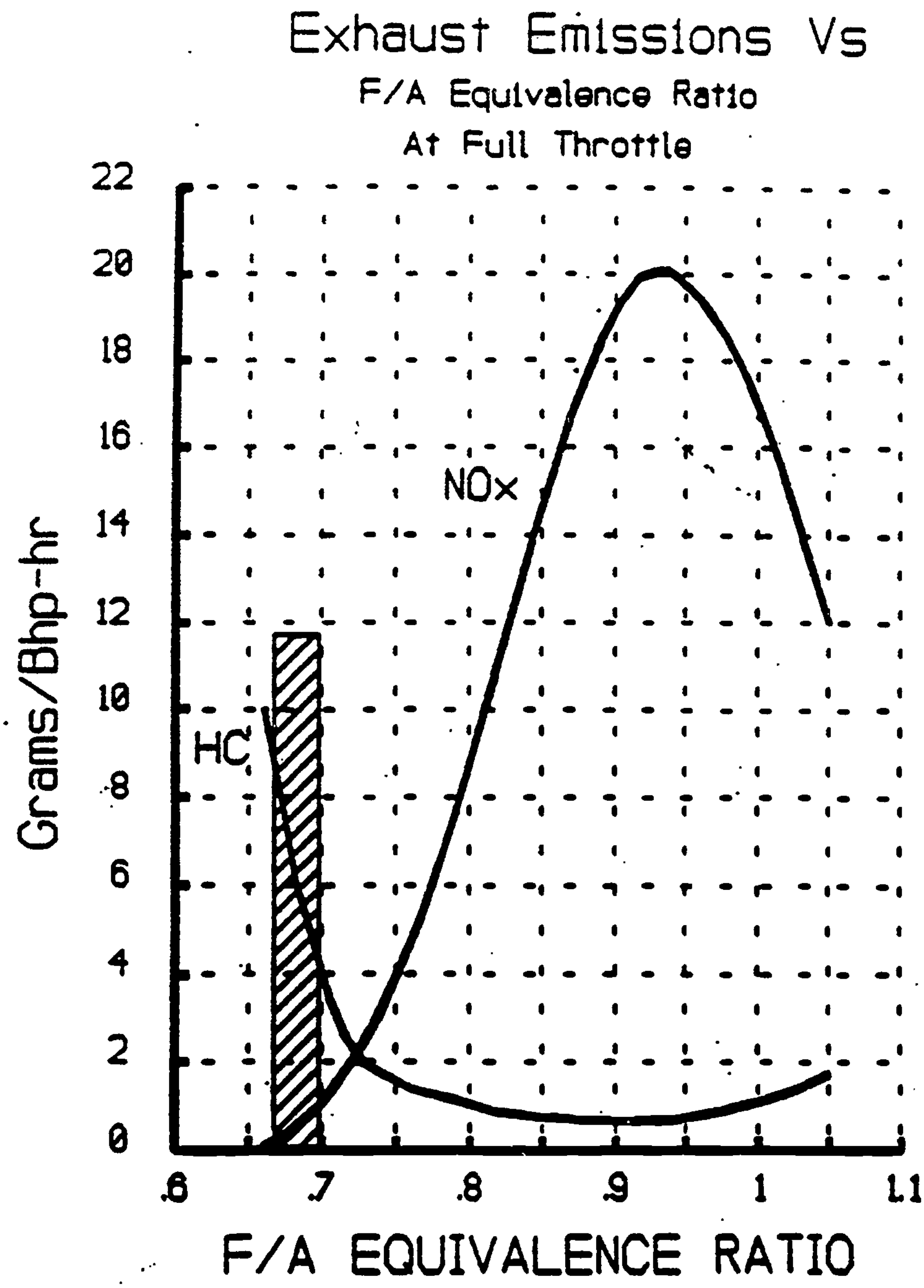
Engine designers have long been experimenting with approaches to minimizing engine emissions while producing satisfactory torque and power outputs. Three approaches that are now being developed are the prechamber fast-burn/lean-burn concept, the low turbulence piston design, and the open-chamber lean-burn homogeneous combustion system.

The fast-burn/lean-burn CNG-fueled engine concept features a prechamber in the cylinder head that includes a spark plug and its own separate fuel supply. The mixture inside the prechamber is approximately stoichiometric, which facilitates ignition by the spark plug. As the prechamber combustion progresses, ignition of a lean mixture in the main chamber occurs. The overall effect is to allow operation at a very low equivalence ratio for NOx control while maintaining combustion stability and extending spark plug life.[25]

The low turbulence piston design capitalizes on the most basic property of gaseous fuels—that they exist in a gaseous state. CNG, unlike liquid fuels, readily mixes with combustion air as it is already in a gaseous form. Turbulence is therefore not required to vaporize the fuel and less energy is necessary to mix the fuel-air charge into a completely homogeneous or uniform mixture. The low turbulence piston is thus designed to minimize heat transfer to the air/fuel charge. Reduced heat transfer decreases the charge density and permits increased air flow. The increased air flow enables the engine to produce the required output at higher air-to-fuel ratios. NOx emissions are reduced.[26, 27]

Prechamber system disadvantages include a complex control system, high part-load hydrocarbon emissions, and design complexity for the cylinder head. An open-chamber lean-burn combustion system, on the other hand, features simpler hardware and controls. Limiting factors for the open chamber concept include reduced

Figure 14



Exhaust Emissions Vs
F/A Equivalence Ratio
At Full Throttle
Grams/Bhp-hr
22
20
18
16
14
12
10
8
6
4
2
0
NOx
HC
.6
.7
.8
.9
1
1.1
F/A EQUIVALENCE RATIO

torque rise, unless sophisticated electronic controls are used. Figure 15 indicates hydrocarbon versus NOx trade-offs for various gas engine combustion approaches.[28]

Natural Gas Engine Emissions

Before presenting emissions results, it is useful to understand how engines are emissions tested and certified. The Transient Emission Test Cycle is the standard by which the EPA certifies new heavy-duty engines for sale in the United States. In the transient cycle test the engine, mounted on a test stand, is coupled to a motoring/absorbing dynamometer. If used, post-combustion emission control equipment is connected. Exhaust hydrocarbon emissions are measured continuously with a flame ionization detector; CO is measured with non-dispersive infrared instrumentation, while NOx is measured by chemiluminescence techniques. Particulate emissions are determined from filter weight gains.[29]

The transient cycle itself is described as a percentage of the engine's maximum torque and rated speed for each 1-second interval, over a test cycle of 1199 seconds in duration. The test consists of cold-start and hot-start transient cycles with the same engine command cycle used in both cases.

After an engine stands overnight in an ambient temperature of 68 degrees to 86 degrees F, the cold-start transient cycle begins when the engine is cranked. Following the cold-start test sequence, the engine is allowed to stand for 20 minutes. Then the hot-start cycle is administered.[29]

Composite transient cycle emissions results are weighted in the following manner:

$$\textit{Brake Specific Emissions} = \frac{\frac{1}{7}\,(\textit{mass emissions, cold}) + \frac{6}{7}\,(\textit{mass emissions, hot})}{\frac{1}{7}\,(\textit{cycle work, cold}) + \frac{6}{7}\,(\textit{cycle work, hot})}$$

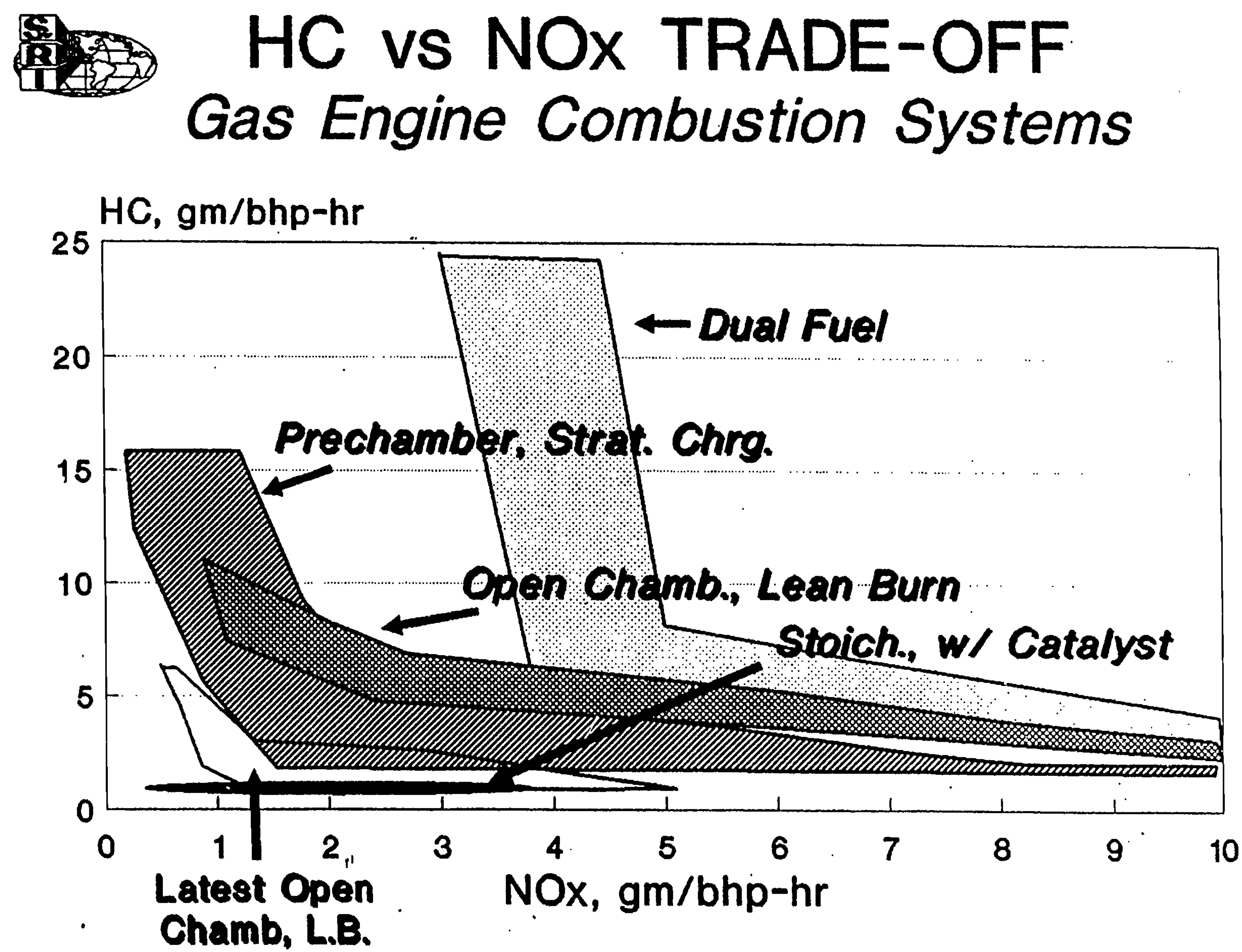
Emissions test results are now available for three dedicated CNG engines that are frequently used in school or transit buses. These engines are the Hercules GTA 3.7L, the TecoDrive 7000, and the Cummins L-10. Emissions results, compared with the 1994 EPA Heavy Duty Diesel Standards, are indicated in Table 6.[8,12,13]

Table 6
Emissions From Dedicated CNG Engines
Values in grams per horsepower hour (g/hp hr)

	Pollutant			
	NMHC*	CO	NOx	Particulates
1994 EPA Heavy-Duty Diesel Standards	1.3	15.5	5.0	0.1
Hercules GTA 3.7L	1.3	3.55	1.68	0.1
Cummins L-10-240G (with catalytic converter)	0.12	0.65	4.87	.075
TecoDrive 7000**	0.2	9.3	1.1	

*NMHC=Non-methane hydrocarbons
**The TecoDrive 7000 compressed natural gas engine was tested in accordance with EPA's Heavy-Duty Gasoline Transient Test procedures.

