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SCHOOL BUS PROGRAM: TRANSITION TO ALTERNATIVE FUELS

Chris Colucci, National Rewnewable Energy Laboratory
Atlas Hill, California Energy Commission

ABSTRACT

The California School Bus Program is the largest alternative fuel bus program in the nation. It has been in existence for over five years and has gathered data on alternative fuel bus operations, maintenance, emissions, engine performance and cost. To date, there have been approximately 787 advanced technology and alternatively-fueled buses purchased through this program.

The program has been developed in three five-year phases allowing manufacturers to further develop commercially-available alternative fuel technologies between phases. Methanol, compressed natural gas (CNG) and advanced diesel technology have been used to power buses in the first two phases.

This paper compares alternative fuel types in a real world environment. The development of methanol and CNG fueling station infrastructure and fuel cost comparisons are discussed. During the development of alternative fuel school buses, safety technology is discussed. Emissions testing has been required for engine manufacturers to meet California Air Resources Board (CARB) emissions standards for each phase of the program. Phase three will add electric buses to the program and this paper discusses the development of electric bus technology. Distance, performance, cost, battery technology and electric school bus design specifications are discussed.

The intent of this paper is to provide fleet managers, and others, with information on the choices in using alternative fuel buses.

1. INTRODUCTION

The Safe School Bus Clean Fuel Efficiency Demonstration Program (School Bus Program) was established in July 1989 by California Assembly Bill 35 (Chapter 1426, Statutes of 1988). The program was established to provide California public school districts with new energy-efficient school buses that meet current federal safety standards. It is the largest program of its kind in the United States to date in terms of the number of alternative fuel school buses in a single demonstration program.

California has over 12,000 publicly-owned school buses, more than half of which were manufactured before the federal government imposed minimum safety standards in April 1977. According to the California Department of Education, 56 percent of the fleet is between seven and 19 years old, and 15 percent of the fleet is more than 20 years old. Nearly one-third of all California school buses are older than the National Transportation Safety Board standards for acceptable service life. These buses produce excessive air pollution, have high repair costs, and fail to meet current safety standards.

A minimum of 35 percent of the buses purchased by the School Bus Program must be operated with a clean burning alternative to conventional petroleum fuel, such as methanol or compressed natural gas. The percentage of program buses replaced to date has been approximately 50 percent alternative fuels. The replacement buses used 100 percent methanol (M100), 15 percent gasoline and 85 percent methanol (M85), CNG, or low sulfur diesel.

The School Bus Program is being implemented in three phases. In Phase 1, 163 buses (103 advanced diesel, 50 methanol and 10 CNG) were placed in 14 school districts. In Phase 2, an additional 400 buses (200 advanced diesel, 100 methanol and 100 CNG) were delivered to 46 school districts. In 1996, Phase 3 will place 224 buses (107 advanced diesel, 107 CNG and 10 electric) in 48 school districts. Although not included in early phases of the program, electric buses have been included as another alternative to petroleum fuel for the final phase of the program.

The California Energy Commission (Commission), in cooperation with the Highway Patrol and Department of Education, established a selection process to determine which buses would be replaced. Program Opportunity Notices (PONs) were sent to each public school district in California, inviting their participation in the program. Interested school districts were asked to submit information on the age and mileage of each bus in their fleet,

maintenance practices, fueling facilities, and the air quality attainment status for their air districts. Based on the responses provided in the PON, school districts were selected through a competitive process and their qualifying pre-1977 school buses were chosen for replacement.

As a condition for qualification, if a school district accepts a School Bus Program bus, they can no longer purchase pre-1977 buses from other school districts. The school district must also agree to provide operating and maintenance information on program buses to the Commission for a five-year period.

As a part of the School Bus Program, the Commission held workshops with manufacturers to provide guidelines for alternatively fueled buses. Several months after the workshops, manufacturers were invited to bid on the construction of advanced technology buses for the School Bus Program.

The program will replace nearly 850 pre-1977 buses by the end of the program and a large number of them were manufactured in the 1950's. Specific pre-1977 buses not replaced were selected for use as control buses and information is being collected on all buses for comparison purposes.

2. DATA COLLECTION

Over a five-year period, for each of the three planned phases of the School Bus Program, bus data will be collected for operating and maintenance costs. School district staff then enters the data into their on-site computers using software specially designed for the School Bus Program. In addition to manually collected data, approximately 100 buses, including pre-1977 control buses have been equipped with on-board data loggers to provide engine specific performance data. This smaller population of buses is subjected to exhaust emission tests to identify emission levels produced by their respective fuels while the buses are in operation.

Maintenance data and costs are collected to make comparisons between alternatively fueled and conventionally fueled buses. Maintenance data indicate the type of repair occurrence; warranty item, scheduled, unscheduled or a road call. Warranty information is usually the most difficult data to collect. If the school district does not pay for the repair, because the bus is under warranty, the information is not normally recorded. Warranty repair records are kept by school transportation organizations that are authorized by the bus manufacturer to perform their own warranty work and are reimbursed by the manufacturer. The Commission has requested selected school districts receiving warranty information to provide it along with other maintenance data. The school districts were provided with maintenance log sheets to record parts, labor and costs for all work performed. Retrieved maintenance data are coded based on a national parts coding system. The coding system was developed by the American Trucking Association and is consistent with the system used by the National Renewable Energy Laboratory (NREL) in their Alternative Fuel Data Center.

Operational data include daily miles traveled and refueling data, which are recorded by the driver and/or fuel attendant. Daily log sheets contain: odometer readings, refueling quantities, the addition of oil, number of stops made for the day, cost of fuel and oil, number of routes traveled for the day, number of field trips taken for the day and whether or not the bus was out of service. Data are recorded at each school district using a custom computer software called the Remote Site Input Module (RSIM). Validation checks are built into the RSIM to enhance data accuracy.

At regular intervals (currently every two weeks), the bus data from each school district are downloaded via a modem into another custom computer software program called the School Bus Information System (SBIS). The SBIS can generate reports for data review, analysis and graphing.

3. ENGINE TECHNOLOGIES

PHASE 1 - 103 advanced diesel and 50 methanol buses were manufactured by Crown Coach Inc. Both bus types were 78-passenger, rear engine transit style buses. The engines for both the advanced diesel and methanol were 6V92, manufactured by Detroit Diesel Corporation (DDC) (two-stroke engines which utilize the Detroit Diesel Electronic Control system.) The two engines are similar in design, but the methanol application incorporates several unique features. Some of these are a consequence of the higher auto-ignition temperature of methanol as compared to diesel fuel. For example, methanol engines incorporate a glow plug system to heat the cylinders for cold start and to assist in partial-load operation. The compression ratio of the engine has been increased from 17:1 to 23:1 in order to increase the heat of compression and improve ignition characteristics. Finally, a bypass blower system regulates the supercharger input and determines the amount of scavenged air supplied to the cylinders over the engine operating range. This allows some of the exhaust gases to be retained in the cylinders to provide additional heat and improve ignition under partial load conditions.

