Direct Comparison of CNG, Methanol, and Gasoline Ford Tauruses in Fleet Operation in New York

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ABSTRACT

This alternative fuel vehicle (AFV) demonstration project is characterized by its unique approach of comparing CNG, methanol and gasoline fueled vehicles of the same model in operation in a single fleet in Monroe County, (Rochester) New York. Parameters compared include emissions, fuel economy, maintenance and vehicle driveability. The 13 fleet vehicles, including methanol (flexible fuel), CNG (bi-fuel) and gasoline control Ford Tauruses, met requisite safety standards and operated without any safety problems for the test period of three years, accumulating over 240,000 miles. During the data collection period, no fuel system safety problems occurred and no significant fuel system failures occurred. Laboratory testing using the City, Highway and NYCC driving cycles revealed that the flexible fuel vehicles (FFVs) using M85 had the highest energy economy, followed by the gasoline control vehicles and the bi-fuel vehicles using CNG. The bi-fuel vehicles operating on CNG averaged higher CO and NO_x emissions but lower NMHC emissions compared to the FFVs operating on M85 and the gasoline control vehicles. During performance testing the gasoline control vehicles accelerated faster than the FFVs which in turn were significantly faster than the CNG bi-fuel vehicles. The FFVs had fuel system related maintenance whereas the CNG bi-fuel and the gasoline control vehicles had none. Both M85 and CNG fuel vehicles experienced some cold starting problems.

PROJECT DESCRIPTION

The objective of this project was to evaluate methanol (M85)[1] and compressed natural gas (CNG)[2] as alternative vehicle fuels in the same model vehicle as part of the New York State Energy Research and Development Authority's (NYSERDA) Alternative Fuels for Vehicles Fleet Demonstration Program (AFV-FDP). The goals of the AFV-FDP are to develop timely data regarding AFV emissions, so the State can make informed decisions about strategies for meeting federally mandated air quality standards, and to develop an AFV knowledge base enabling fleet operators to act upon mandates requiring adoption of AFVs to improve air quality and reduce dependence on petroleum.

This fleet demonstration is characterized by its unique approach of comparing two alternative

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[1]M85 is a mix of 85 volume percent methanol and 15 volume percent gasoline.

[2]CNG is natural gas compressed to decrease its storage volume, allowing the fuel to be carried in compact form suitable for motor vehicles. Typical storage pressures are 2400 psi, 3000 psi, and 3600 psi.

fuels, M85 and CNG, by using them in the same fleet, in similar vehicles, supported by the same maintenance staff, and in the same climatic conditions. Monroe County (the city of Rochester is in Monroe County) co-funded the purchase and conversion of the alternative fuel vehicles with NYSERDA. Additional funding was also provided by the local utility company, Rochester Gas and Electric. The Monroe County test fleet obtained important operational and maintenance information from the M85 flexible fuel, CNG bi-fuel and gasoline control Ford Tauruses. The operation of the fleet began in September 1992 for the M85 vehicles and in May 1994 for the CNG vehicles. A total of 63 emission tests were performed using the City and Highway Cycles of the Federal Test Procedure, and the New York City Cycle. Over 170 vehicle-months of alternative fuel vehicle operating data were obtained.