Figure 15



HC vs NOx TRADE-OFF
Gas Engine Combustion Systems
HC, gm/bhp-hr
25
20
15
10
5
0
0
1
2
3
4
5
6
7
8
9
10
NOx, gm/bhp-hr
Dual Fuel
Prechamber, Strat. Chrg.
Open Chamb., Lean Burn
Stoich., w/ Catalyst
Latest Open
Chamb, L.B.

The emissions test results indicate that currently available CNG-fired engines are capable of meeting EPA's 1994 standard when only reactive, non-methane hydrocarbon emissions are considered. This finding is not unexpected, however, as the 1994 standard is aimed at reducing allowable particulate emissions. CNG-fueled engines, by their nature, are low particulate emission powerplants.

In-service school and transit bus emissions testing data are not yet available. CARB and the South Coast Rapid Transit first constructed emissions centers with dynamometers capable of testing heavy-duty engines in mid-1991. The Federal Department of Energy (DOE) is building a transportable heavy-duty emissions test facility that can be used for internal testing of transit buses participating in the Urban Mass Transit Authority (UMTA) demonstration program. DOE has also allocated funds for the future emissions testing of the Tulsa School District's Ward buses with dedicated CNG-fired Hercules 5.6L engines. Finally, the California Energy Commission is working with EPA to conduct an extensive monitoring and evaluation program for the advanced diesel and alternative-fueled school buses purchased under its Safe School Bus Clean Fuel Efficiency Demonstration Program.

Emissions from After-Market Conversions of Gasoline-Powered Vehicles

A vehicle retrofitted to gaseous fuels must operate in an engine environment designed for gasoline. This places performance limitations on the retrofit resulting in reduced combustion efficiencies and increased emissions. Similarly, the retrofit vehicle must operate using an emissions control system optimized for gasoline instead of gaseous fuels. Again, vehicle emissions suffer due to poor control efficiencies.

In addition to these design limitations, a retrofit must also deal with a variety of vehicle-specific conditions that directly impact performance. Factors include the type and condition of the vehicle at the time of conversion, the sophistication of the conversion equipment, the quality of the installation, how well and how often the equipment is calibrated, and the type and condition of the vehicle's emission control equipment. As a result, emissions will vary from vehicle to vehicle, with some retrofits achieving excellent emissions while others operate poorly.

For example, the Canadian-sponsored 1990 World of Wheels measured total HC emissions of 0.98 g/mile for a participating natural gas vehicle.[30] By comparison, HC emissions for a gasoline vehicle measured 0.18 g/mile, while a propane-powered vehicle was measured at 0.16 g/mile. The 1988 Canadian standard for HC is 0.41 g/mile. Nitrogen oxide (NOx) measurements for the natural gas vehicle were also higher than the Canadian standard, as well as those recorded for the gasoline and propane vehicles participating in the program.[30]

In contrast to the World of Wheels results, an on-going study by the United Parcel Service (UPS) showed significantly lower levels of emissions resulted from its conversion of 10 UPS vans to compressed natural gas. The UPS reported NOx reductions of 22 percent and non-methane hydrocarbon reductions of 86 percent for the CNG vans when compared with comparable gasoline-powered vehicles.[2]

Both the Canadian and UPS study results are representative of much of the emissions literature for after-market conversions. The findings are interesting in that they show the variability in retrofit emission performance. They also show the difficulty in predicting emission performance based on other vehicle results. With the possible exception of an OEM-sponsored retrofit, emission test data are valid only for the vehicle tested and cannot be used to predict how other retrofits will perform. Consequently, retrofit emission test results are useful only as a reference and not as a guarantee of performance.

Meaningful emissions results are scarce. In a recent comprehensive assessment of emissions from CNG-powered vehicles, the EPA published emissions test results for only five dual-fueled light-duty vehicles.[2] One EPA official stated that "it's cheaper to buy a new fleet than to test one." Ideally, emissions testing should occur before and after a gaseous fuel conversion. For dual-fueled vehicles, test results should be obtained when the converted vehicle is operated on gasoline as well as the alternative fuel.

The California Air Resources Board (CARB) tests alternative-fueled vehicles when they are made available to them. CARB's vehicle testing program is designed to establish: 1) the magnitude of emissions benefits from alternative fuels; 2) vehicle performance and driveability; and 3) vehicle emissions control system and engine durability. CARB's tenth interim report summarizes 1989-1990 emissions data for a test fleet of 20 alternative-fueled vehicles. Nineteen of the vehicles are dedicated M-85 (85 percent methanol, 15 percent gasoline) or flexible fueled vehicles. A single tested vehicle was dual-fueled with CNG and gasoline. No propane-powered vehicles were tested.[31]

CARB intensified their gaseous fuel exhaust emissions testing activities during the 1990-1991 period. Rigorous emissions testing was conducted for 18 light- and medium-duty clean fuel vehicles using the federal CVS-75 emission test procedure. Each vehicle's emission control system was checked prior to testing. Of the 18 vehicles tested, 8 were flexible-fuelled methanol-powered vehicles, 9 were dual fuel CNG vehicles, and 2 were LPG vehicles. All 11 of the gaseous-fueled vehicles were 1989 or 1990 model years. The CNG vehicles were supplied by the South Coast Air Quality Management District or participating California gas utilities, and the two LPG vehicles were supplied by the LPG industry.[32]

The CARB test results show that emissions from all 11 gaseous-fueled vehicles were low enough to pass both the federal and California 1994 NMOG standards, as well as the 1997 federal Clean Fuel and California LEV standards for NMOG. Emission test results for CO and NOx were not as good, however. Four of the CNG vehicles tested exceed the 1994 CO emission standards by a factor of 2 or more. Similarly, six out of nine of the CNG vehicles failed the 1994 NOx standard of 0.4 grams per mile. For comparative purposes, two production gasoline vehicles were also tested. While both gasoline vehicles were able to meet 1994 emission standards for NMOG, CO, and NOx, neither vehicle met the 1997 Clean Fuel or LEV standard for NMOG. Interestingly, gasoline and methanol vehicles equipped with electrically heated catalysts were able to meet the stricter light-duty vehicle ULEV standards. Test results are given in Table 7.[32]

Table 7
CARB-Dual Fuel Vehicle Emissions Summary
CVS-75 Federal Test Procedure (g/mile)

Year	Model	Fuel	NMHC	CO	NOx
1989	LeSabre (PC)	CNG	0.04	0.38	0.56
1990	LeSabre (PC)	CNG	0.07	0.13	0.37
1990	Taurus (PC)	CNG	0.09	0.07	1.27
1990	Dynasty (PC)	CNG	0.17	27.04	0.19
1990	Dynasty (PC)	CNG	0.06	3.68	0.90
1990	Dynasty (PC)	CNG	0.09	29.95	0.14
1990	Astro Van (MDT)	CNG	0.07	0.31	0.61
1990	Club Wagon (HDT)	CNG	0.15	0.32	2.00
1990	F-350 XLT (HDT)	CNG	0.06	11.19	1.12
1989	Delta 88 (PC)	LPG	0.10	2.45	0.09
1989	Pont. 6000 (PC)	LPG	na	1.15	0.21
1988	Toyota Camry (PC)	Gasoline	0.189	2.33	0.32
1990	Ford Tempo (PC)	Gasoline	0.16	3.268	0.135

PC—Passenger Car, MDT—Medium-Duty Truck, HDT—Heavy-Duty Truck

Although the CARB drew no conclusions from the tests, the results support the accepted belief that a vehicle retrofitted to operate on CNG and/or propane can achieve reduced hydrocarbon and CO emissions, but that NOx control is problematic. The data also suggest that emissions may vary widely from vehicle to vehicle and that air quality improvements are not guaranteed.

An EPA analysis of CNG use in heavy-duty engines generally agrees with the CARB results. The EPA concludes that while NOx reduction remains a problem, hydrocarbon and CO emissions may be lowered depending on the quality of the conversion and how well the vehicle is tuned. On a reactivity-equivalent basis, EPA projects that NMHC emissions from light-duty, CNG dual-fuel vehicles can be 36 to 47 percent less than typical gasoline vehicle emissions. EPA did not project CO emission reductions, instead observing that the potential for reducing CO emissions is significant provided that the vehicle is properly calibrated and that the calibration is maintained during use. The EPA also noted that optimizing for CO emissions can degrade NOx emissions.[33] The EPA based its conclusions on light-duty dual-fuel vehicle results, noting that it was unable to find any transient testing for heavy-duty dual-fuel engines. A similar EPA report evaluating the environmental effects of propane as a vehicle fuel has not yet been completed.

Recent developments in gaseous fuel engine control and fuel system technology should help improve the reliability and performance of retrofit emissions. Current retrofit technology uses a mechanical gas-air metering and mixing device similar to a gasoline carburetor. While this device has a proven record of operation, it is mid-seventies technology and can not adequately respond to changes in engine speed and load. Further, because it is a mechanical device, factors such as friction, wear, and sticking can cause it to drift out of tune and degrade emissions.

Two companies, Ortech International and IMPCO Technologies Inc., have developed an electronic fuel injection (EFI) system for gaseous fuels. Along with the development of catalytic converters, EFI equipment is largely responsible for the tremendous emission improvements experienced by production gasoline vehicles over the last decade. The equipment developed for gaseous fuels is similar to that used for gasoline engines and will allow for direct control of the air-fuel ratio over changing engine speeds and load.

Finally, both the State of Colorado and the California Air Resources Board have established a certification program for approving CNG and LPG conversion systems. Equipment manufacturers must receive approval from the state prior to selling or installing conversion equipment. The certification requires that the equipment pass an emissions test for a given class of vehicles.

Emissions Sensitivity to Fuel Composition

The Southwest Research Institute (SWRI) has been involved in the performance testing of exhaust catalysts and oxygen sensors in stoichiometric gasoline and diesel engines converted to operate on CNG fuel. SWRI has also examined the emissions characteristics of natural gas engines when fueled with natural gas of different compositions.

The primary emissions control mechanism for light-duty vehicles is a three-way catalytic converter with the engine equipped with a closed-loop fuel-control system. SWRI tested seven different three-way catalysts that were specially formulated for natural gas service. It was found that precise control of air-to-fuel ratio is necessary to ensure three-way catalyst performance. The catalysts tested tended to have high NOx reduction efficiencies when operated under rich conditions, as CO, prevalent under these conditions, is necessary to reduce NOx. NOx removal efficiencies drop to less than 10 percent when the catalysts are operated lean at a .98 equivalence ratio. The "operating window" for acceptable catalyst performance was found to be very narrow, on the order of 0.5 percent variance in equivalence ratio.[28]

Oxygen sensors were found to exhibit a slight signal shift to the lean or rich side of stoichiometric, depending upon sensor type. Air-to-fuel ratio control precision was found to vary depending upon the type of fuel injection system used. Air-to-fuel measurements at individual exhaust ports of a multi-point injection system indicate considerable variation between cylinders, showing a maximum of 15 to 20 percent under lightly loaded conditions. Throttle body injection systems, on the other hand, allow for premixing, which leads to acceptable air-fueled distribution results.[28]

SWRI's most surprising results came from a study of emissions versus natural gas composition. Five samples of gas were obtained from throughout the United States. These gases are characterized by their Wobbe index, which the gas industry has traditionally used as a means of correcting for changes in gas composition. The Wobbe index is an indication of the amount of energy that will pass through a fixed orifice size given a fixed pressure drop. The equivalence ratio varies almost linearly with the Wobbe index.[28]

SWRI found that slight changes in the Wobbe index could lead to considerable increases in emissions. For instance, a lean-burn engine tuned to provide 1.0 g/bhp-hr NOx with a low Wobbe index gas could emit as much as 7.0 g/bhp-hr given substitution of a high Wobbe index fuel. This seven-fold increase in emissions occurs solely due to changes in fuel composition, with no change being made to the engine. The impact of gas composition on NOx, CO, and HC emissions for lean-burn and stoichiometric natural gas fired engines is illustrated in Figures 16 and 17.[28]

It is apparent that changes in natural gas composition can dramatically change the emissions and performance of a stoichiometric or lean-burn, natural-gas-fired engine if no corrective actions are taken. In order to "adapt the engine to fit the fuel," a properly programmed closed-loop electronic fuel control system is required. Without an adaptive control system, engine emissions will vary with gas composition, and the emissions reduction benefits anticipated from using a "clean-burning" fuel may not materialize.