DDC recommended the use of a proprietary fuel additive, Lubrizol, manufactured by Lubrizol Corporation for use with methanol fuel. Lubrizol acts as a lubricant and has the added benefit of increasing fuel injector life. This additive is mixed by the school districts at a rate of .06% by volume.

To allow for equivalent driving range with the lower energy content of methanol fuel, the methanol buses are equipped with a 757 liter (200-gallon) fuel tank, as compared to the 378 liter (100-gallon) fuel tank on the diesel buses. This increases the Gross Vehicle Weight Rating (GVWR) by about 544 kg (1200 pounds) (the total GVWR is 16,420 kg (36,200 pounds) for the diesel and 16,964 kg (37,400 pounds) for the methanol). Other changes made for the methanol buses are the addition of a methanol compatible remote fuel pump and a return

fuel cooler to reduce the risk of vapor lock in the fuel system.

The ten Phase 1 CNG school buses were built by Blue Bird Body Company and are 66-passenger conventional type with the engine in the front of the bus. The fuel storage system is composed of six fiberglass-reinforced steel cylinders which hold a combined total of 35.7 cubic meters (1,260 cubic feet) of CNG at 20.3 MPa (3,000 psi). These cylinders provide enough fuel for an approximate 480 km (300 mile) operating range. There are several safety features which ensure protection of the fuel lines, valves, and vent the passengers compartment from any escaped gas.

Tecogen, a division of Thermo Power Corporation, purchased the rights from General Motors to develop and market the CNG version of their seven liter spark ignited engine, the Tecogen 7000L. This engine is dedicated to operate only on CNG and develops 194 Bhp at 4,000 rpm. The compression ratio has been increased from the standard 8:1 to 10.5:1 to accommodate the anti-knock properties of the CNG. The standard exhaust gas recirculation system has been removed and emissions standards are met by using a 3-way catalyst. The fuel metering system is a positive flow progressive throttle body.

PHASE 2 - Thomas Built Buses, Inc., supplied 200 advanced diesel 78-passenger, rear engine transit style Westcoaster buses with the Caterpillar 3116TA engine developing 249 Bhp. The mechanically controlled engine has a catalytic converter to satisfy the 1994 CARB emission standards.

The 100 Phase 2 methanol powered buses built by Carpenter Manufacturing, Inc., were originally a spin-off design of the Phase 1 Crown Coach 78 passenger buses. After many modifications, the bus became a new product line for Carpenter using the DDC 6V92 TAC. Improvements were made to the air-fuel mixture and the fuel injectors. The Carpenter bus used two 378 liter (100-gallon) tanks for the fuel supply in place of one large tank, as in Phase 1.

For Phase 2, Blue Bird supplied 100 CNG transit style, rear engine, 78-passenger All American buses, using a turbocharged Tecodrive 7000T CNG engine developing 222 Bhp at 3,600 rpm. As in Phase 1, the six CNG fuel tanks are located under the chassis outside the frame rails. However, the rear-mounted engine required additional cooling for heat dissipation.

PHASE 3 - Blue Bird will supply 214 transit style, rear engine, 78-passenger All American buses for Phase 3. 107 advanced diesel and 107 CNG buses will be distributed to 48 school districts. Blue Bird advanced diesel buses will be powered by a Caterpillar 3126 and the CNG buses by a John Deere 6081HFN.

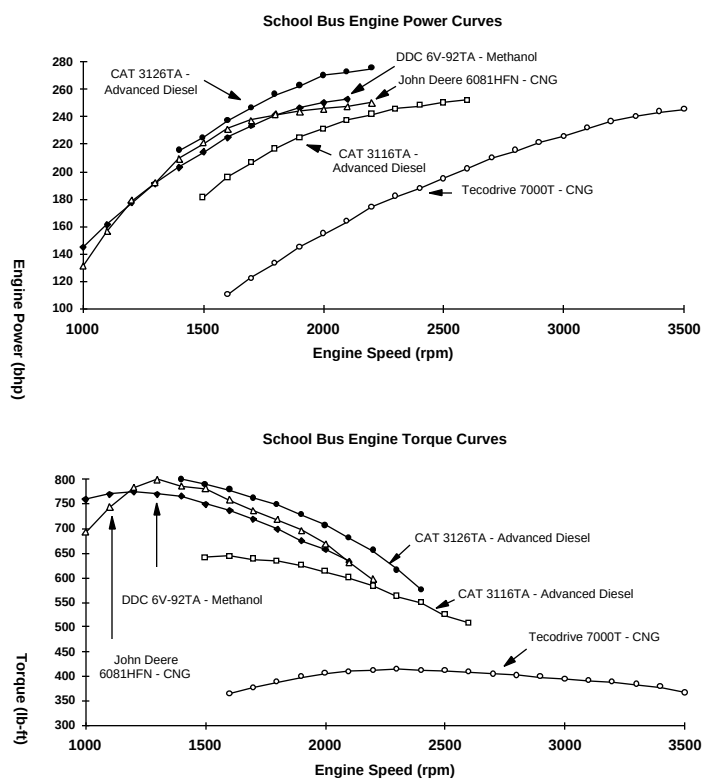
The Caterpillar 3126 engine is an improved version with a displacement of 7.2 liters (440 cubic inches) and 250 Bhp @ 2,200 rpm. The computerized electronic control module on the 3126 offers better fuel economy and emission control than its predecessor in Phase 2. Much of the improved efficiency for the engine comes from the hydraulic electronic unit injection fuel system, which has a 9 percent fuel economy increase over the mechanical system on the Phase 2 Caterpillar 3116.

The John Deere 6081HFN natural gas engine has been undergoing in-service testing in California school districts since February of 1995. John Deere has developed this natural gas derived engine to operate on CNG and installed an advanced electronic control system. This bus has four CNG cylinders located between the frame rails for added safety. This 8.1 liter (494 cubic inches), 250 Bhp engine has double the driving range (approximately 965.4 km (600 miles)) of the Phase 2 CNG bus.

Table 3-1 on page four provides a detailed description of the engine technologies for all three phases.

ENGINE POWER and TORQUE - Engine power and torque for school bus applications has typically been kept low, more in the range of medium-duty applications than heavy-duty. Bus drivers have requested engines with higher power for emergency acceleration situations, such as, rapidly moving into and out of busy intersections and climbing steep hills from a dead stop. **Figure 3-1** shows a comparison of engine power and torque curves. The DDC 6V-92TA has power and torque curves that are similar for both advanced diesel and methanol, only the methanol has been shown. This engine application has been popular in transit applications and is very popular with school bus drivers because of its available power. Performance of the CAT- 3116TA engine in hilly regions of the state has prompted some bus drivers to request more power. The Tecodrive 7000T, operating on CNG, has also prompted drivers to request more power. In contrast, preliminary drivability data on the John Deere 6081HFN, operating on CNG, has appeared to have left

Figure 3-1 Engine Power and Torque Curves



most drivers content with its available power. Currently, there are no operating CAT 3126TA engines in the School Bus Program.