VEHICLES

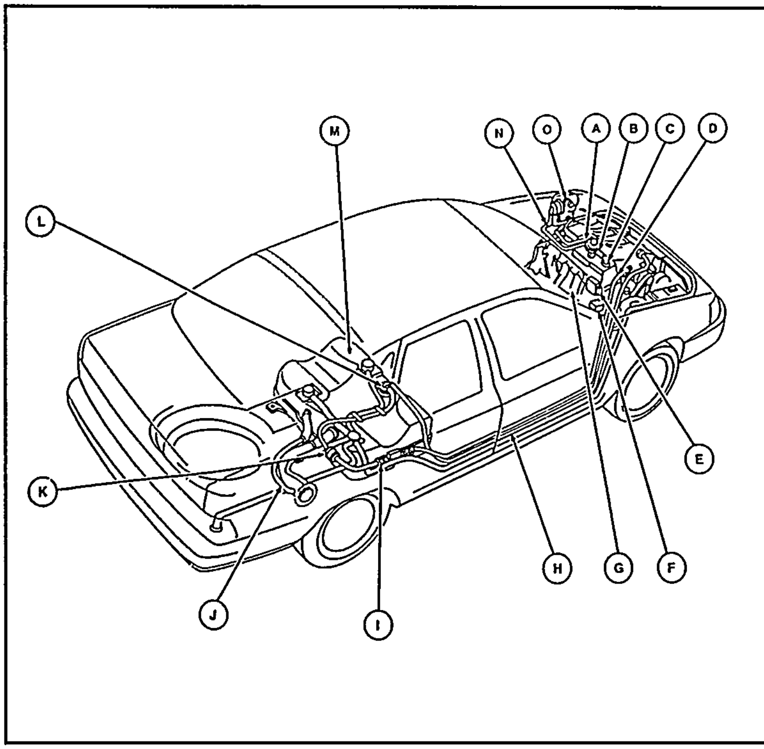
The Monroe County alternative fuel demonstration fleet consisted of both M85 and CNG fueled vehicles, listed in Table 1. In addition to these vehicles, this paper also includes the emissions and fuel economy of more recent technology FFVs for comparative purposes. The FFVs used port fuel injection systems with closed-loop control. The bi-fuel vehicles used a port fuel injection system for gasoline and an IMPCO mechanical fuel mixer (carburetor) with electronic feedback control fuel system for CNG. The vehicles operated in suburban/metropolitan traffic conditions. All fleet vehicles operated without any major problems in an extreme temperature environment spanning 115 degrees Fahrenheit.

Table 1. Project Vehicles

No. of Vehicles	Vehicle Type	Fuel System Configuration	Engine Configuration
5	1991 Ford Taurus	Flexible Fuel M85/gasoline (operates on M85 and gasoline)	3.0 liter V-6, 144 hp
3	1994 Ford Taurus	Bi-Fuel CNG/gasoline (manual fuel selection)	3.0 liter V-6, 140 hp
5	1992/94 Ford Taurus	Gasoline Only (Control Vehicles)	3.0 liter V-6, 135 hp (1992) 3.0 liter V-6, 140 hp (1994)

Methanol Flexible Fuel Vehicles

The M85 vehicles consisted of five FFVs capable of operation on both M85 and gasoline. The FFVs started operation in the fall of 1992 and continued through October 1994, when at Ford's request, the five FFVs were converted to dedicated gasoline operation because Ford was no longer going to support these vehicles with FFV replacement parts. Figure 1 shows a schematic detailing the fuel system related components of the FFV Taurus that are modified from those for gasoline only operation. Of these, the methanol fuel sensor and the cold-start injector mounted on the throttle body are the only added components.



COMPONENT SUMMARY	
A	Spark Plugs
B	Fuel Injectors
C	Fuel Rail
D	Fuel Pressure Regulator
E	EEC-IV Microprocessor
F	Wiring Harness
G	Engine Oil
H	Fuel Supply/return/vapor Lines
I	Fuel Sensor
J	Filler Pipe
K	Fuel Filter
L	Fuel Pump Assembly/ Fuel Sending Unit
M	Fuel Tank
N	Cold Start System
O	Evaporative Emissions System

Figure 1. M85 Flexible Fuel Taurus Schematic
Courtesy: Ford Motor Company

CNG Bi-fuel Vehicles

In the spring of 1994 CNG fuel systems were added to three new 1994 Ford Tauruses making them bi-fuel gasoline and natural gas vehicles. One Brunswick CNG tank per vehicle was used for fuel storage and was placed in the trunk compartment. The fuel tank is made from composite materials for weight savings and has a storage capacity equivalent to 9 gallons of gasoline. When operating on CNG alone, the vehicle should be able to go 200 miles plus an additional 350 miles on gasoline for a total of 550 miles.

The total conversion cost per vehicle was approximately $4,200. The CNG system uses the existing O_2 sensors to provide a signal to adjust the mixture strength of natural gas and air. The vehicles began operation in May 1994. Figure 2 illustrates one of the CNG bi-fuel vehicles.