Figure 16 GAS COMPOSITION EFFECTS

Lean Burn Engine

5 Different Gases

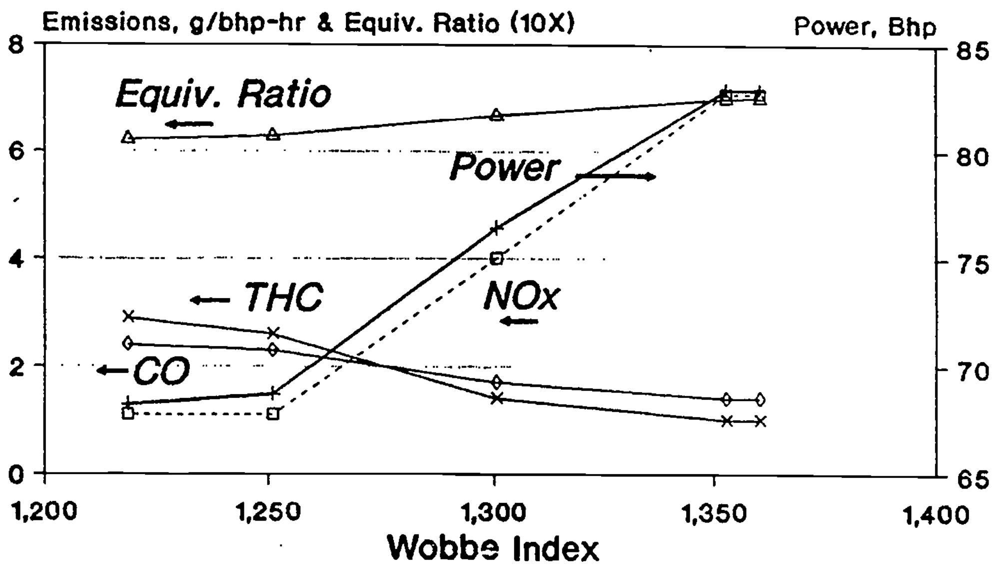
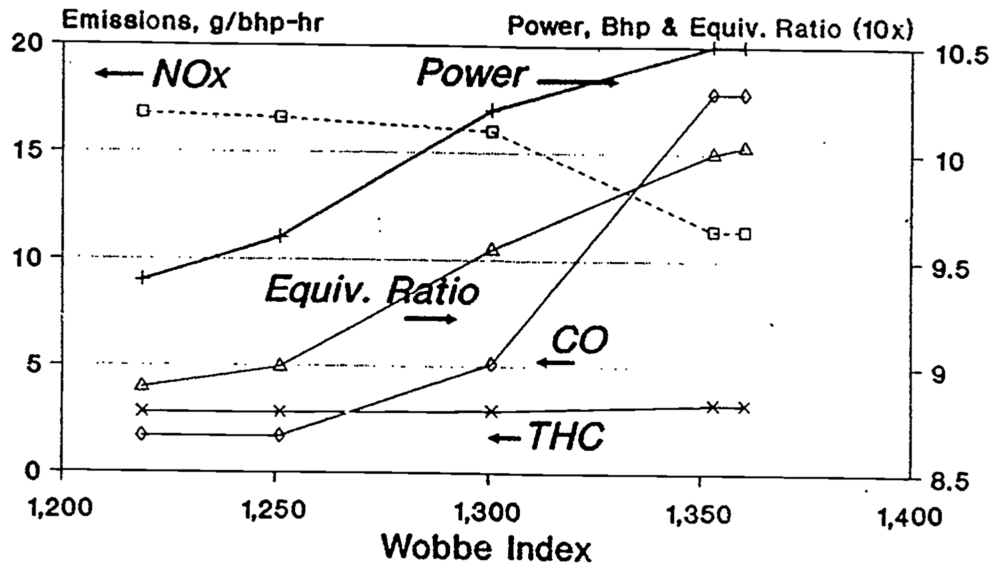


Figure 17

GAS COMPOSITION EFFECTS

Stoichiometric Engine

5 Different Gases



Chapter 7
Economic Benefits From Alternative Fuels Use In School Buses

In this chapter, the cost-effectiveness of the various alternative fuel paths will be examined. In addition to original equipment full and/or incremental costs, the chapter discusses fuel economy, fuel prices, refueling station purchase, installation and operating costs, and alternative fuel taxation policies.

Compressed Natural Gas

A school district can take three actions that result in the availability of compressed-natural-gas-fueled buses. The potential scenarios are: 1) initially purchasing a dedicated CNG bus directly from the factory, 2) repowering or replacing an existing diesel- or gasoline-powered engine with a dedicated CNG-fueled engine at the end of the original engine's useful life, and 3) retrofitting or converting an existing gasoline-powered engine to operate with dedicated CNG or propane fuel or in a dual fuel CNG plus gasoline mode. As the technology to convert diesel engines to CNG or propane use is not well developed, this action is not recommended at this time.

Each scenario for acquiring alternative fueled vehicles offers different choices with different economic outcomes. In addition, a time-fill or fast-fill refueling station must be supplied that is sized to meet existing plus anticipated filling requirements.

Original Purchase

For this scenario, the cost of procuring the alternative-fueled bus is the factory price less the cost of purchasing an equivalent diesel- or gasoline-fueled unit. Unfortunately, good comparative cost information is difficult to obtain as different states have different minimum standards. Bus manufacturers also offer as many as 800 different options on the body alone. Typical variables include axle type and ratio, wheelbase, engine size and type, gauges provided, transmission, brakes (drum or disc/hydraulic or air), steering system, tires, heater capacity and location, mirror size and location, seating configuration, and warranties. Districts thus tend to purchase "specification-built" buses.

In Washington, buses are not purchased under a single state contract. Instead, each school district prepares unique bid specifications for the procurement of 2, 5, or 20 buses. Economies of scale are not captured as manufacturers must establish separate production lines to produce only a few units. Finally, there is the question of quality. A Cadillac is not equivalent to a Chevrolet. Factors such as perceived body leak-tightness are very important to school district fleet administrators.

Tumwater School District received two bids in response to their May 1991 solicitation for five 68-passenger CNG-powered Type D buses. AmTran Ward submitted a base ex. tax price of $57,321 ($ 61,849 with tax) for its Senator model while Carpenter came in at $ 62,777 ($ 67,548 with tax). Both bids reflected use of the Hercules GTA 5.6L engine mounted on a Crane-Carrier chassis. In both cases, the buses would be equipped with 3-1260 cubic feet natural gas fuel storage tanks. The composite gas storage volume of 3,780 cubic feet is expected to result in an operating range of 140 to 175 miles.

Tumwater selected the AmTran Ward bus and purchased an optional 5-year/100,000 mile extended warranty for an additional $375 per bus. Incremental costs for the factory-built dedicated CNG buses are unfortunately not available as Tumwater did not seek bids for conventional diesel buses. Had Tumwater sought to obtain diesel units, it indicates it probably would have purchased Blue Bird buses with Caterpillar 3208 engines at a cost of approximately $ 65,000 each. Under these circumstances, the incremental cost of the alternative-fueled buses is negligible.

Tulsa, Oklahoma, is the only other school district nationwide to have experience with the Ward dedicated CNG buses. Tulsa retrofitted and tested a bus equipped with a Hercules 5.6L engine, then purchased 45 AmTran Ward 66-passenger factory-built buses at a cost of $ 50,000 each. Its buses went into route service for the 1991-92 school year.

Carpenter estimates an additional cost for a 190 hp Hercules GTA 5.6L powered bus of $6000 to $7000 over a similar bus driven by a 160 hp Cummins engine. Additional chassis modifications and refueling tank costs account for $3260 of this total while low volume production incurs a cost increment of $3000 to $4000.

Repowering

Medium-duty diesel engines typically run from 100,000 to 130,000 miles before a major overhaul. For a bus with a fuel economy of 7 miles per gallon that consumes 2000 gallons of fuel per year, the expected useful engine life is on the order of 7 to 9 years. In contrast, a typical bus body life exceeds 15 years.

If the core is not damaged, a diesel engine may be rebuilt for $5000 to $8000. Installing a new diesel engine costs approximately $10,000, while a gasoline-powered replacement can be installed for $3500. Tulsa School District reports that a new International DT 360 diesel engine costs about $6500 "ready to stick in." Tulsa also priced a Hercules GTA 5.6L natural-gas-fired engine at $6400 through a distributor. A Hercules representative indicates a base cost of $5000 for the 5.6L engine coupled with $1200 for a state-of-the-art gaseous fuel injection system. The incremental cost of the alternative fueled engine is thus limited to the costs of purchasing and mounting fuel storage tanks, vents, and the refueling connector and gauge. The total additional equipment plus installation costs for repowering with a dedicated CNG versus a diesel-fueled engine should amount to less than $4400.

Vehicle Conversions

Many companies manufacture kits that allow gasoline-powered engines to be converted to operate on gaseous fuels. With appropriate modifications to ignition timing and optimum air to fuel ratio, any 4-cycle spark ignition engine can be made to operate on natural gas. Older style kits consist of high pressure cylinders to contain the natural gas at 2400 to 3000 psi; a pressure reducer and regulator to lower the natural gas pressure; and a mixer placed in series with the gasoline-engine carburetor to mix the natural gas with intake air in the appropriate ratio.