4. VEHICLE PERFORMANCE

Preliminary evaluation of fuel economy and operating expenses has been made using data from the SBIS for 1994. The goal of the preliminary evaluation was to calculate fuel economy and cost per mile for all fuel types.

FUEL ECONOMY - The fuel economy calculation for the liquid fuels (M100, M85, advanced diesel, and control diesel) were straightforward:

$$\frac{\text{Distance Traveled (Miles)}}{\text{Fuel Consumed (gallons)}} = \text{Fuel Economy (MPG)}$$

where:

Distance Traveled (miles) = Current - Previous Odometer
Fuel Consumed (gallons) = Quantity Refueled

For CNG buses there are three methods of obtaining the amount of fuel consumed. For school districts that meter fuel flow at the pump in therms, no additional calculations are necessary. Other districts receive their CNG from public stations that meter fuel flow in pounds. For those districts, the RSIM converts pounds into therms using the following equation:

Fuel Consumed (Therms) = Quantity Refueled = Fuel Consumed (Pounds) x K_1

where:

K_1 = 4.33(Therms/Pound)

When fuel flow is not metered by the fueling station, it is calculated using a variation of the ideal gas law:

$$\text{Fuel Consumed (Therms)} = \frac{P_2}{T_2 x Z_2} - \frac{P_1}{T_1 x Z_1} \text{ x } K_2$$

T_1 = Tank temperature before refueling (°R)
= BeforeTemperature (° F) + 460 ° F
P_1 = Tank pressure before refueling (psia)
= Before Pressure + 14.7 psig
Z_1 = Compressibility of natural gas @ T1 & P1 (Assumed = 1)
T_2 = Tank temperature after refueling (° R)
= After Temperature (° F) + 460 ° F
P_2 = Tank pressure after refueling (psia)
= After Pressure + 14.7 psig
Z_2 = Compressibility of natural gas @ T_2 & P_2 (Assumed = 1)
K_2 = 8.164 (Therms)

Temperatures and pressures are measured for the calculation above. The compressibility factor (Z) has been assumed to be one to approximate therm usage early in the program. A more accurate calculation of Z is being programmed into the SBIS using the measured temperatures and pressures. The use of the ideal gas law calculation is limited to buses connected to slow-fill stations and has been checked using gas utility billings.

When the fuel consumed is obtained for CNG buses from one of the above methods, it is then used to calculate fuel economy in miles per therm (MPT) with the following equation:

$$\frac{\text{Distance Traveled (Miles)}}{\text{Fuel Consumed (Therms)}} = \text{Fuel Economy (MPT)}$$

CNG is converted from MPT to a diesel equivalent of miles per gallon (MPG) using a low heat conversion factor of 1.25 therms per diesel gallon.

MPT x 1.25 therms/diesel gallon = MPG

Table 4-1 shows three organizations that have independently developed preliminary fuel economy calculations from a sampling of buses in the School Bus Program. The first organization was the University of California at Riverside, College of Engineering, Center for Environmental Research and Technology (CE-CERT) which provided preliminary calculations with data taken from the SBIS. The second is the California Association of School Transportation Officials (CASTO), which represents most school district transportation organizations in California. In 1994, CASTO surveyed all of its members participating in the School Bus Program and asked them to provide fuel economy information. The Commission also performed a preliminary evaluation of fuel economy data during the same time period as the CASTO survey. Data was taken from the SBIS using a different data set than CE-CERT.

Table 4-1 Average Fuel Economy

CE-CERT (Phases 1& 2)

	CNG	Control	Diesel	M85	M100
Average MPG	3.8	6.9	5.8	2.3	1.9
Sample Size	80	12	248	91	18

CASTO (Phases 1& 2)

	CNG	Control	Diesel	M85 *	M100
Average MPG	3.7	5.7	6.6	2.2	2.1
Sample Size	41	5	70	55	18

Commission (Phase 2)

	CNG	Control	Diesel	M85 & M100
Average MPG	3.0	6.5	6.3	2.2
Sample Size	23	8	14	36

Note: This is preliminary data and is not intended to represent final results. Bus fuel types for Phases 1 and 2 were compiled together for CE-CERT and CASTO, with one exception: the (*)CASTO survey information was only compiled for Phase 2 school districts operating buses using M85. Only Phase 2 buses were compiled for the Commission and M85 and M100 fuel ecomony averages were compiled together.

As observed, CNG values are very close for CE-CERT and CASTO (3.8 and 3.7 MPG, respectively) and the MPG for the Commission (3.0 MPG) is approximately 20 percent lower. A partial explanation for the difference is all of the Commission data was taken from school districts operating Phase 2 CNG buses. CE-CERT and CASTO combined CNG MPG from both Phases 1 and 2. The CNG buses in Phase 1 were smaller, lighter, 66 passenger buses without turbochargers and were achieving approximately 5.0 to 5.6 MPG early in the program. The Phase 2 CNG were 78 passenger, rear engine, transit style buses and the engines were turbocharged. Averaging the Phase 1 and 2 CNG MPG values would show a fuel economy increase over Phase 1.

Diesel MPG for control and advanced diesel buses are in a comparable range. Typically, control bus fuel economy has been slightly higher than advanced diesel. It was generally accepted advanced diesel engine emission requirements would result in slightly lower fuel economy. This early conclusion is not necessarily proven by the data presented. It was assumed each phase of the program would bring an increase in advanced diesel fuel economy, but additional analysis is needed to support this assumption.

Methanol MPG is relatively close for both M85 and M100 fuels for all three organizations. Since M100 has a slightly lower energy content, M85 MPG values are expected to be slightly higher. Further analysis is needed to better understand the fuel economy differences between M85 and M100.

COST PER MILE - Maintenance data from the SBIS was used to provide a preliminary evaluation of operating cost. To obtain a cost per mile calculation, data was separated by fuel types. The fuel cost was calculated by using the following equation on the operational data:

$$\text{Fuel Cost per Mile} = \frac{\text{Fuel Consumed (unit)} \times \text{Fuel Cost (\$/unit)}}{\text{Distance Traveled (mile)}}$$

Parts and labor cost per mile were calculated using the following equation on the maintenance data for the different fuel types:

$$\text{Part Cost per Mile} = \frac{\text{Total Parts Cost (\$)}}{\text{Total Distance Traveled (mile)}} \text{ and}$$

$$\text{Labor Cost per Mile} = \frac{\text{Total Labor Cost (\$)}}{\text{Total Distance Traveled (mile)}}$$

Results shown in **Table 4-2** for CE-CERT, CASTO and the Commission are for comparison purposes only. All information presented is preliminary and is not intended to represent final results.