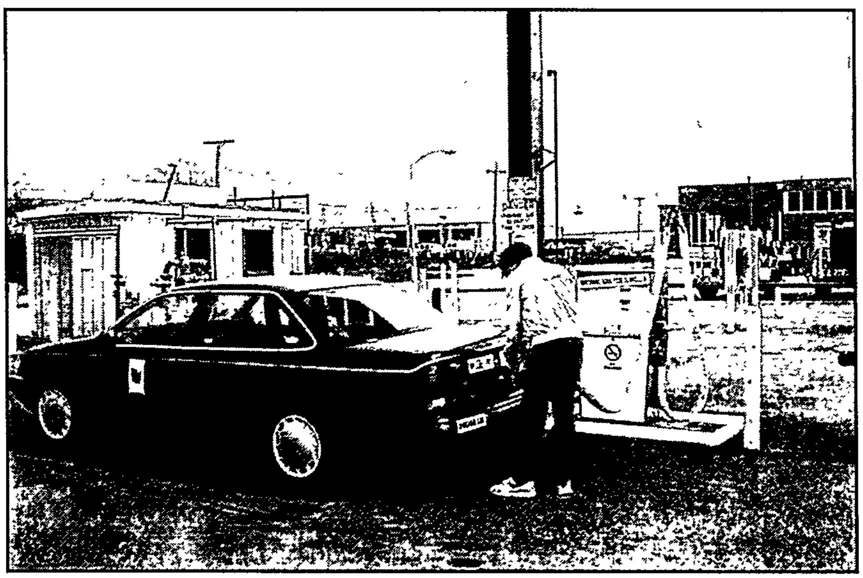


Figure 2. CNG Bi-fuel Vehicle Being Refueled

FACILITIES

Refueling Facilities

The M85 refueling facility, shown in Figure 3, consisted of a 1,000 gallon aboveground storage tank and dispenser. The storage tank, its accessories, and the dispenser were designed and specified for use with both neat methanol and its blends such as M85. Both the storage tank and the M85 dispenser were configured for Stage II vapor recovery. The system functioned in the same manner as a conventional gasoline dispensing system. The fire suppression system for the refueling facility provided both overhead and curb level fire protection.

Figure 3. M85 Refueling Facility

Figure 4 illustrates the CNG refueling facility that was installed by Rochester Gas and Electric (RG&E) and is located on their own property, approximately 2.5 miles from the Monroe County maintenance facility. While not open to the general public, the CNG station is available for fueling private vehicles by prior arrangement. Vehicles need a RG&E-issued refueling card in order to use the facility.

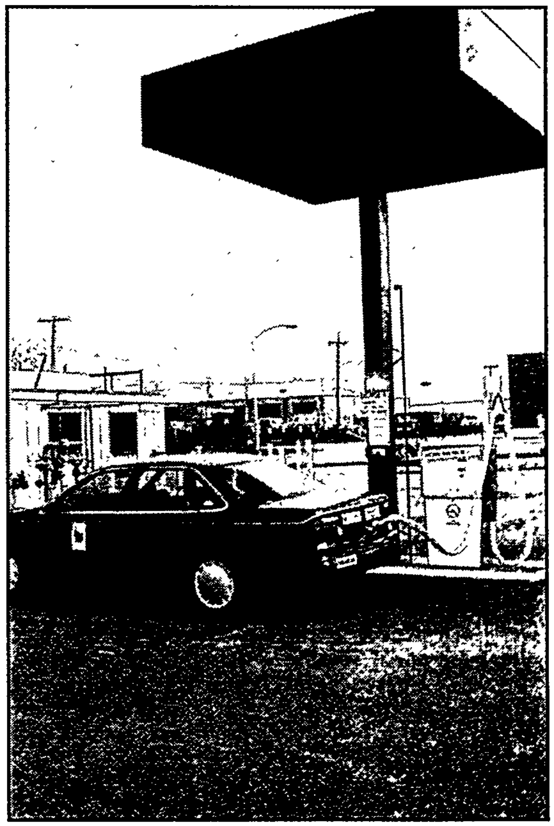


Figure 4. CNG Refueling Facility

Maintenance Facilities

Before the FFVs were implemented, Monroe County personnel were given safety training about handling methanol fuel. In that training personnel were taught how to properly store and dispose of waste M85 during vehicle maintenance activities. No modifications of the maintenance facility were deemed necessary at that time to accommodate the FFVs.

A site safety assessment of the vehicle storage and maintenance facilities was performed in April 1994 in anticipation of maintaining and storing the CNG bi-fuel vehicles. In compliance with the recommendations of this site assessment, Monroe County upgraded their hoist, lift, and garage door opener for the CNG bay. These upgrades were electrical modifications intended to minimize the risk of overhead ignition sources. New procedures for risk minimization were adopted, including keeping CNG vehicles outdoors overnight and servicing them when CNG tank pressure is low. Future upgrades, currently awaiting funding, include purchasing of a methane detection system, higher speed ventilation fan, and installation of a heating system that does not present ignition sources.