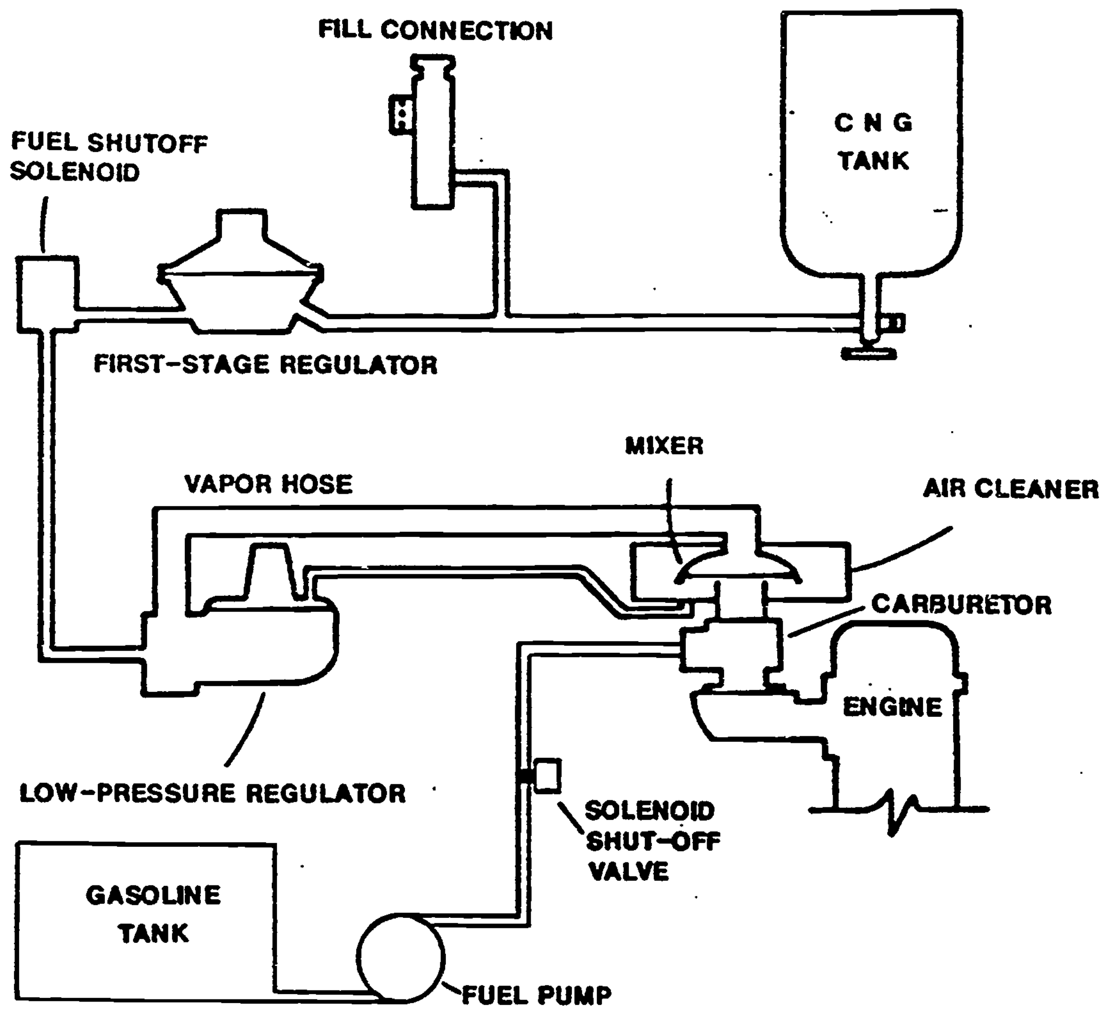
Typically, converted gasoline buses operate in a "dual fuel" mode. They retain the ability to operate with gasoline, when supplies of natural gas are depleted. The conversion system also includes valves to stop the gasoline flow when the natural gas system is in use and vice versa. Additional components include a tank pressure gauge to indicate the "fuel fill level" and controls in the passenger compartment that allow switching from one fuel to the other. Components of a typical compressed natural gas conversion are shown in Figure 18.[34]

Converted gasoline engines with mechanical mixers experience a power loss of 10 to 25 percent when operating on natural gas. This power loss is due to the displacement of combustion air by the natural gas fuel, by ignition and combustion problems imposed by the slow-burning characteristics of natural gas/air mixtures, and by the inability of the conversion systems to maintain appropriate air-to-fuel ratios under all speed and load conditions.

In addition to purchasing dedicated factory-built CNG school buses, the Tulsa School District purchased 40 66-passenger Blue Bird buses equipped with gasoline-powered, electronically fuel injected GM-366 cubic inch engines. In the summer of 1991, these buses were converted to CNG use, using IMPCO equipment, at a total cost of $3600 each. This cost quote includes 3-1260 cubic foot gas storage cylinders plus the purchase and

Figure 18

Components of a Dual-Fuel CNG Conversion



installation of all conversion kit components. This cost might increase by $1000 if an advanced electronic gaseous fuel injection system is used.

The EPA cites estimates for the conversion of diesel engines to dedicated spark ignition CNG operation ranging from $3000 to $5000. These cost estimates are for the engine conversion only and do not include such vehicle-related components as CNG fuel cylinders.

Cylinder costs vary with respect to quantity ordered. Fiber-wrapped steel 16.3 x 53.6 (1260 scf) cylinders cost $1077 each if ordered in small quantities. The unit cost is reduced to $777 when the cylinders are ordered in lots exceeding 200 units. A typical school bus retrofit would require three of these cylinders.[33]

Refueling Station Costs

As natural gas is delivered through pipelines in gaseous form, it must be compressed prior to storage onboard a vehicle. Specialized refueling equipment is thus necessary for metering, compressing, and dispensing this gaseous fuel. Generally, fleet operators may choose between "fast-fill" or "slow-fill" CNG vehicle refueling stations. A "fast fill" refueling facility consists of a gas metering system, a compressor, dispensing terminals, and multiple "cascades" or racks of high-pressure gas storage bottles.

The direct cost of a refueling station with the capacity to serve 24 buses, designed to dispense the equivalent of 270 gallons per day, and with the capacity to quick fill 135 gallons per hour, is $ 114,000.[36] A cost breakout by item is included in Table 8. An additional $10,000 must be budgeted for shipping and installation costs; to provide a weather cover, reinforced compressor pad, and barricades; and to perform leak testing on high-pressure gas interconnections.

Table 8
CNG Refueling Station Cost

Compressor complete with 4 storage cascades, sequential and priority panel, and methanol injection with 2 hose drops	25 cfm	$74,000
2 Hose CNG metering system		32,000
Pilot operated solenoid valve		500
Compressor blowdown recovery system		1,000
Card Control System		5,500
Electric meter interface card		0
Printer with interface		1,000
Junction box for printer		0
Gasoline pump pulser		0
Total		**$114,000**

A minimum annual fuel consumption is necessary to justify a district's or a gas utility's investment in a refueling station. As districts typically purchase a small number of buses each year, the conversion of existing gasoline-powered buses may be necessary to obtain an aggregate fuel consumption that warrants investment in a refueling station. The converted buses could then be replaced with dedicated fuel buses at the end of their operating lives.

Due to range limitations, it would be unusual for a district to operate an entire fleet of dedicated CNG-fueled buses. Some diesel or dual-fueled units would be necessary for extra-curricular activities. Conversions are commonly considered when a district makes an initial decision to embark on an alternative fuels program. While SPI discourages the conversion of older buses to extend their operating lives beyond their depreciation schedules, newer, gasoline-powered buses are attractive conversion candidates.

The "fast-fill" refueling process is simple and takes the same amount of time as filling with gasoline. The compressor fills the cascades to 3,600 pounds per square inch (psi), and the vehicle storage tanks are charged from the cascades to 2,400 psi. Four vehicles could fill at one time; however, this type of system does not have the capacity to fill continuously for a long period of time. Due to limited compressor capacity, filling of vehicles must be spread over the working day and not grouped into small time periods in the morning or afternoon.

School bus operations, with their morning, kindergarten mid-day, and afternoon runs, naturally lend themselves to "time-fill" operations. A typical time-fill configuration is indicated in Figure 19. Here, drivers park their buses in slots adjacent to refueling posts. After parking a bus, the driver attaches a refueling probe to a filling connector and a compressor automatically fills the bus with fuel between daily operations and during the evening. The Tumwater, Yelm and Tacoma school districts currently use time-fill refueling stations. The cost of a time-fill arrangement capable of refueling 24 school buses is $ 69,000.[36]

It should be noted that refueling stations serving fleets of dedicated CNG-fueled buses may require redundant or backup compressor capacity. A prolonged compressor outage would not adversely impact the operations of a fleet of dual-fueled vehicles, but would restrict the ability of a fleet administrator to refuel dedicated fuel vehicles.

Operating and Maintenance Cost

Vehicles: Oil change intervals definitely can be extended given operation with "clean-burning" gaseous fuels. The Tumwater School District changes oil at a 3000 mile interval for its gasoline-powered buses. This increment has been extended to 10,000 miles for dual-fuel buses. These buses operate one day per week on gasoline to satisfy engine lubrication needs. The changeout interval is expected to be much longer, perhaps on the order of 100,000 miles, for the dedicated CNG engines.

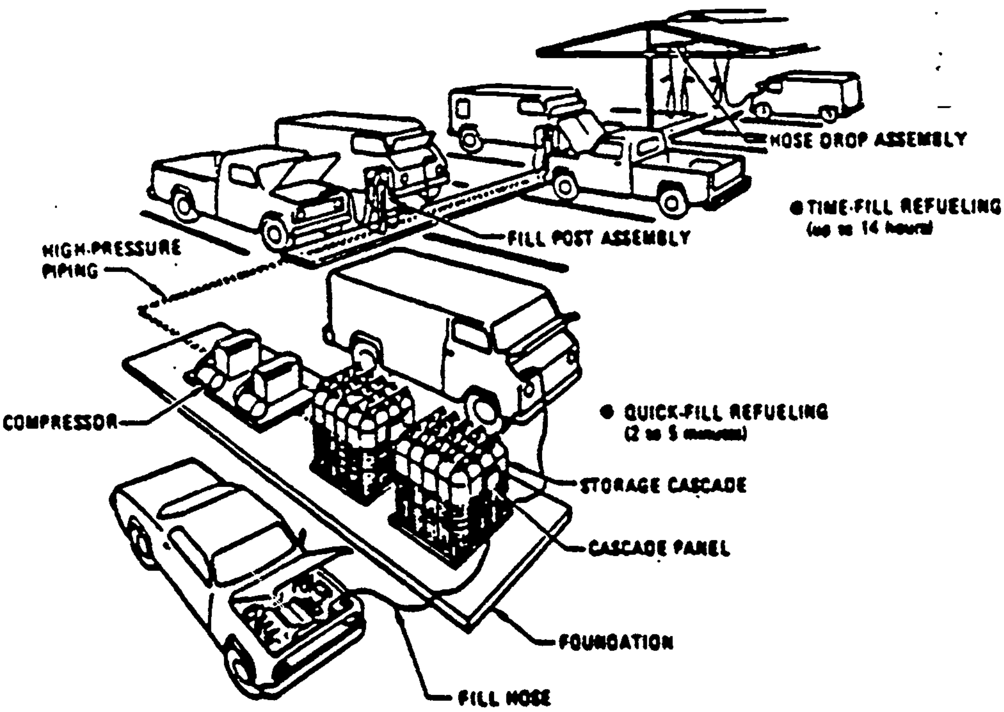
Tumwater will initiate an oil testing program to monitor engine wear and oil additive breakdown. Testing results will be used to determine the appropriate changeout interval. Spark plug changeout intervals are also extended when gaseous fuels are used.

Refueling Stations: Annual refueling station operating and maintenance costs can be broken into two segments: electrical energy required to operate the electric-motor-driven compressor used to compress the natural gas during refueling and direct equipment servicing and maintenance costs.