Table 4-2 Average Cost per Mile

CE-CERT (Phases 1 & 2)

	CNG	Control	Diesel	M85	M100
Fuel	0.26		0.15	0.39	0.30
Parts	0.15		0.13	0.39	0.08
Labor	0.30		0.05	0.07	0.04

CASTO (Phases 1 & 2)

	CNG	Control	Diesel	M85 *	M100
Fuel	0.25	0.15	0.11	0.38	0.25
Parts					
Labor	0.18	0.37	0.08	0.06	

Commission (Phases 1 & 2)

	CNG	Control	Diesel	M85 & M100
Fuel	0.35	0.11	0.14	0.31
Parts	0.03	0.21	0.07	0.12
Labor	0.09	0.15	0.13	0.16

Note: This is preliminary data and is not intended to represent final results. CE-CERT compiled bus cost for all fuel types in both Phase 1 and 2, but not for control buses. The CASTO survey did not request information on parts and only fuel costs were available for M100buses. (*)CASTO survey information was compiled only for Phases 2 school districts operating buses using M85. The Commission compiled bus costs for all fuel types in both Phases 1 and 2, however, M85 and M100 buses were combined.

It is very difficult to draw specific conclusions from preliminary data due to the large number of variables involved. Driving habits, terrain, route length and stops can greatly affect fuel economy; school districts often change route lengths and number of stops for buses during the year. Variations in maintenance from one school district to the next can also cause significant changes in miles per gallon (MPG) and cost per mile (CPM) for buses. Buses operating on M100 had previously been operating on M85 and little data was available for M100 buses during this preliminary evaluation. Information provided in the CASTO survey and available data in SBIS, shows fuel cost and labor rates vary greatly throughout the State.

SINGLE SITE EVALUATION - In Phase 2, Antelope Valley Schools Transportation Agency (AVSTA), is the only school transportation organization to operate all the fuel types and provide a degree of consistency to the data collection effort. **Table 4-3** provides preliminary data from AVSTA as a single source comparison.

Table 4-3 Average MPG & CPM for AVSTA

	CNG	Diesel	M85
MPG	2.80	6.69	2.25
Fuel Cost per Mile	0.29	0.10	0.34
Sample Size	16	8	16

Note: No control buses were compiled for an average and M100 fuel was not used at this school district when the data was collected. CNG fuel cost per mile was calculated by using a three month average of utility bills.

Contractors with alternative fuel experience will analyze SBIS data in greater detail and work with school districts to provide a control set of data for analysis. This will produce a clear picture showing the development of alternative fuel within the School Bus Program.

5. ELECTRIC BUS

The Commission is planning to operate two groups of electric buses in Phase 3. Five buses will operate on lead acid and five on nickel cadmium batteries. An electric bus typical of what may be purchased under the program is a 72-passenger Blue Bird with a power plant developed by Westinghouse Automotive Systems Division. AVSTA is currently operating this bus on a daily basis. The performance of this bus is being monitored very closely by the Commission.

The bus operated by AVSTA uses a total of 112 batteries. The batteries are stored in four battery boxes (28 batteries each) located beneath the bus and outside the frame rails. The lead acid gel batteries, made by GNB Battery, along with an oil cooled electric motor, produce a total of 336 volts and 400 amperes of current and provides 170 kw (230 horsepower) at nearly 12,000 rpm. When the batteries are fully charged, the bus has a driving range of 130 km (80 miles) at a constant speed of 65 km/h (40 miles per hour). To assist in obtaining optimum mileage, the bus uses a regenerative braking system, Michelin 11R22.5LRGXT1 ultra-low rolling resistance radial tires and, where possible, light weight composite materials.

A motor controller is used to convert electrical energy at the wheel and is transmitted to a speed reducer which turns the differential on the rear axle. The motor controller, located outside the frame rail behind the right rear axle, can generate up to 640 amperes of AC line current which will produce 338.9 N·m (250 ft-lbs) of torque at the motor shaft. The speed reducer uses a steel link chain drive and is manufactured by Emerson Power Transmission.

When the bus is traveling forward at 88.5 km/h (55 miles per hour), the motor turns at 12,500 rpm. In reverse, the motor turns at 4,500 rpm, limiting the speed to 24 km/h (15 miles per hour). Exxon 2389 turbine oil is used to cool the motor, motor controller, and drive train components. The drive train cooling system consist of fans, radiators, a battery, pump, motor and is located outside the frame rails, behind the left rear axle. **Table 5-1** provides a summary of electric bus specifications for the Antelope Valley prototype.

Very little operational data is available on this prototype electric bus, but estimated operating cost per mile for recharging is between 8 and 9 cents. This cost is lower than diesel fuel operating cost per mile. The general maintenance on electric buses is reduced significantly, compared to conventionally powered buses. However, the major cost for electric buses after the initial installa-

tion of a charging system is the replacement of batteries. Battery cost can vary greatly depending on the type of batteries purchased. The life of the batteries also depends on the type of batteries purchased and how often the batteries are recharged. A school district could be replacing a set of $15,000 lead acid batteries within a couple of years or a set of $60,000 nickel cadmium batteries within four or five years. The bottom line for electric buses and all other electric vehicles is the need to improve battery technology to increase power, prolong life and reduce cost.

The School Bus Program has attempted to develop alternative fuel technology from one phase to the next and electric buses are meeting program objectives. With Phase 3 being the final phase, the development of electric bus technology will take place in the two groups of electric buses as described previously. The Commission will solicit contract assistance from technical contractors with alternative fuel experience to perform a detailed analysis of electric bus performance, the results of which will be published at the end of the program.

6. FUELING INFRASTRUCTURE

The School Bus Program has greatly influenced the installation of CNG and methanol stations throughout the State. Many of these stations are publicly accessible and have CNG, methanol and conventional fuels available for customers. **Figure 6-1** on page nine shows stations that have been constructed as a result of the School Bus Program and are accessible by buses. The natural gas distribution service area for the State's three largest gas utilities is also shown. The figure shows CNG is available in all of the populated areas of the State.

CNG - Several factors are involved in placing CNG buses at specific school districts. Two major deciding factors are the availability of CNG within a reasonable distance of the participating school district and the willingness of local utilities to construct new fueling stations on or near school district property. The Commission, in conjunction with the California Natural Gas Vehicle Coalition (CNGVC), identified locations for CNG refueling stations to ensure adequate availability of CNG to support the School Bus Program. School districts were responsible for station contruction with the assistance of utilities. School districts also made their own arrangements for funding, often with utility support.