FUEL USAGE AND MILEAGE ACCUMULATION

Table 2 gives the details of fuel usage and mileage accumulation for all the demonstration vehicles. The FFVs accumulated over 120,000 miles over 26 months of operation and the CNG bi-fuel vehicles accumulated approximately 29,000 miles over 15 months of operation. M85 and CNG usage remained high throughout the duration of the project and M85 accounted for 66% of the total fuel consumption (volume based) for FFVs and CNG accounted for 78% of the total fuel consumption (energy based) for the CNG bi-fuel vehicles. Figure 5 illustrates the cumulative distance traveled and the fuel consumed by the M85 vehicles. Figure 6 illustrates the cumulative distance traveled and total fuel usage by CNG vehicles.

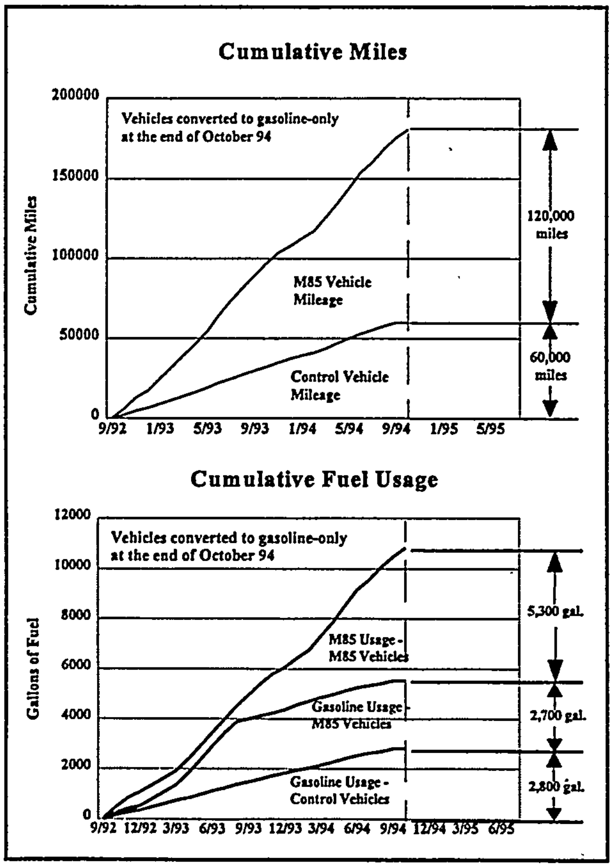


Figure 5. Cumulative Miles and Fuel Usage - M85 Vehicles

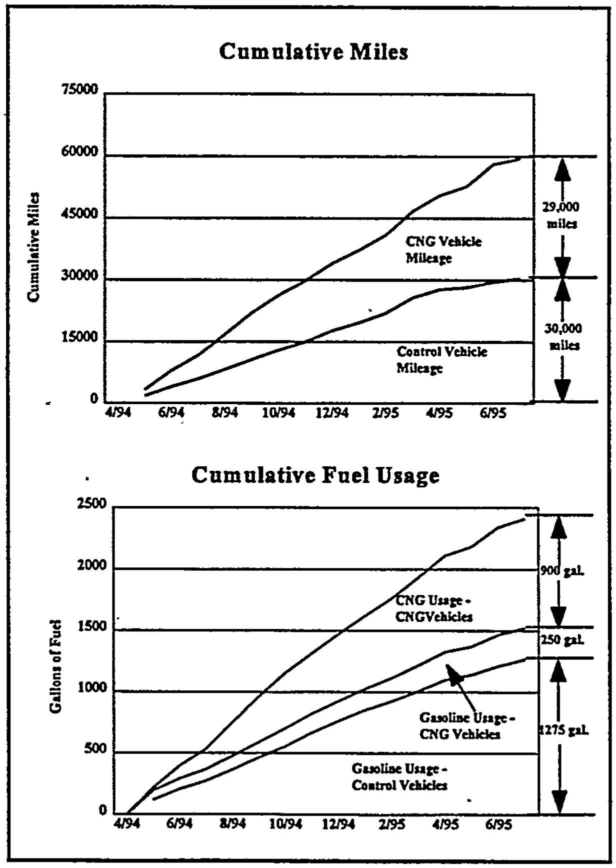


Figure 6. Cumulative Miles and Fuel Usage - CNG Vehicles

Table 2. Fleet Fuel Consumption and Mileage Accumulation

Vehicle Information		Miles/ Vehicle	Months of Service	Miles/ month/ vehicle	Alternative Fuel Usage (Gals.)	Gasoline Usage (Gals.)	Alternative Fuel Usage (% of total fuel used)
Type	#						
1991 M85 - FFVs	5	24,103	25	964	5,285	2,737	66%
1992 Gasoline Control	3	20,029	25	801	NA	2,423	NA
1994 CNG - Bi-fuel	3	9,662	16	604	886	256	78%
1994 Gasoline Control	2	15212	16	951	NA	1268	NA