The annual electrical energy cost is dependent upon the gas supply and delivery pressures, size and efficiency of the compressor, and the price of electricity. The EPA reports that the energy required to power compressors ranging in size from 20 to 178 scfm varies from 0.0075 to 0.0099 kWh/scf. This translates into a consumption of 0.73 to 0.96 kWh/therm given a natural gas energy content of 1030 But/scf. This further translates into a cost of 3.6¢ to 4.8¢ per delivered therm given an electricity price of 5¢/kWh. The EPA also reports that maintenance cost experience with a variety of CNG refueling stations indicates annual expenses between 25¢ to 50¢ per

Figure 19

Typical CNG Refueling Station



million Btus delivered. This is equivalent to 2.5 to 5.0¢ per therm. Total refueling station operating and maintenance costs are expected to be in the range of 6.1 to 9.8¢ per therm.[33]

Liquid Petroleum Gas (Propane)

Unlike compressed natural gas (CNG), a school district interested in operating a propane-powered bus fleet is limited to after-market conversions. Neither repowering or initial purchase of a liquid petroleum gas (LPG) bus is an option at this time as currently there is no involvement from bus manufacturers to produce a dedicated LPG-powered bus. This situation may change, however, as both Ford and GM have begun production on a dedicated LP-gas engine that would be suitable for a small to medium bus.

Vehicle Conversions

Since LPG was first used in vehicles some 60 years ago, it has proven to be an effective fuel for automotive use with more than 330,000 vehicles currently operating on propane fuel in the United States. Most gasoline-powered cars and trucks can be converted for gaseous fuel operation while, diesel engines cannot.

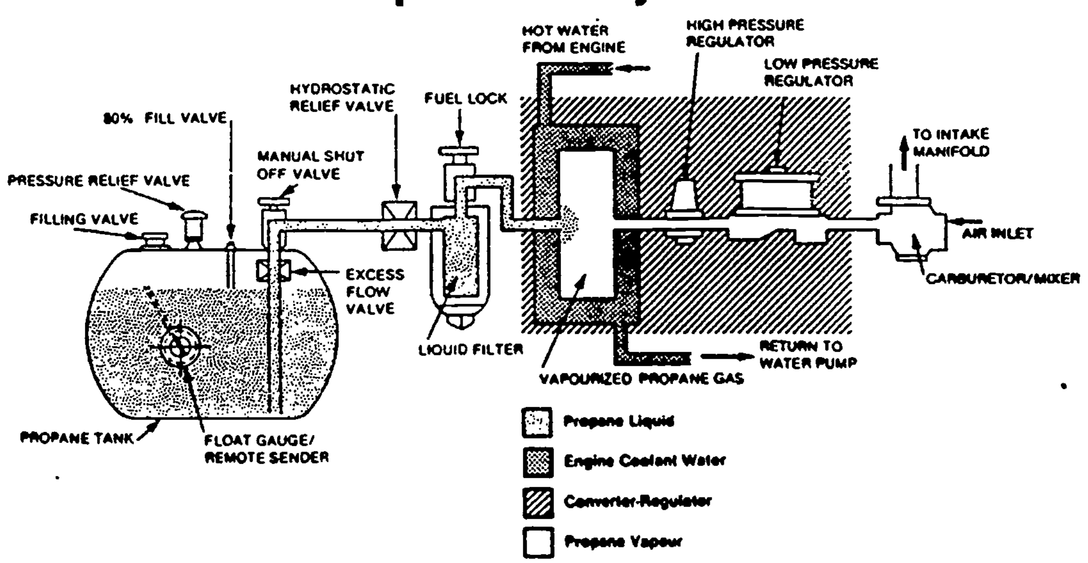
Four basic components are required for the conversion of a gasoline engine to operate on propane: a fuel tank, a lockoff valve, a converter, and a mixer or carburetor. The ASME or DOT approved *fuel tank* must be capable of withstanding a pressure three to four times greater than any pressure it will ordinarily be subjected to. Actual working pressures are on the range of 175 pounds per square inch (psi). The integrity of the tank is further protected by installing safety or pressure relief valves.

A *fuel lockoff valve* is used to automatically stop the LPG flow when the engine stops even if the ignition switch remains on. A *converter* is used to reduce the fuel pressure and to return the liquid fuel into its original gaseous form. Finally, an LPG *carburetor* meters the vaporized fuel and mixes it with air in the proper ratio for complete combustion. Various valves and fittings are also required, such as a liquid service valve, a safety relief valve, a liquid outage gauge, a filler valve, a fuel level gauge, and a fuel filter.[37]

Mechanically, nothing inside the engine changes. During the engine conversion, the distributor may be recurved and the spark plug gaps tightened. Additional modifications to the exhaust manifold and ignition system are usually also required. The installation of hardened valve seat inserts has been recommended during gaseous-fuel engine conversions. This is not a requirement for newer cars operating on lead-free gasoline as such cars already have hardened valve seats.

Figure 20

Propane Fuel System



The LPG equipment can typically be reused at the end of the vehicle life. As there are few moving parts, the equipment has a great longevity, with some systems operating for 20 years or more. A schematic of a typical propane fuel system is presented in Figure 20.[38]

Conversion Costs

Propane conversion equipment has been commercially available for more than 60 years, with prices fairly well stabilized. The cost of converting a vehicle to operate on propane, however, is dependent upon vehicle type, age, engine modifications required, and the capacity of the installed fuel tank. Average conversion costs are indicated in Table 9.[39]

Table 9
Propane Vehicle Conversion Costs (1988$)

Vehicle Type	Small Fleet	Large Fleet
Passenger Car	$1,999	$1,660
Van	$1,922	$1,604
Bus	$1,486	$1,216

Conversion costs could increase by as much as $1,000 if an advanced electronic fuel injection system is used. Current propane conversions utilize a mechanical mixer that can limit vehicle performance and emissions reduction potential.

Annual vehicle operating costs are dependent upon fuel consumption and base fuel cost; imposed federal and state fuel taxes; oil, filter, and spark plug changes; and annual engine maintenance costs.

Refueling Station Costs

Many fleet operators install an above-ground propane storage tank on their premises. The refueling system, consisting of a tank, pumps, and meter, is typically sold or leased to the fleet operator. For smaller fleet applications, a fuel storage tank capable of storing from 1,000 to 2,000 gallons of fuel is typical. Some large municipalities have purchased bulk storage facilities in excess of 10,000 gallons, which allows them to obtain large quantities of fuel at bulk or transport rates. Other users save money by joint purchasing or by anticipating seasonally varying prices. Refueling station costs are presented in Table 10; they do not include site-preparation costs.[39]

Table 10
Propane Refueling Station Costs

Capacity	Cost
2,000 Gallons	$10,000
14,000 Gallons	$57,000

Operators of propane-powered vehicles should also be aware of refueling station locations. Without service station availability, the range of propane vehicles is limited by their carrying capacity. There are over 25,000 LPG dealers in the United States. The National LP Gas Association (NLPGA) publishes an LP gas refilling directory. The refueling time is about the same as for gasoline. Some propane distributors, such as Cal-Gas in Puyallup, have installed a system that allows customers to fill up late at night by using a special key that unlocks the

Cal-Gas tanks. The transaction is recorded on the company computer after the customer's account number is entered at the pump.

Operating and Maintenance Costs (O&M)

Some debate exists over whether or not propane vehicles incur fewer maintenance costs than gasoline-powered vehicles. Indications are that, like CNG, propane vehicles may experience extended oil change intervals and spark-plug life. However, because actual operations data are scarce, it is assumed that maintenance costs for propane vehicles is the same as for gasoline vehicles. Similarly, propane refueling station O&M costs are considered equivalent to a gasoline or diesel station as propane does not incur the high compression costs associated with CNG.

Fuel Equivalency and Fuel Economy

Compressed Natural Gas

It is appropriate to compare natural gas versus gasoline or diesel fuel consumption on either an energy or "equivalent gallon" basis. At its high heating valve (HHV) natural gas contains an energy density of about 1,030 Btu/scf. The EPA states that the low heating value (LHV) for natural gas is about 90 percent of the HHV or 930 Btu/scf. Gasoline contains about 114,132 Btu/gal and diesel fuel contains 129,400 Btu/gal (LHV). Thus, approximately 1.26 therms of natural gas contains an energy content equivalent to one gallon of gasoline while 1.43 therms is required to displace one gallon of diesel fuel.[33]

An engine design parameter affecting thermal efficiency is the compression ratio. For stoichiometric engines the compression ratio is, in large part, dictated by the octane rating (anti-knock quality) of the fuel used. For a diesel or spontaneous compression ignition engine, the compression ratio and thermal efficiency is higher than for a spark-ignited gasoline engine. When a CNG-fueled engine is derived from a diesel carcass, the compression ratio must be reduced to control knock. Efficiency is reduced and fuel economy suffers. Conversely, when a gasoline engine base is used for a dedicated CNG engine, the compression ratio can be raised, increasing the thermal efficiency.

The EPA has reported fuel consumption data for several lean-burn CNG engines that have undertaken the heavy-duty engine emissions test. The EPA results indicate that 1.4 to 1.45 Btus of natural gas are required to offset one Btu of diesel fuel, while only 0.9 Btu are necessary to displace one Btu of gasoline. The EPA test results are summarized in Table 11.[33]

Table 11
Energy Consumption of Heavy-Duty CNG Engines (Btu/BHP-hr)

Engine	Diesel fuel	Gasoline	CNG
Cummins L-10 (lean burn)	7,180		10,000
Caterpillar 3406	7,430		10,800
Chevy 454 (Gasoline test cycle)		10,036	8,950

The EPA results are substantiated by data provided by the Cummins Engine Company. By mid-1991, 34 CNG fueled L-10 engines had been installed in transit buses while one had been installed in a refuse truck. Over 440,000 miles had been accumulated on these engines. Eleven transit authorities provided fuel consumption information for L-10 powered coaches while five provided information on diesel coaches subjected to similar route service. On average, the L-10 powered buses obtained 2.87 miles per equivalent gallon (approximately 126,000 to 128,000 Btu) of diesel; the diesel coaches obtained 4.89 mpg.[15] Thus, approximately 2.4 therms is required per gallon of diesel fuel displaced. The low fuel economy of this engine reflects its pre-commercial nature and is not necessarily representative of the next generation of L-10 engine or other dedicated CNG engines when compared to diesel powerplants.

On the whole, the development of heavy-duty dedicated CNG-fueled engine technology is in its infancy. Improvements in both emissions performance and fuel economy can be expected. Fuel economy data for school buses driven by CNG-powerplants are scarce and difficult to obtain even after units are placed into operation. Both the Tumwater and Tulsa School Districts operate time-fill natural gas refueling stations. Here, fuel consumption for the entire fleet is monitored with a single gas meter. It is not possible to isolate consumption for a single bus or class of buses. Either metered dispensing hoses, which are very expensive, or billings by a public access CNG filling station are required to verify and document fuel economy.

Hayward United School District, of Hayward, California, operates three Blue Bird buses equipped with Tecodrive 7.0L dedicated CNG engines. It purchases fuel from a gas utility operated refueling station and is thus able to report a fuel economy of about 5.0 miles to the equivalent gallon.

CNG is expected to perform with a thermal efficiency about midway between that of conventional gasoline and diesel liquid fuels. Tulsa School District believes that its dedicated CNG-fired Hercules 5.6L engines will obtain about 5.5 miles per equivalent gallon, about 1.5 mpg better than its gasoline-driven units. Diesel-powered buses obtain about 7.5 to 8.0 mpg.

Propane

Propane contains 91,740 Btus per gallon as compared to 123,000 Btus per gallon for gasoline.[37] Liquid propane gas, like gasoline, is a compound of carbon and hydrogen (C_3H_8). The chief physical difference between the two fuels is that LPG remains in a vapor state at atmospheric pressure and temperature.