In Phase 1, CNG buses were limited to specific routes and assignments due to their limited 300 mile range and a limited number of CNG refueling stations. Today, school districts operating CNG buses are not limited in the use of their buses. They have begun assigning them to long-distance field trips, secure in the knowledge that one or more CNG refueling stations are well within the range of the buses. There are currently 16 CNG refueling stations throughout California with the primary purpose of refueling CNG-powered school buses. Ten of the 16 are located on school district property. Overall, there are over 120 CNG refueling stations in California and 78 of those are publicly accessible. Stations located on school district property are generally accessible to other school districts operating CNG buses on field trips.

CNG refueling stations vary in size, capacity, and capability. Stations located on school district property are generally "slow-fill" stations, consisting of individual fueling hoses for each bus coupled to dispensing equipment which allows an unattended trickle-type fill over several hours. Slow-fill fueling equipment can be purchased for considerably less than fast-fill equipment. Fast-fill fueling is similar to liquid fueling in that the dispenser accomplishes the fueling task in a matter of minutes instead of hours.

METHANOL - The methanol fueling infrastructure consists of 53 publicly accessible stations within the State and 17 school districts providing on-site fueling. It is common for school districts within the same geographical location to use fueling facilities at other school districts and share the cost of fuel.

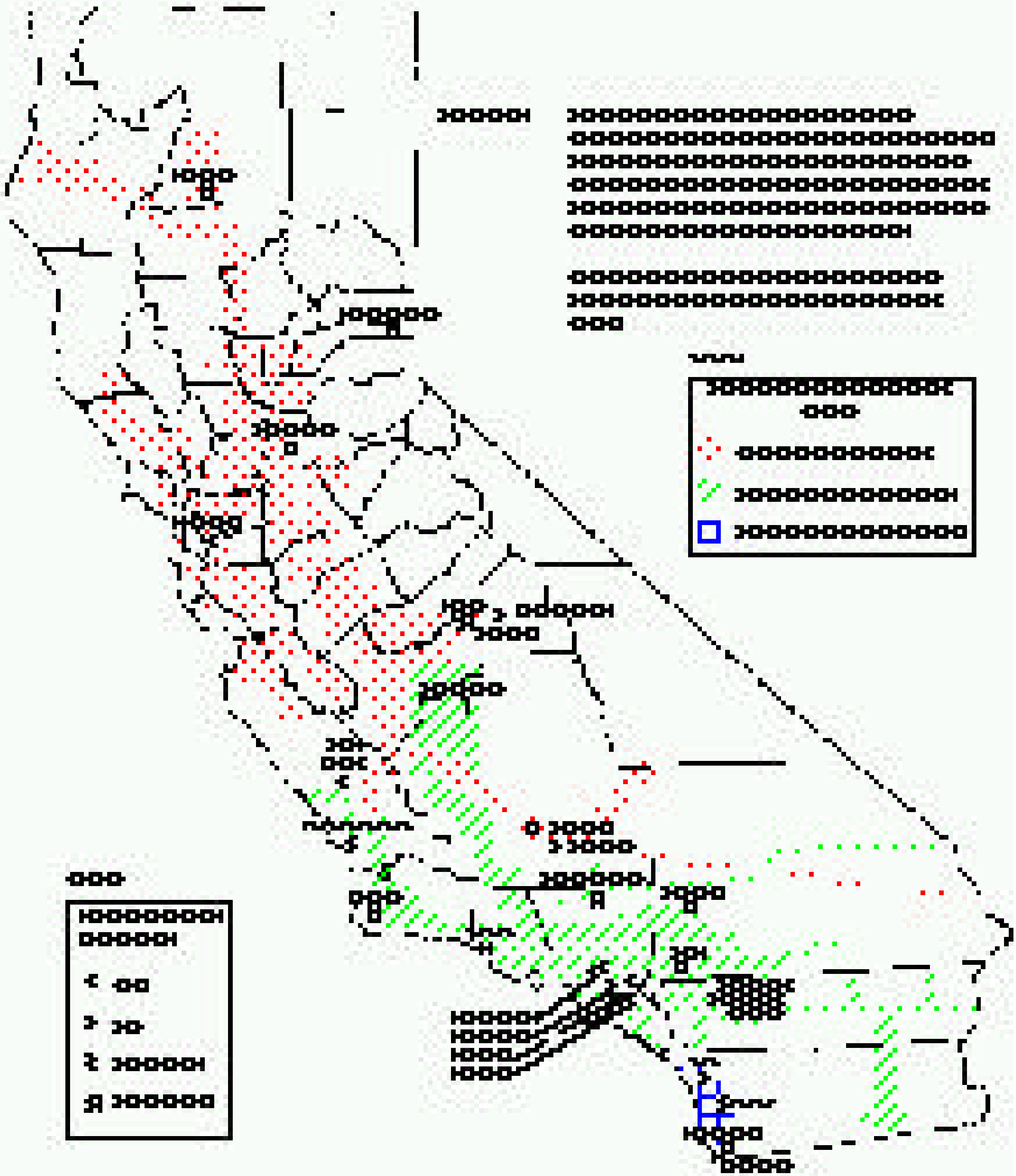
School districts with on-site fueling are responsible for the installation and maintenance of the fueling facilities as well as the cost of the fuel. Methanol is purchased through the California Fuel Methanol Reserve (CFMR). The CFMR provides a secure supply of methanol at a consistent price which is reviewed on a quarterly basis.

There are a total of 150 methanol buses operating in 30 school districts throughout California. Most of the school districts have been operating on M85, however, a few school districts were chosen to operate buses on M100.

The DDC 6V92 methanol engine, used in Phases 1 and 2, was originally designed to operate on M100 and was modified to operate on M85 with 15 percent gasoline for the School Bus Program. Safety was the main reason for this change in operating fuels. Initially the CARB supported the use of M85, because M100 lacked flame luminosity. Several air quality districts support M100 as a safe, less polluting fuel. In November 1993, two school districts were allowed to operate their fleets on M100 as an experiment. These school districts requested to use M100 for several reasons, not the least of which was a reduction in nitrogen oxides (NOx) emissions.

By switching to M100, a school district would experience a reduction in emissions, but suffer a fuel economy reduction. M85 is 1.819×10^7 Joule/liter (65,350 Btu/gal) and M100 is 1.573×10^7 Joule/liter (56,500 Btu/gal). The properties of M100 also make it difficult to ignite and burns with a lower heat flux than either gasoline or diesel fuel. M85 will ignite at a lower temperature and burns similarly to gasoline. Engines operating on M85 have more frequent fuel injector failures (occurring at approximately 19,300 km (12,000 miles)) than engines operating on M100. During the early years of the program the increasing prices of gasoline caused the price of M85 to also increase. School districts using M100 were expecting to save money by removing the gasoline component of the fuel, extending the life of injectors and hoping to get emission credits from the air quality districts to offset reductions in fuel economy.