The cost of fuel varied during the course of the project. Gasoline prices ranged from $0.50/gal in the beginning of the data collection period in 1993 to $0.70/gal after the summer of 1995. Similarly, CNG prices[3] varied from $0.50/gal in early 1994 to $0.67/gal in the summer of 1995. M85 prices were steady and averaged $1.32/gal. This is equivalent to $2.30 per gasoline equivalent gallon. (All reported prices do not include taxes.) Gasoline was typically 3-4 cents more expensive than CNG per equivalent gallon.

DRIVEABILITY

Starting problems during the cold winter months were initially present with the FFVs caused primarily by M85 with insufficient vapor pressure. (The M85 was splash-blended using summer grade gasoline.) This resulted in some of the drivers refueling their cars using gasoline instead of M85. A fresh batch of M85 using winter grade gasoline was procured and the starting problems were cured.

In the winter of 1994, cold weather also caused the CNG vehicles to have longer starting times. During acceptance testing after installation of the CNG fuel systems, a hesitation problem was found. This problem was fixed by resetting a dip switch in the ignition electronics box of the CNG fuel system. Since that time, the problem has not recurred. The fleet manager at Monroe County reported that the overall driveability of these vehicles was acceptable. There was a reduction in acceleration time, which is discussed in the next section.

ACCELERATION TESTING

Acceleration performance was recorded by conducting quarter-mile, wide-open-throttle acceleration runs from a standing start. Figure 7 presents the speed vs. time relationships for the

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[3] CNG prices are reported per gasoline equivalent gallon.

CNG bi-fuel, the 1993 M85 flexible fuel, and gasoline control vehicles. Table 3 gives the 0-60 mph acceleration times. The FFVs operating on M85 averaged 11.6 seconds to accelerate from 0-60 mph and were 0.9 seconds slower than the gasoline control vehicles which averaged 10.7 seconds. On gasoline the FFVs averaged 0.2 seconds slower than on M85 for the same test. The 0-60 mph times for the CNG bi-fuel vehicles operating on CNG averaged 14.4 seconds, 3.7 seconds slower than the gasoline control vehicles. The loss of power when using CNG is due primarily to fuel system calibration and not vehicle weight increase (about 140 lbs.), because when running the CNG bi-fuel vehicles on gasoline, the acceleration time was just slightly slower than the gasoline control vehicles.

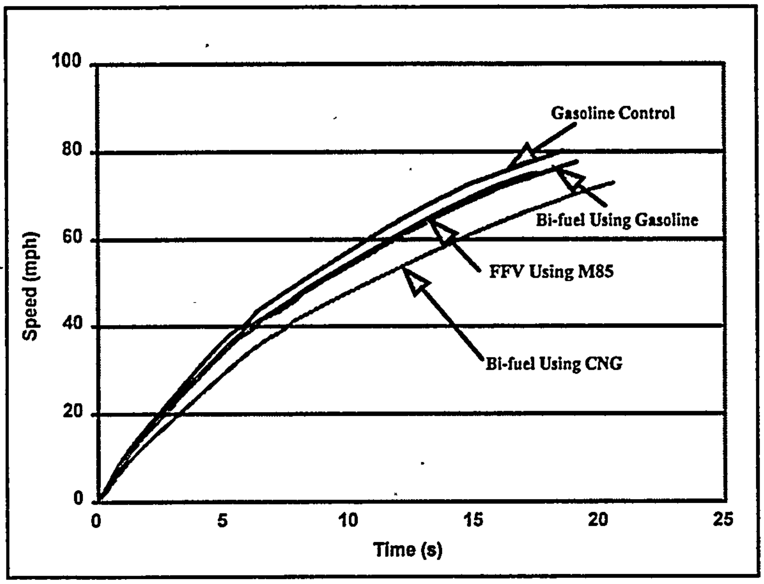

Figure 7. Acceleration Performance

Table 3. Acceleration Performance

Vehicle	Fuel	Time (s) 0-60 mph
FFV	M85	11.6
FFV	Gasoline	11.8
Bi-fuel	CNG	14.4
Bi-fuel	Gasoline	11.8
Control	Gasoline	10.7

MAINTENANCE

Analyses of fuel system related repairs were conducted to look for trends between vehicle types, with respect to weather and with accumulated mileage. It was expected that maintenance actions regarding the fuel and cranking system would be more frequent in winter periods. Figure 8 shows the vehicle starting problems with time through the project duration and the average daily temperature. As expected, in periods of cold ambient temperatures the frequency of starting problems increased.