When released from a storage vessel, propane will boil into a vapor at any point down to (-) 44 degrees F. LPG is typically stored and transported as a liquid in U.S. Department of Transportation (DOT) and American Society of Mechanical Engineers (ASME) approved pressure containers.[37] The liquid in the tank flows under its own pressure and is converted to vapor before reaching the carburetor. As LPG mixed with air is flammable only over a narrow concentration range (2.5 to 9.5 percent propane by volume), the carburetor serves as a precision mixer. Fuel system problems are greatly reduced compared to gasoline powered vehicles as most LPG carburetors have only one moving part. Fuel pumps, floats, needle valves, jets, and chokes are not required in a propane-powered vehicle.[37]

As it does not have to be atomized into a gas, LPG fuel does not condense on cold manifold walls. Thus, LPG engines are better able to start in cold weather than gasoline engines. This is an important advantage for vehicles, such a buses, that are not garaged and remain outdoors overnight. In addition, because LPG is a dry gas, it will not vapor lock in warm weather.

Some users experience a decline in vehicle mileage (miles per gallon) of 10 to 15 percent when converting to propane fuel. Others claim LPG mileage to be very close to that achieved with gasoline.[37] Reported mileage deviations are to be expected due to varying vehicle weights, temperatures, engine conditions, maintenance practices, and operating parameters. Although LPG has a lower Btu content than gasoline, this disadvantage may be partially offset by improved performance during the cold-start and warmup portions of the driving cycle.[37] A mileage loss of 10 percent is typically assumed for simple payback evaluations.

Fuel Price

Compressed Natural Gas

School Districts in Washington State may fall within the service territories of four investor-owned or private utilities: Washington Natural Gas Company, Cascade Natural Gas, Washington Water Power, and Northwest Natural Gas. In addition, several small municipal utilities, including Ellensburg, Enumclaw, and Buckley, provide local gas service. Areas served by the gas utilities are depicted in Figure 21.

The rates charged for natural gas used as an automotive fuel vary. The Washington Natural Gas (WNG) Company has two rate schedules—Schedule 86 and 31. Schedule 86—Interruptible Rate Schedule—has a per therm charge of \$.36949. Schedule 31—Commercial and Industrial Firm Rate—shows charges of \$.5197 per therm for the first 100 therms, dropping to \$.42695. Washington Water Power charges \$.[illegible]2/therm while Cascade Natural Gas imposes a charge of \$.458/therm under Schedule 512. Cascade also has a special compressed gas schedule that is indexed to the price of unleaded premium gasoline. Northwest Natural Gas has established a rate of \$.43/therm for the first 3600 therms, dropping to \$.33/therm.

The Tumwater School District owns its own refueling station and currently purchases natural gas for 38¢ per equivalent gallon (of gasoline). The fall 1991 gasoline price was \$1.07 gallon while diesel fuel was procured for \$1.09 to \$1.11 per gallon.

Propane

Propane has been used as a transportation fuel for many years. In 1960, propane supplied 2/10ths of one percent of the transportation fuels for Washington.[40] Propane's market share increased slowly up until the late 1970's when propane use increased tenfold in 6 years reaching a maximum market penetration of 9/10ths of a percent in 1984. This rapid increase in the late 70s was due to the strong surge in gasoline prices. Since then gasoline prices have declined and propane's market share has dropped back to 4/10ths of one percent.

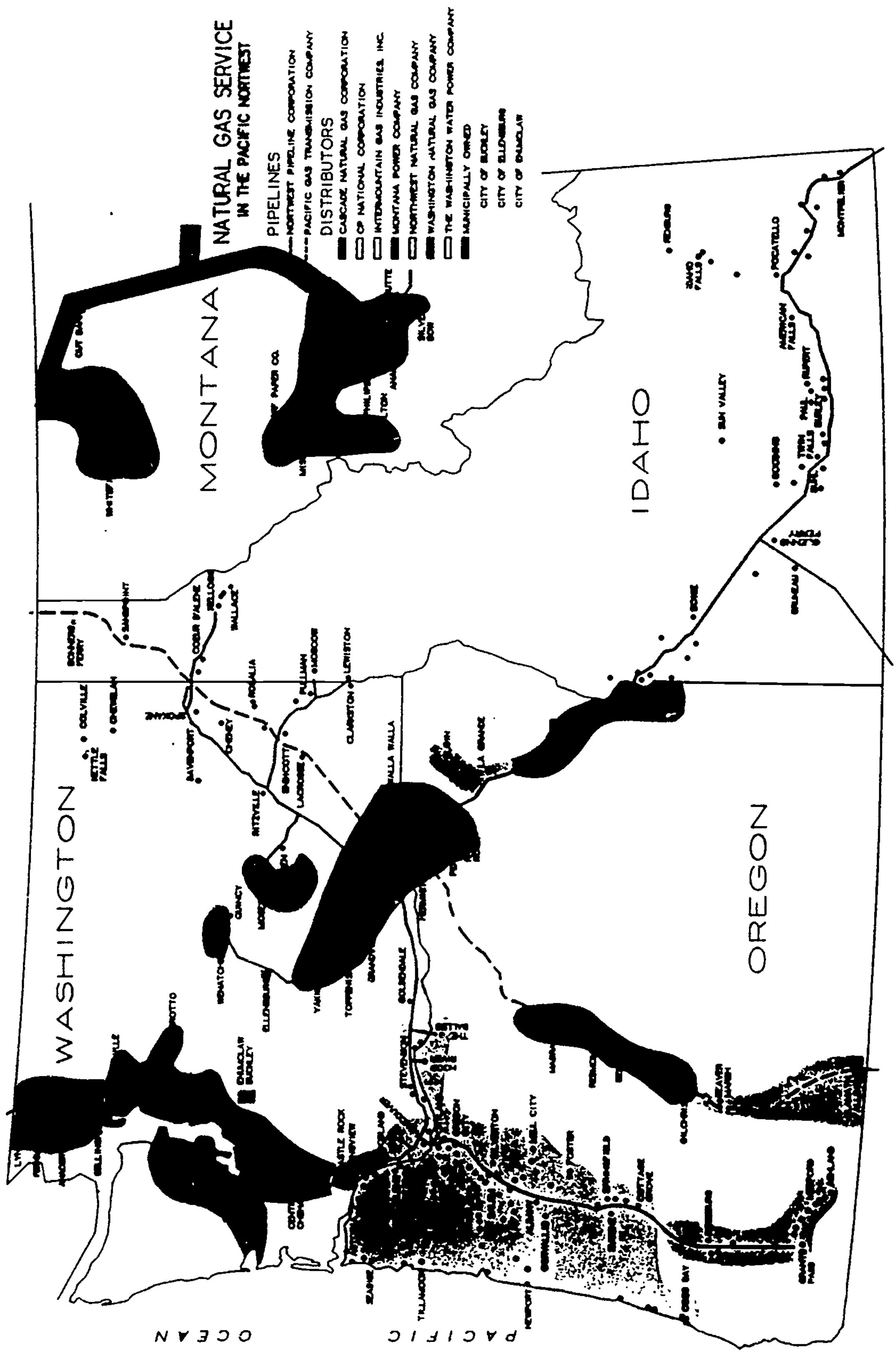
There are two sources of propane—petroleum refineries and natural gas liquids facilities. Propane is a by-product from both of these sources. Washington's refineries supply an average of 50 percent of the state's propane demands. That percentage has ranged from a low of 29 percent in 1985 to a high of 78 percent in 1988.[40] The refinery industry can use propane as a fuel for running its own processes and does so if it is less costly than the alternatives, such as natural gas. In 1985 natural gas prices were relatively high and propane was used internally at the refineries. The shortfall is met by imports from Canada.[40]

Canada produces large quantities of propane from its natural gas fields. Propane and other gases are removed from the gas at natural gas liquids processing facilities before the gas is put in the pipelines and marketed as natural gas. Canadian propane production is greater than its demand and 50 percent is exported. Washington uses about 6 percent of Canada's exported propane.

Propane prices, relative to gasoline, have steadily increased since 1970. In 1970, a gallon of propane cost 60 percent less than a gallon of gasoline.[40] Since 1983, retail propane prices are only 10 percent less than gasoline prices. As of November 1991, the price for 1000 gallons of propane was quoted at \$1.09 per gallon in Seattle and \$1.24 per gallon in Spokane. These prices reflect a seasonal high as propane is primarily a heating fuel. Large users can avoid the seasonality in propane pricing by purchasing bulk lots during the off-season. In addition, users can purchase propane at transport rates provided they have storage in excess of 10,000 gallons. Historically, transport rates have been as low as \$0.35 to \$0.43 per gallon.

Figure 21

Natural Gas Service Areas of the Pacific Northwest



59

Annual Propane and CNG Fueled Vehicle License Fee

School Districts are subject to the 23¢/gallon state fuel use tax but are exempted from the federal government's 14¢/gallon highway use tax. Washington State and Federal Highway Fuel taxes are summarized in Table 12.[34]

Table 12
Washington State and Federal Highway Fuel Taxes

Gas & Diesel	Pre April 1, '83	April 1, '83	July 1, '83	July 1, '84	Sept. '91
Washington	12¢	12¢	16¢	18¢	23¢
Federal	4¢	9¢	9¢	9¢	14¢
Total	16¢	21¢	25¢	27¢	37¢

In order to encourage the use of nonpolluting motor vehicle fuels, such as compressed natural and propane, the State of Washington imposes an annual license fee in lieu of the state highway fuel use tax. The annual fee is dependent upon gross vehicle weight (GVW) and is determined by the schedule given in Table 13.

Table 13
Annual License Fee For CNG and LPG-Powered Vehicles

Vehicle Tonnage (GVW)	Fee
0-6,000	$45
6,001	$45
10,001-18,000	$80
18,001-28,000	$110
28,001-36,000	$150
36,001-and above	$250

To determine the actual annual license fee imposed for a registration year, the appropriate dollar amount set out in the above schedule is multiplied by the motor vehicle fuel tax rate in cents per gallon as established by RCW 82.36.025 effective on July 1st of the preceding calendar year and the product divided by 12 cents. The current annual license fee for a 18,000 to 28,000 GVW vehicle is thus $110 times 23¢ divided by 12¢ or $210.

Cost-Effectiveness of an Alternative Fuels Conversion

The direct economic benefits due to purchasing and operating fleets of dedicated propane- or CNG-fueled vehicles, or through converting existing vehicles to alternative fuels use, are dependent upon several factors. The major variables include the vehicles' annual miles driven, fuel economy (for gasoline or diesel, and for the alternative fuel of interest); fuel price differential; incremental vehicle procurement or conversion costs; state and federal government highway fuel use taxing polices; and the cost of a refueling station.

School districts frequently use a simple payback criteria to compare investment opportunities. The simple payback is simply the time required, in years, for the annual benefits or savings associated with a project to offset its initial costs. The simple payback may be expressed mathematically as:

$$Payback, years = \frac{Initial\ Costs}{Annual\ Benefits}$$

For an alternative fuels project, the initial costs include the refueling station equipment plus installation charges, which is a function of throughput (capacity) and type of equipment selected plus the incremental purchase price or vehicle conversion cost. The initial purchase price is dependent upon the conventional and the alternative fueled engines under consideration, while conversion costs are related to the carburetion/ignition system selected (mechanical versus electronic) and the vehicle range desired (i.e. numbei of natural gas storage cylinders required.)

The annual fuel savings benefits due to purchasing or converting to dedicated alternative fueled vehicles can be determined with the following equation:

$$Savings = Gal \cdot (P_{LF} - P_{AF} \cdot FE) - LF$$

Where

Savings =	Annual alternative fuel savings, dollars
Gal =	Gallons of diesel or gasoline fuel displaced
P_{LF} =	Gasoline or diesel fuel price, \$/gal
P_{AF} =	Alternative fuel price, \$/therm or \$/gal (including compressor O & M costs for CNG of 6.8 to 9.8¢ per therm)
FE =	Fuel economy correction factor, therms/equivalent gallon or gallons propane/equivalent gallon of gasoline or diesel fuel)
LF =	Annual state alternative fuels license fee for the number and GVW of vehicles under consideration.