To date, it is not clear that there is a financial savings



from operating on M100. However, it is generally accepted as a safe fuel and school districts are being allowed to switch to M100 upon request. In January 1994, there were 42 buses out of 150 operating on M100. By June 1996, that number is estimated to be over 100.

7. EMISSIONS

One of the major goals of the School Bus Program is to determine the degree of emissions benefits when operating on CNG or methanol as opposed to diesel. A sufficient population of buses (powered by different engine types) operating on each fuel type is tested to evaluate fuel effects on exhaust emissions. The same buses are retested to determine the effects of engine and emission control equipment degradation. Buses tested are removed from regular service and are tuned to meet manufacturer's specifications prior to testing. During emission testing, each fuel is analyzed to determine the additives and properties of the fuel.

Prior to bus purchase, each engine manufacturer is required to provide the CARB with a certifying document stating that their engine meets or exceeds current emission standards. For the buses purchased in both Phases 1 and 2, all emission certifications exceeded CARB standards. **Figure 7-1** shows the standards for 1991 (Phase 1), 1994 (Phase 2) and certified exhaust emission levels submitted by engine manufacturers for NOx and particulate matter (PM). From Phase 1 to Phase 2 the manufacturer's certified exhaust emission levels have typically shown a decrease in emissions for each fuel type. This decrease is typical for NOx engine emissions with one major exception, the Phase 2 Tecogen engine operating on CNG. The increase in NOx is probably due to higher head temperatures and pressures resulting from turbocharging the engine. Decreases in PM engine emissions are clearly shown for advanced diesel and M85. M100 and CNG PM emissions are significantly lower than the standards and will probably remain at that level for Phase 3.

Table 7-1 shows CARB bus engine emission standards used for the different phases of the program.

Table 7-1 CARB Bus Engine Emission Standards

Phase	Year of Standard	NOx (g/bhp-hr)	PM (g/bhp-hr)	CO (g/bhp-hr)	NMHC (g/bhp-hr)
1	1991	5.0	0.25	15.5	1.2
2	1994	5.0	0.10	15.5	1.2
3	1998	4.0	0.05	15.5	1.2

CARB certification for the Phase 3 Caterpillar 3126 engine is not available at this time. However, preliminary tests (shown in **Table 7-2**) on the Phase 3 John Deere 6081HFN engine show it to be well under 1998 CARB standards.

Figure 7-1 **EMISSIONS CERTIFICATION PHASES 1 & 2**

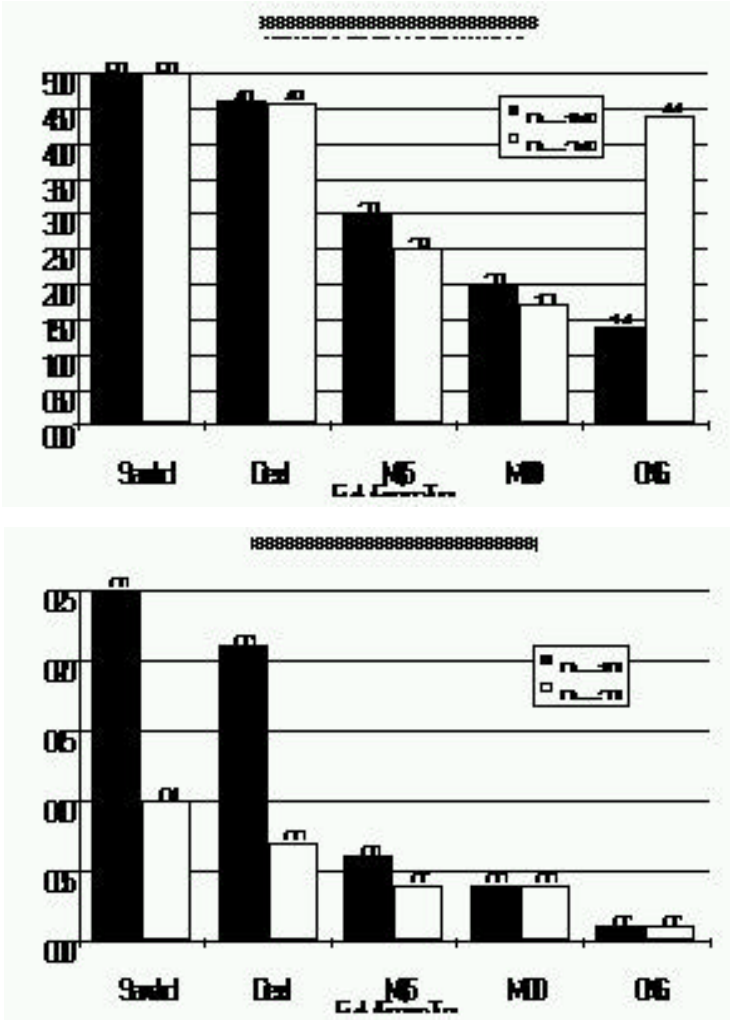


Table 7-2 John Deere 6081HFN Emissions

NOx (g/bhp-hr)	PM (g/bhp-hr)	CO (g/bhp-hr)	NMHC (g/bhp-hr)
1.77	0.015	1.66	0.24

Buses are tested over a predetermined duty cycle on a chassis dynamometer at the Los Angeles County Metropolitan Transportation Authority's (MTA) emissions testing facility. The MTA facility can test for the following emissions: carbon monoxide, total hydrocarbons, NOx, carbon dioxide, PM, and unburned alcohols and aldehydes.

There are three main duty cycles used during dynamometer testing: the Central Business District cycle (CBD), the EPA Urban Drive cycle, and arterial phases cycle. The CBD is most often used to duplicate the stop and go driving of a regional transit bus and is similar to the operation of a school bus. **Figure 7-2** shows CBD