Further analysis of the differences between the M85, CNG, and gasoline control vehicles reveal that while CNG system starting problems were present in the winter of 1994-1995, they remained well under the level of the FFVs using M85. Most of the initial FFV starting problems were caused by M85 with insufficient vapor pressure, which was subsequently corrected. However, the most cold start problems with these FFVs occurred when the temperature was the coldest in the winter of 1993-94. FFVs using M85 appear to be inherently more difficult to start in cold weather than gasoline or CNG vehicles. This is likely due predominantly to the fact that

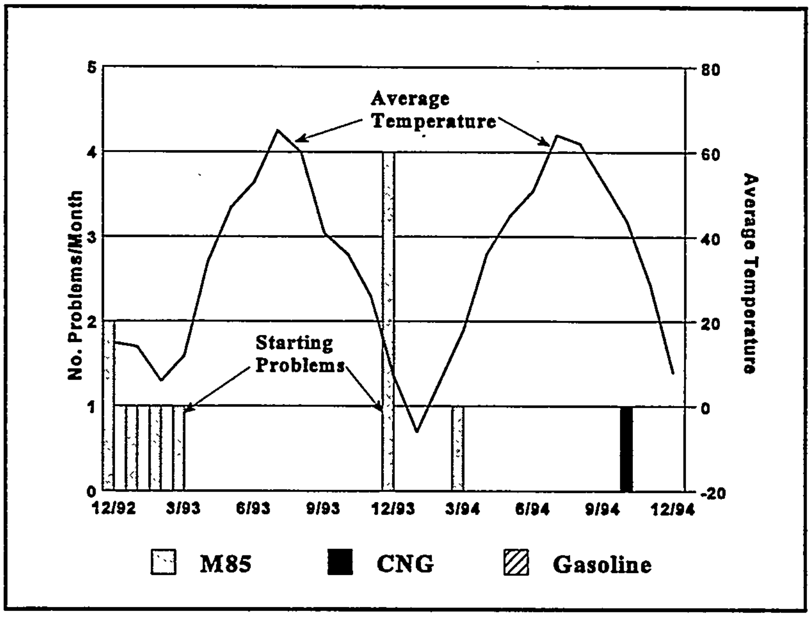

Figure 8. Vehicle Starting Problem Frequencies by Date

methanol does not vaporize as rapidly as gasoline does, and that methanol is conductive, and will short circuit spark plugs wet with liquid methanol. As the outside air temperature drops, a methanol fueled vehicle adds more fuel to assure that sufficient vapor is produced for cold-start. This increases the probability of the spark plug wetting and fouling. M85 fleets have sometimes chosen to add more gasoline to the methanol/gasoline blend during cold weather, which makes more gasoline available to vaporize so that the engine is able to start more reliably. Once started and warmed up, the methanol and gasoline are ignited with no further problems. The gasoline control vehicles had no starting problems during the period of data collection.

Over the course of the project there were four failures of the Ford M85 fuel pump module and two failures of the fuel sensors. Replacement components were installed for each of these failures. This was a common problem in 1991 Ford Taurus FFVs and also occurred in earlier model FFVs such as the Ford Crown Victoria. Figure 9 presents the fuel system repairs. The figure shows that all repairs were for the flexible fuel systems. The CNG and gasoline systems had no fuel system maintenance.

Oil changes for all the vehicles averaged between 3,000 and 4,000 miles. No attempt was made to optimize oil change frequencies based on the fuel used. All vehicles had similar, acceptable oil consumption rates.