The number of possible vehicle, usage, engine fuel economy, and fuel price combinations makes it difficult if not impossible to construct general alternative fuels investment "rules of thumb." Previous Washington State Energy Office experience with gasoline-powered vehi le conversions, however, indicates that vehicles using more than 1000 gallons of fuel annually are candidates for al rnative fuels conversion or procurement, and that under heavy vehicle usage conditions, simple paybacks on invcstment of 4 years or less are attainable. Faster paybacks may be secured given the availability of federal or state grants or low-interest loan funds. School districts should also check with their local gas utility to determine if refueling station or vehicle conversion incentive programs are in place.

SPI School Bus Replacement Funding Policies

SPI currently distributes state funding for school bus replacement. These funds are required to be placed into a separate fund dedicated to the purchase of school buses.

The amount of state funds paid each year to replace a school bus varies depending on replacement cost and anticipated useful lifetime. Anticipated useful lifetimes have historically included references to gasoline- and diesel-fueled engines. Diesel-powered buses have been assigned longer anticipated lifetimes due to longer expected service compared to gasoline powered buses. In the past, gasoline engines have been converted to alternative fuels and assigned expected lifetimes consistent with gasoline fueled buses. This has been done to meet the goal of having the funding match the anticipated useful lifetime of the school bus, regardless of fuel type used.

SPI is proposing to make major modifications to policies for school bus replacement. The proposed policies are directed at the removal of aging and obsolete buses from the state-wide school bus fleet. SPI is convinced that existing scheduled lifetimes of school buses are too long. The proposal reduces scheduled lifetimes of school buses to increase the emphasis on school bus safety standards. This is necessary to ensure that school buses are retired from service within reasonable time following ongoing changes to school bus safety standards.

As currently proposed, the school bus replacement funding system would discontinue reference to fuel type as a criterion for useful bus life. This means in the future, if the current proposal is enacted, the amount of state funds for school bus replacement would not be affected by the type of fuel. Each school district would have discretion to choose engine, fuel type, and other specifications desired by the school district.

Chapter 8
Institutional Issues Affecting Alternative Fuels Use

This chapter discusses safety issues, codes and regulations, and related issues.

Safety Issues

Safety is the primary concern of both parents and school administrators when it comes to student transportation. As a result, school buses are one of the safest forms of motor vehicle transportation. Bus safety improvements are continually under development.

School Bus Standards

While individual states and/or school districts are responsible for developing their own school bus specifications, the National Highway Traffic Safety Administration (NHTSA) has the authority to issue Federal Motor Vehicle Safety Standards (FMVSS) that must be met by bus manufacturers. Between 1967 and 1973, 19 bus safety standards were issued by the agency covering such items as braking systems and materials flammability. In 1974, an across-the-board review and upgrade of bus safety standards was mandated by Congress. As a result, three new bus safety standards were passed (FMVSS No. 220, 221, and 222) covering crash-worthiness issues. In addition, four standards (FMVSS No. 105, 111, 217, and 301) were amended dealing with emergency exits, brake systems, and fuel system integrity requirements. Manufacturers were required to meet these new or revised requirements on or after April 1, 1977. Consequently, retiring all school buses manufactured prior to 1977 is in the interest of school bus fleet administrators.

The 1974 Amendments mark a watershed for bus safety standards. A study completed in 1987 by the National Transportation Safety Board (NTSB) indicated that the NHSTA's school bus standards "significantly" improved the safety of buses manufactured after April 1, 1977. Concern over the safety of pre-1977 gasoline-powered school buses intensified after the disastrous May 1988 Carrollton, Kentucky accident. A retired school bus (a church activity bus) was involved in a head-on collision at highway speeds with the intoxicated driver of a pickup truck. The crash and subsequent fire fatally injured the bus driver and 26 passengers. Contributing to the severity of the accident was the puncture of the bus fuel tank, partial blockage of the rear emergency door by the bench seats, and flammability of the materials in the bus seat cushions.[41]

According to a 1990 survey of state school bus administrators, only 12 percent of the nation's in-service school bus fleet of 372,133 buses were manufactured prior to 1977.[5] Washington State exceeds the national average, with 30 percent of the state's bus fleet consisting of buses built prior to 1977. Only two other states have a greater proportion of pre-1977 buses in operation, California with 39 percent pre-1977 buses, and Oregon, with 32 percent.[5]

Safety Issues for Gaseous Fuels

In April 1990, the US EPA completed a report evaluating the safety and environmental effects of natural gas use as a vehicle fuel.[33] A similar EPA report evaluating the use of propane as a motor fuel is underway.

CNG

Because of the lack of sufficient in-use data for heavy-duty CNG vehicles, the EPA was unable to directly compare the safety of CNG vehicles with conventionally fuelled vehicles. The EPA did acknowledge a survey conducted by the AGA in 1987 that indicates that the injury rate for CNG vehicles is significantly less than for all U.S. vehicles. The EPA also notes that light-duty natural gas vehicles have seen significant use in the U.S. and abroad and appear to have a good safety record.

In the absence of heavy-duty CNG vehicle data, the EPA relied on "expert projections" to assess the safety of CNG as a heavy-duty vehicle fuel. This analysis considers the physical properties of CNG as compared to gasoline and diesel fuels. Some of the conclusions are as follows:[33]

- Toxicity: Natural gas is non-toxic; however, it is an asphyxiant so adequate ventilation is required. On the other hand, gasoline and diesel fuels are toxic if ingested or inhaled with possible effects due to acute exposure including nausea, liver, kidney, and central nervous system damage. In addition, both diesel and gasoline are suspected carcinogens.

- Flammability: Ignition of fuels is dependent on the properties of the fuel and the conditions in which the fuel leak or spill occurs. Under conditions of good ventilation, the EPA rated diesel as the safest fuel, with gasoline the most dangerous, and natural gas somewhere in-between. A study conducted by Los Alamos National Laboratory similarly concludes that CNG fuel is safer than gasoline due to its higher rate of dispersion and its higher gas-to-oxygen ignition ratio. Diesel fuel, however, is identified as the safest material due to its relatively high flash point of 125 degrees F.

  Diesel is also considered the safest fuel under conditions of poor ventilation due to it low volatility. The EPA notes that both gasoline and CNG pose a serious risk of flammability and explosion in situations of inadequate ventilation; however, no conclusion was made with respect to the comparative safety of gasoline versus CNG under these conditions. Because CNG is lighter than air, natural gas would reach explosive concentrations near the ceiling, whereas the risk of a gasoline fire or explosion is near the ground. This difference suggests that ignition sources near the ceiling should be eliminated and proper ceiling ventilation be provided at facilities where indoor work on CNG-powered vehicles is performed. A further discussion of facility design issues is presented in the section dealing with codes and standards.

- Fire Hazards: The greatest difference between liquid fuel fires and natural gas fires is the amount of smoke produced and the rate of combustion. Both diesel and gasoline produce large amounts of smoke during combustion, which poses a serious health risk and could inhibit fire fighting activities. By comparison, natural gas produces a relatively small amount of smoke and toxic materials during combustion.

  Combustion rates also differ between the fuels. Diesel fires start slowly but become violent, while gasoline immediately erupts into a fully developed fire. Unlike liquid fuels that pool, pressurized natural gas tends to burn like a torch at the site of the leak. This has the advantage of confining the burn to a smaller area than a liquid fuel fire. Furthermore, because a natural gas fire is confined to the leak site, the flame can be controlled by the rate of fuel release. In other words, the fire could be extinguished by shutting off the fuel at the tank either manually, through fuel release regulators, or through solenoid valves.

- Special Issues: The central concerns over CNG involve potential pressurized gas handling and storage problems. While the handling of a pressurized gas can involve such hazards as injury from a flailing hose or the possibility of frostbite, these risks can be minimized by proper equipment design and handling techniques. Similarly, the hazard of an explosion resulting from a fuel leak in a shop or garage can be eliminated by installing adequate ventilation and by removing equipment that could serve as an ignition source.

  Of greater concern is the integrity of the fuel storage cylinder. CNG cylinders have successfully passed numerous abuse tests, including impact and explosion tests, as well as rupture tests resulting from small caliber gunfire. Further, the cylinders have an enviable safety record in operations throughout the world.

  This safety record is not unblemished, however, as a catastrophic failure of a CNG cylinder occurred in New Zealand in 1989. The failure was traced to a small manufacturing defect that apparently could have been avoided. While an isolated incident, this event points out a major concern of the natural gas vehicle industry—the need for more effective CNG cylinder certification and recertification procedures.

Currently, most CNG cylinders are D.O.T. certified. The shortfall with this process is that the D.O.T. certifies cylinders used to transport hazardous materials such as fuels, and has no authority over cylinders that are used for on-board storage of a motor fuel. Both the regulators and the natural gas industry are working towards rectifying this problem and are developing specific certification and inspection standards for CNG cylinders.

The EPA concluded its safety analysis of CNG as a heavy-duty vehicle fuel by stating that "...there are no safety issues which cannot be dealt with which would preclude the development of CNG as an alternative fuel." EPA further states that CNG is "...certainly no more dangerous than gasoline as a vehicle fuel," and that CNG "...has some properties which are superior (from a safety viewpoint) to those of conventional fuels."

Propane

The National Fire Protection Association states that "...The potential fire hazard of LP-Gas is comparable to that of natural or manufactured gas, except that LP-Gas vapors are heavier than air."[42] The NFPA further states that "...The ranges of flammability are considerably narrower and lower than those of natural gas." A similar conclusion was reached by both the Canadian Ministry of Energy, Mines and Resources, and the U.S. D.O.T. Both conclude that propane is as safe or safer than gasoline.

While various authorities agree on the relative safety of propane as a motor fuel, there are major differences between propane and natural gas. The primary difference between the two fuels is that propane is a liquefied gas while CNG is a compressed gas. As a result, propane is stored at a working pressure in the range of 150 lbs. per sq. in. (psi), versus the much higher pressures of 2400 to 3600 psi for CNG. This lower storage pressure minimizes some of the potential hazards associated with high pressure such as flailing hoses and frostbite. However, because of its density, propane will pool as a result of a fuel leak and is less likely to dissipate in an unconfined space.

Like CNG, propane cylinders are designed to withstand pressures far greater than their actual working pressure. A typical propane fuel tank is constructed of high tensile strength material capable of withstanding internal pressures of 1000 psi without bursting. In the event of a collision this translates into a resistance of failure more than 20 times that of a gasoline or diesel tank. Crash-testing of LPG vehicles conducted in the Netherlands during the late seventies substantiate the robust nature of the LPG tank. When subjected to various tests the LPG tank performed well and came through without serious mishap. LPG tanks fitted with pressure relief valves were directly exposed to extreme heat and pressures during the tests and were found to be explosion resistant. Additional testing by the South San Francisco Police Department has documented the rupture resistance of LPG tanks when subjected to various firearm projectiles.

Codes and Regulations

EPA's finding that there are no technological or safety aspects that would preclude the use of CNG as a motor fuel could also apply to LPG. The critical item is not so much whether gaseous fuels are dangerous, but rather, how specific safety issues are dealt with by equipment manufacturers, installers, regulators, and consumers.