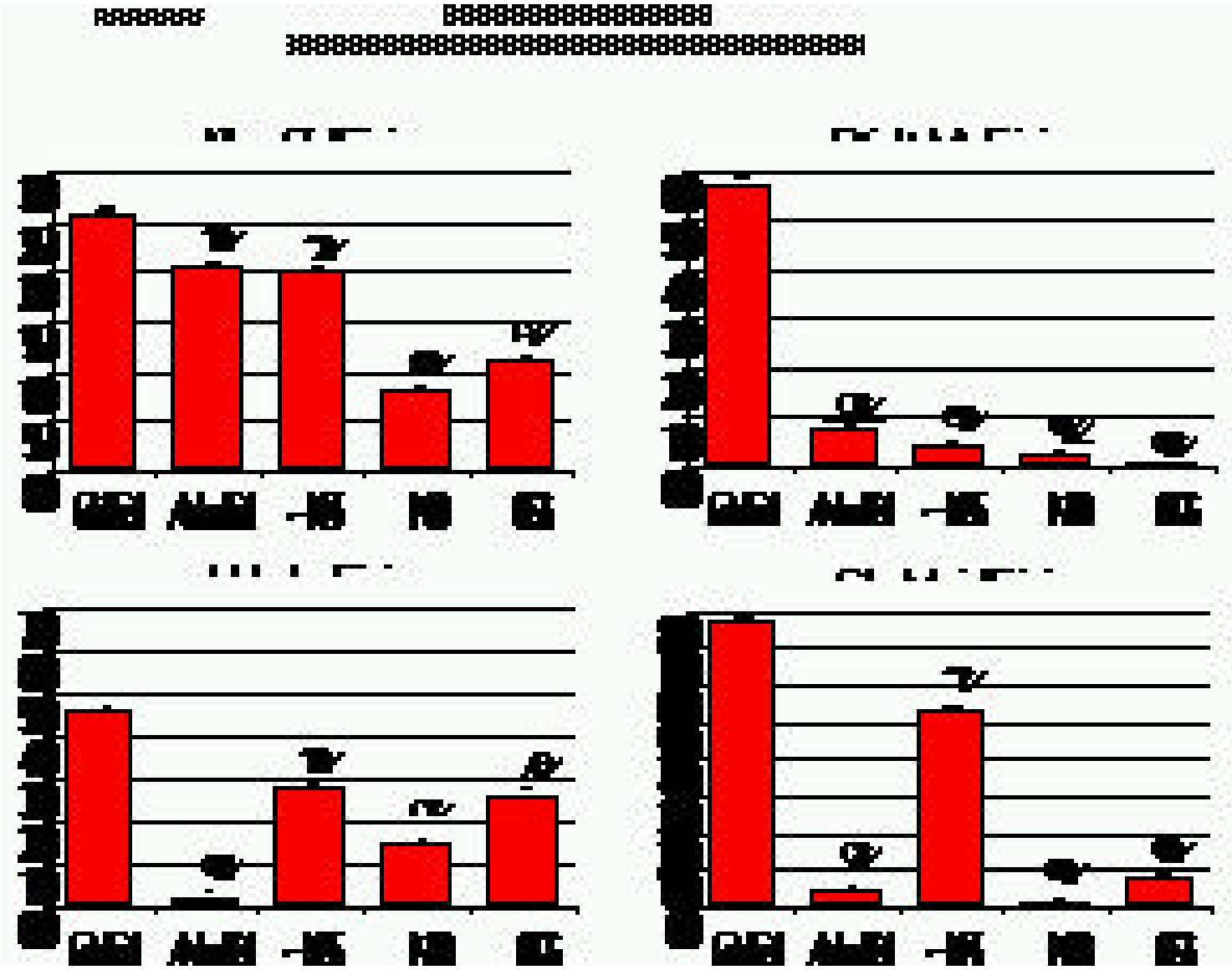
emission test results on each of the different fuel types represented in the program. In many cases all three cycles are run for buses being tested. Usually more than one test run is made for each cycle. The CBD has been the most consistently used cycle with more than one run for all the buses tested.

To date, one bus of each fuel type has been tested from Phases 1 and 2, with the exception of methanol. All methanol emission tests have been from Phase 1 buses. Additional tests are planned, so comparisons can be made with bus emissions from each phase. Tests show M100 emissions to be less than M85, mainly due to the gasoline component of the M85 fuel. All alternative fuels show a reduction over control diesel emissions. Advanced diesel shows major reductions in PM, CO and HC emissions over the control diesel. NOx emissions show a 20 percent reduction with both control and advanced diesel school buses operating on low sulfur diesel fuel.

8. SAFETY

The School Bus Program bus specifications contain a variety of improvements and safety features. Safety was the primary concern in development of the bus body and engine specifications. Safety considerations in the bus specifications exceed federal government requirements and conform to current state specifications. These specifications represent safe bus technology intended to serve as a new standard for future state school bus purchases. Major improvements to previous state school bus specifications include the items A through H as described in **Figure 8-1.** To ensure the safe operation of the buses, tests are conducted to determine their performance and durability.

Methanol and CNG buses were crash tested to address fuel tank safety concerns. **Figure 8-2** shows the placement of fuel tanks, or in the case of electric buses,