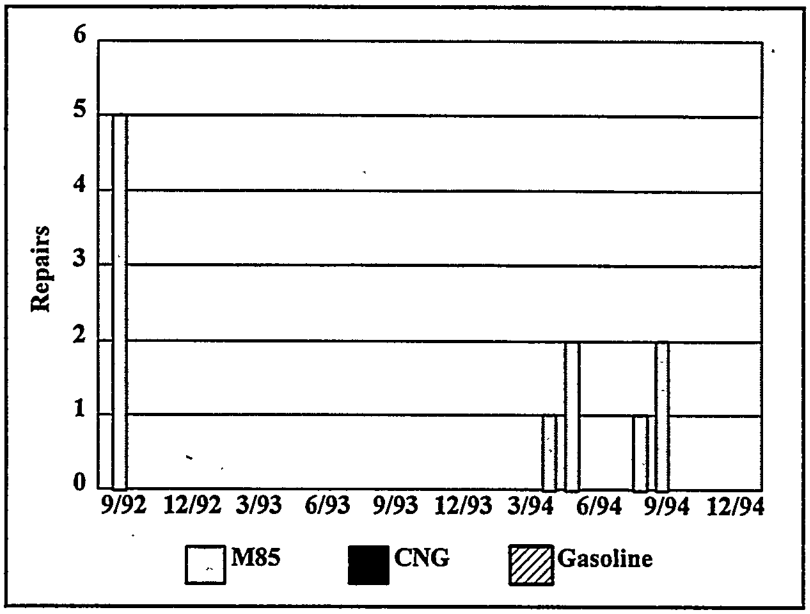

Figure 9. Fuel System Repair Frequencies

FUEL ECONOMY

Energy economy[4] was measured and compared both in the laboratory under highly controlled conditions and on-road in actual use. Table 3 compares average values for both the laboratory and on-road fuel/energy economy results.

Table 3. Comparison of Average Laboratory and On-Road Fuel Energy Economies

			Highway	City	NYCC	On-road
M85 FFV	1991	M85 (Volumetric)	20.3	12.4	6.3	13.4
		M85 (Energy Eq.)*	35.8	21.9	11.2	23.7
		Gasoline	33.0	19.5	10.0	22.5
	1993	M85 (Volumetric)	20.2	12.6	6.6	N/A
		M85 (Energy Eq.)*	35.7	22.2	11.6	
		Gasoline	35.3	21.6	11.1	
Control	Gasoline		34.4	21.0	10.9	22.2
CNG Bi-fuel	CNG*		33.7	19.4	9.6	24.0
	Gasoline		36.1	21.5	11.1	23.6

* M85 and CNG fuel economy reported in miles/gasoline equivalent gallons
N/A- The 1993 M85 FFVs were operated by the New York State Thruway Authority. Since they operate mostly on the Thruway (similar to most interstates) at relatively high and constant speeds, their on-road mileage is not comparable.

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[4] Energy economy is the distance in miles traveled by the vehicle on fuel which contains the same amount of energy as a gallon of gasoline i.e. 115,400 Btu.

Laboratory Fuel Economy

Laboratory fuel economies were obtained as an integral part of the emissions testing conducted on the demonstration vehicles. For these tests three 1991 model year M85 flexible fuel, four 1993 model year M85 flexible fuel, three 1994 model year CNG bi-fuel, and three gasoline control Ford Taurus vehicles were tested from 1993 through 1995. The fuel economy results from these tests are presented in Figures 10 and 11. These figures present the laboratory fuel economy results for the Highway and Urban (City) Cycles of the Federal Test Procedure and the New York City Cycle (NYCC) driving cycles in the form of floating bars. The top of the bar represents the maximum, the bottom represents the minimum and the line inside represents the average fuel economy sampled. The on-road fuel economies are represented similarly.