It is generally accepted that high-quality equipment and proper installation are the keys to a safe and successful alternative fuel program. This position is supported by the Government of Netherlands, which concluded that LPG-related accidents in the Netherlands were primarily due to improper installation. The use of appropriate codes and standards help guarantee installation and equipment integrity and should be applied as a matter of course. The application of appropriate codes and standards is of particular importance in the conversion market, where attention to safety is largely the responsibility of the consumer.

After-Market Conversions

To ensure the integrity of an after-market conversion, performance and safety requirements must be established. Currently, there are no federal regulations specific to after-market conversions although there are a number of industry sponsored standards. This may soon change as the National Highway Traffic Safety Administration (NHTSA) is currently reviewing the need for establishing motor vehicle standards for CNG and propane. A Notice of Proposed Rule Making covering fuel system integrity standards for gaseous fuels is to be released in late 1991 or early 1992.

Although there is no single, federal standard at this time, a number of voluntary requirements can be referred to and used for specification purposes. The four major standards governing the use of gaseous fuels are:

- The National Fire Protection Association (NFPA) 52 Standard for Compressed Natural Gas (CNG) Vehicular Fuel Systems, 1988 edition[45]

- The National Fire Protection Association (NFPA) 58 Standard for The Storage and Handling of Liquefied Petroleum Gases, 1989 edition[42]

- The American Gas Association (AGA) Requirements for Natural Gas Vehicle (CNG) Conversion Kits, No. 1-85, 1985 edition[44]

- The U.S. Department of Transportation (US DOT) CFR Title 49, Subparagraph 173.34 "Qualification, Maintenance, and Use of Cylinders" and subparagraph 173.302 "Charging of Cylinders with Non-Liquefied Compressed Gases"[45]

Both NFPA 52 and 58 establish the engine fuel system, storage, and dispensing requirements for compressed natural gas and propane fuels, respectively and have been adapted by most state fire marshalls. The standards are voluntary industry guidelines and establish design criteria for cylinder location, venting, support systems, and refueling activities. The AGA requirements Nos.1-85 specifically address CNG conversion kit performance and design, including the on-vehicle fuel storage system and associated piping and hardware. The AGA also certifies kits to AGA standards.

The U.S. DOT standards establish both maximum operating and burst pressure for natural gas and LPG cylinders, the type of testing required before use, and a periodic cylinder inspection and recertification test. Unfortunately, these standards were developed for cylinders used to transport hazardous materials and not for on-board storage of motor fuels. Additionally, the standards are enforced under authority of the Hazardous Materials Transportation Act, which does not currently apply when cylinders are used for on-board storage of a motor fuel. This lack of a federal cylinder integrity standard for motor fuel use is of concern to both the natural gas industry and federal regulators. The standard is currently under review by the NHTSA.

Many public and private entities have adopted one or more of the above standards as a requirement for conversions. For example, both the State of Pennsylvania and the Pacific Gas and Electric Company of California require AGA certification for all conversion kits installed within their jurisdiction. Other states, including New York, Texas, and Colorado, have adopted portions of the NFPA 52 standards as a basis for addressing CNG fuel system and refilling station safety issues, while NFPA 58 is reported to have been adopted all or in part by more than 40 states. It should be noted that all of these standards are being considered for adoption by the NHTSA committee investigating gaseous fuel vehicle standards and could form the basis for a single federal standard.

Original Equipment Manufacturer (OEM) Buses

Currently, there is no Federal Motor Vehicle Safety Standard (FMVSS) for gaseous fuel vehicles equivalent to liquid fuel Standard 301, Fuel System Integrity. The NHTSA investigation of gaseous fuel system integrity is addressing such issues as crash-worthiness testing, the integrity of the overall fuel system, the integrity of the fuel storage cylinder, and pressure relief systems.

While the current lack of a federal safety standard for OEM vehicles is significant, it is of less concern than the lack of a federal standard for retrofits. The reason for this is that the OEM vehicle is designed, built, and optimized by the manufacturer for gaseous fuel operations. This ensures a level of detail and quality control that may be absent in after-market conversions. In addition, the manufacturer can be expected to incorporate state-of-the-art safety improvements if for no other reason than to avoid future liability claims.

If a purchaser is unwilling to assume that OEM vehicles will be built to the appropriate safety standards, safety specifications can be addressed in the bid document. An example of this approach is the State of California school bus specifications AB-35 Phase II.[46] These specifications were developed by California as part of its school bus alternative fuel demonstration program.

In this document, the State of California referenced a number of codes and regulations including FMVSS 301.27, applicable D.O.T cylinder specifications, and NFPA 52, Chapters 1, 2, and 3. Beyond this, California requires two self-contained combustible gas monitors—one inside the coach, the other under the bus floor—and an optional automatic fuel tank shut-off valve, actuated by a differential pressure sensor. Other requirements refer to accessibility of parts for inspection, dust and collision covers for the CNG equipment, a manually operated and quick-closing valve located between the engine and the fuel tanks, and an engine compartment fire-suppression system. The latter condition is required for all buses regardless of fuel type.

Additional Code-Related Issues

In response to questions from the NHSTA committee investigating gaseous fuels, an AGA representative stated that "...you can have the best piece of equipment, you can have the best components in the conversion kit, but if the equipment is improperly installed by an installer who does not know what he is doing, it's not going to mean a thing if that kit is certified."

The AGA statement summarizes the importance of training in ensuring the performance of the equipment as well as its safe operation. A number of fleet operators and/or sponsors of conversion programs recognize the need for training and include it as an integral part of their operations. The Clean Air Washington Act identifies the need for training and requires a mechanic and operator training and certification program to be offered at selected community colleges in Washington State. The major conversion equipment manufacturers also offer mechanic training courses that are available to the public.

Beyond the need for skilled technicians, differences in CNG refueling nozzles and receptacles, and station refill pressures are additional issues that need to be addressed. Currently, there is no standard nozzle type or station pressure used by the natural gas industry. Consequently, compatibility problems can occur between stations. This problem, while not an issue for a stand-alone facility, needs to be worked through if stations are to be successfully networked.

Chapter 9
Alternative Fuel Initiatives In Other States

In Washington State, the Superintendent of Public Instruction database identifies 24 districts operating one or more propane buses, and three districts operating CNG-powered buses. Most of these alternative fuels programs were started in the early eighties with the intent of reducing fleet operating costs. In general, fleet operators have expressed satisfaction with their programs and believe that they are viable alternatives to gasoline and/or diesel operations.

A number of other school districts in the U.S. operate either CNG or propane school bus fleets. Like the Washington fleets, the majority of these programs were initiated by the individual school districts as a cost savings measure and received little federal or state government support. This situation is changing, however, as a number of states are considering or have instituted state-wide alternative fuel bus programs. These programs are largely a response to air quality issues.

The two programs that currently stand out are operated by the states of California and Texas. The California program is of particular interest as it is actively forcing the commercialization of alternative fuel technologies. The Texas program is also interesting in that it has created a market for alternative fuel buses by mandating alternative fuel use by school districts.

Texas

In August 1989, the Texas legislature passed Senate Bill 740—Alternative Fuels Program. The bill established a broad market incentive for increased use of natural gas and other alternative fuels in the Texas transportation sector. School districts were identified as a primary target for alternative fuel use.

As enacted, school districts with more than 50 buses are required to begin converting their fleets to CNG or other clean-burning alternative fuels. The bill also stipulates that after September 1, 1991, districts are no longer able to purchase or lease vehicles that are not capable of using CNG or other alternative fuels. This deadline is followed by a phase-in period that requires that 30 percent of a school district's fleet must be operated on CNG or other alternative fuels by September 1, 1994, increasing to 90 percent by September 1, 1998. Because of the ambitious nature of the Bill relative to the emerging alternative fuels market, school districts may be exempted from the requirements if refueling stations cannot be provided, or if districts are unable to obtain equipment or facilities at a competitive life cycle cost. This waiver is included since the Act relies on market forces and does little in the way of providing financial assistance to districts.

State alternative fuel managers indicate that most of the school districts in Texas are attempting to comply with the SB 740 requirements, although they are uncertain whether target dates will be met. Program managers also cite the lack of financial assistance, inconsistent conversion quality, and the limited availability of OEM buses as stumbling blocks to the program. To date, compliance has resulted almost exclusively from after-market conversions to CNG and propane.

The Garland School District is often cited as an example of how Texas school districts can meet the Act requirements by using their own resources. The District began converting portions of its bus fleet to CNG in 1983. As of 1991, the District has 81 units operating on natural gas, representing 45 percent of its total fleet. The District financed the conversions and refueling stations on its own. The initial Phase 1 program cost $241,000 in 1983. Program costs included 2 compressors, 58 slow-fill locations, 2 quick-fill dispensers, and 65 bus conversions. In 1986, the District expanded the program to include 20 additional slow-fill slots, 1 additional compressor, and 16 bus conversions. The cost of the expansion was $106,273.

The District is recovering program costs through operational savings and has estimated a 3- to 5-year payback on its investments. In 1985, the District saved $57,614 in fuel costs, plus an additional $8,000 in estimated vehicle maintenance and refilling costs. Operating savings are projected at $145,587 for the 1990-91 school year.

California

Assembly Bill 35 was passed into law in 1988. Titled the Safe School Bus Clean Fuel Efficiency Demonstration Program, it requires the California Energy Commission to conduct a demonstration of new, energy-efficient school buses that meet current safety standards. To fund this effort, $60 million was appropriated from the Petroleum Violation Escrow Account.

Unlike the Texas program, the California Bus Program was set up to demonstrate and in some cases, force the development of alternative fueled buses by original equipment manufacturers. AB 35 also serves the dual purpose of improving the safety of California's school bus fleet by requiring that demonstration buses replace Type D buses manufactured prior to April 1, 1977. This ensures that school buses purchased through the program are manufactured to higher safety standards than those buses being replaced.

Started in 1989, Phase 1 of the program placed 103 advanced diesel, 50 methanol, and 10 CNG buses in 14 California school districts. The 10 CNG buses were purchased from the Blue Bird Body Company. The 66-passenger buses are powered by the Tecodrive 7000 series engine manufactured by Tecogen Inc. The Tecodrive 7000 uses a GM V-8 427 gasoline engine block redesigned for dedicated CNG operations. Emissions testing and performance evaluation of the Phase 1 buses is ongoing.

Phase 2 of the program will place an additional 400 buses in service, of which 200 are advanced diesel, 100 methanol, and 100 dedicated CNG. Originally, Phase 2 was to include propane-powered buses. The CEC removed these buses from the demonstration because of the absence of OEM involvement.

Overall, Phase 2 bus specifications are fuel blind. Outside of a reduced range allowance of 300 versus 500 miles, the CNG buses must meet safety and performance specifications similar to the other buses. Phase 2 bus specifications include a seating capacity of 72 to 84 passengers and a rear or mid-mount engine configuration. The engine specification is largely a response to a California law requiring drivers to escort students across the street. The forward control option lessens driver egress. Bus specifications also require an integral design and will not allow clip-on bodies.

The 100 Phase 2 CNG buses will be placed in 12 school districts located throughout California. Sponsoring gas utilities will provide the refueling stations as long as the districts allow public sector access. As with the Phase 1 buses, performance and emission testing will be on-going. The Phase 2 bids were to be awarded in late fall of 1991.

Other States

A number of other states, including Oklahoma, Virginia, New York, Colorado, Arizona, Louisiana, Minnesota, and Pennsylvania have recently passed legislation encouraging or mandating the use of alternative fuels in public and/or private sector fleets. Most of this legislation specifically identifies school bus fleets as potential candidates for alternative fuel use.

Chapter 10
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