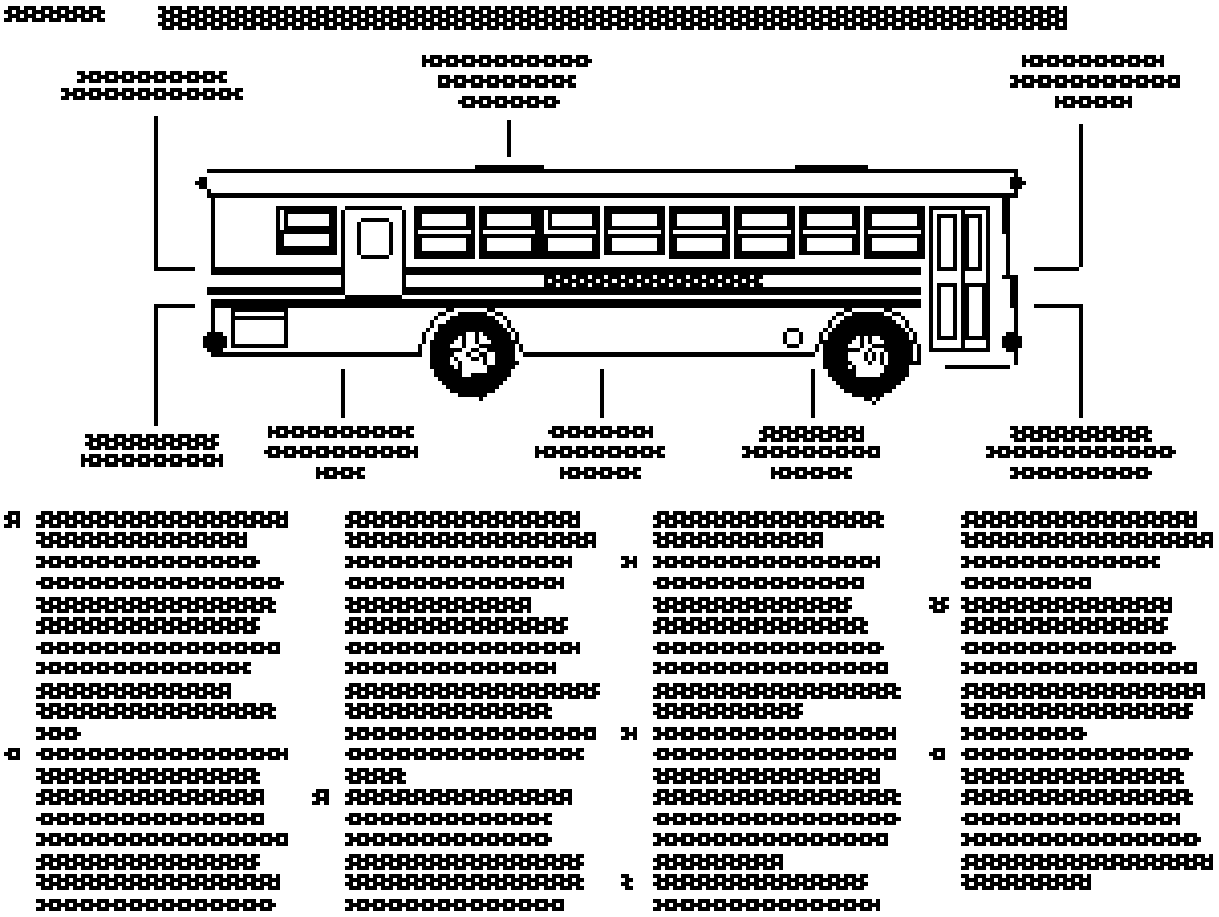
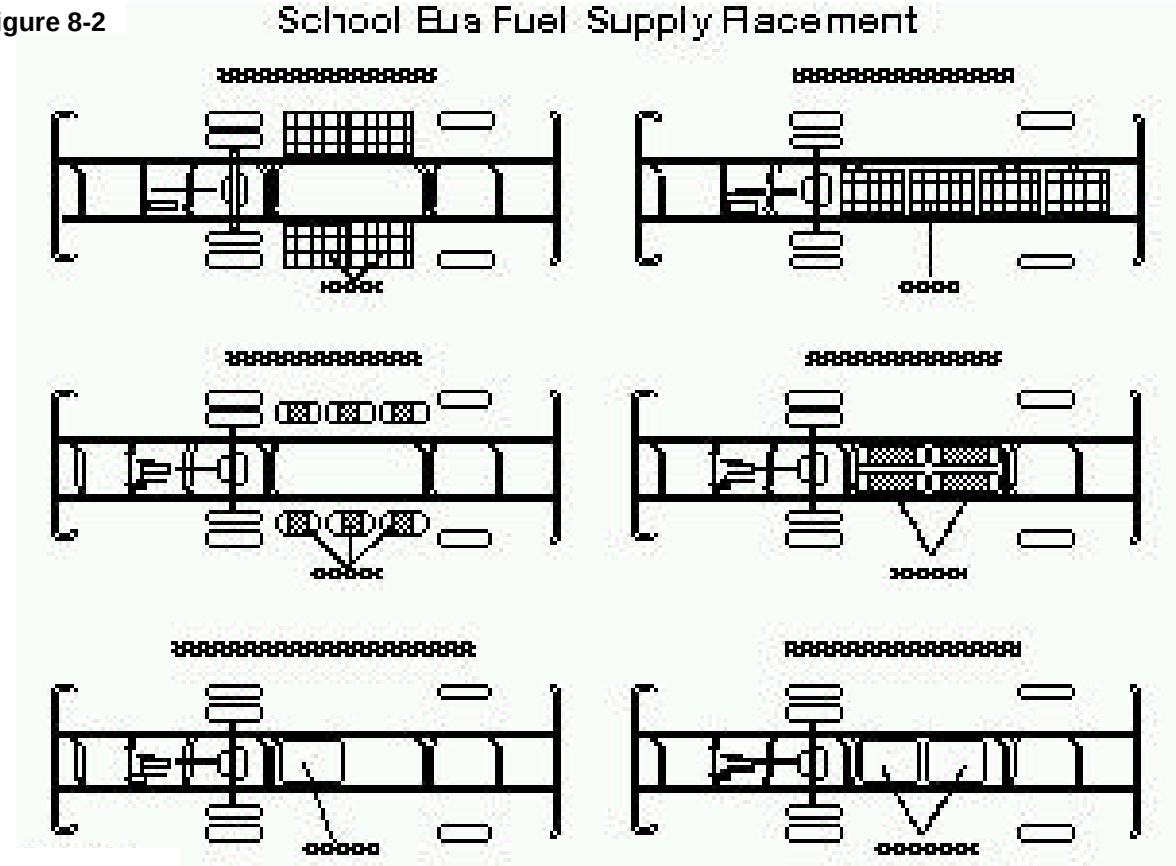


Figure 8-2



batteries. The safest placement of fuel has been between the frame rails. However, for many alternative fuel designs this requires a major re-design of an existing bus. The first placement of fuel for electric and CNG buses has been outside the frame rails. The electric bus being monitored at AVSTA has batteries placed in boxes on either side of the bus (Figure 8-2A) which offer low impact protection. These batteries are a gel-type to prevent the extensive release of harmful fluids. Figure 8-2B shows an alternate design with the batteries between the frame rails. This design is being used by a potential electric bus bidder to the School Bus Program. The CNG bus design (Figure 8-2C) for Phases 1 and 2 are retrofitted with crash cages on either side to protect the CNG tanks. For added safety, Phase 3 will have the CNG fuel cylinders located between the frame rails as shown in Figure 8-2D. Advanced diesel and methanol buses, Figures 8-2E and 8-2F respectively, have had the fuel tanks located between the frame rails since the beginning of the School Bus Program.

To date, the program's commitment to safety has paid off in the form of an enviable safety record for the alternatively fueled and advanced diesel school buses. In over 36.6 x 10^6 km (22.8 million miles) of operation by Phase 1 and 2 buses there have been no accidents or incidents attributed to the alternatively fueled or advanced diesel designs.

9. SUMMARY

The School Bus Program will successfully meet its objective by bringing over 780 safe, clean, alternatively fueled school buses to school districts throughout California. The School Bus Program has already placed over 560 alternatively fueled and advanced diesel school buses in service with 53 school districts and consortia, and anticipates placing another 224 buses with 48 school districts and consortia within the next year for Phase 3. For the first time, electric buses will be included among those being given to school districts.

The phased approach for the School Bus Program contributed to the development of the alternative fuel technologies. Once the technology was in use, the manufacturers would begin receiving bus information from school districts. Warranty information was initially provided and manufacturers analyzed warranty repairs to improve the technology and provide corrective action to prevent re-occurrence. Major advancement in the technology would come over time. The time between phases was an opportunity for the manufacturers to develop bus designs, solicit research funds and build alliances with other manufacturers having skills and abilities to develop advanced technologies. The financial incentive for the manufacturer is obvious, but it is the knowledge of future opportunities to develop improved technologies, organize resources and learn from mistakes that will bring the financial rewards.

The buses contain safety features that meet or exceed national safety standards placing them at the forefront of school bus safety. Emissions tests have shown that these advanced technology buses have significantly lower exhaust emissions than the buses they replace. In addition, the alternatively fueled buses have displaced significant quantities of petroleum fuel.

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