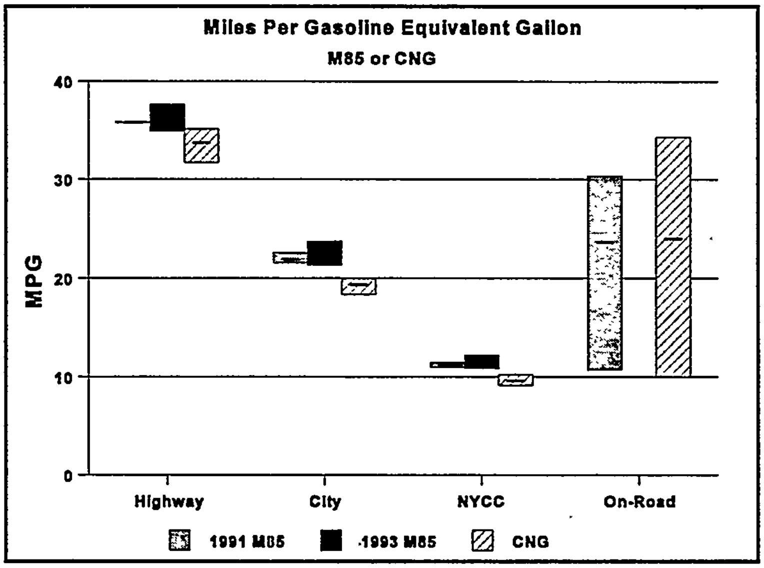

Figure 10. M85/CNG Energy Economy

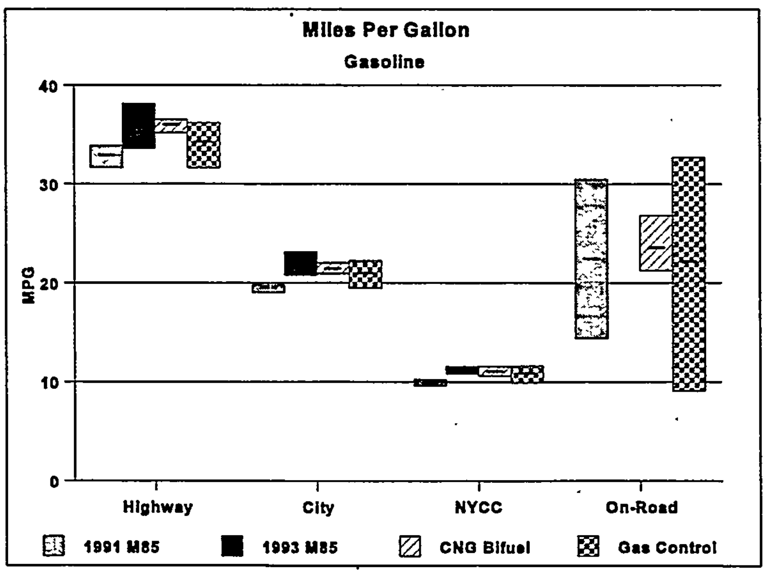

Figure 11. Gasoline Fuel Economy

On Road Fuel Economy

The on-road fuel economies for the 1991 model year FFVs and the gasoline control vehicles were calculated by measuring the amount of miles traveled by each vehicle and dividing it by the number of gallons of fuel consumed in that period. For the CNG bi-fuel vehicles, on-road energy economies were calculated by dividing the miles traveled in a given time interval by the gasoline energy equivalent gallons of CNG consumed in that same interval.

Discussion of Fuel Economy Results

Comparison between on-road and laboratory fuel economies indicate that the laboratory FTP City Cycle fuel economies most closely resemble the on-road fuel economies. This is not surprising due to the fact that the vehicles operated primarily in city/suburban driving conditions.

Direct comparison between M85 and CNG energy economies obtained from laboratory tests indicates that for all of the three test cycles, both 1991 and 1993 model year M85 FFVs averaged higher in energy economy relative to CNG vehicles. A possible explanation for this could be that the M85 vehicles were OEM vehicles and hence better optimized for operation on M85, whereas the calibration of the CNG bi-fuel vehicles is always a compromise. The CNG bi-fuel vehicles also were heavier by the weight of the CNG fuel system and cylinders, estimated to be about 140 pounds.

The energy economies for the 1991 and 1993 FFVs on M85 are very similar and higher than those on gasoline for both dedicated gasoline vehicles and the FFVs. However, the energy economy for operation on CNG is lower than that for operation on gasoline. Average on-road energy economies were similar for the FFVs operating on M85 and for bi-fuel vehicles operating on CNG and gasoline. Gasoline control vehicles and FFVs operating on gasoline had slightly lower energy economies.

EMISSIONS

Collection of emissions data was a very important part of the Monroe County M85/CNG demonstration project. Since 1993 emission tests were performed on three 1991 M85 flexible fuel Ford Tauruses, three 1994 CNG bi-fuel Ford Tauruses, and three gasoline control Ford Tauruses.

In accordance with the Federal Test Procedure, the exhaust of each test vehicle was sampled and analyzed for major emission constituents: carbon monoxide (CO), oxides of nitrogen (NO_x), methane (CH_4), non-methane hydrocarbons (NMHC), and aldehydes (ALD). Figure 12 illustrates the City Cycle emissions for the tested vehicles in the form of floating bars. The top of the bar represents the maximum, the bottom represents the minimum and the line inside represents the average value of the emissions.

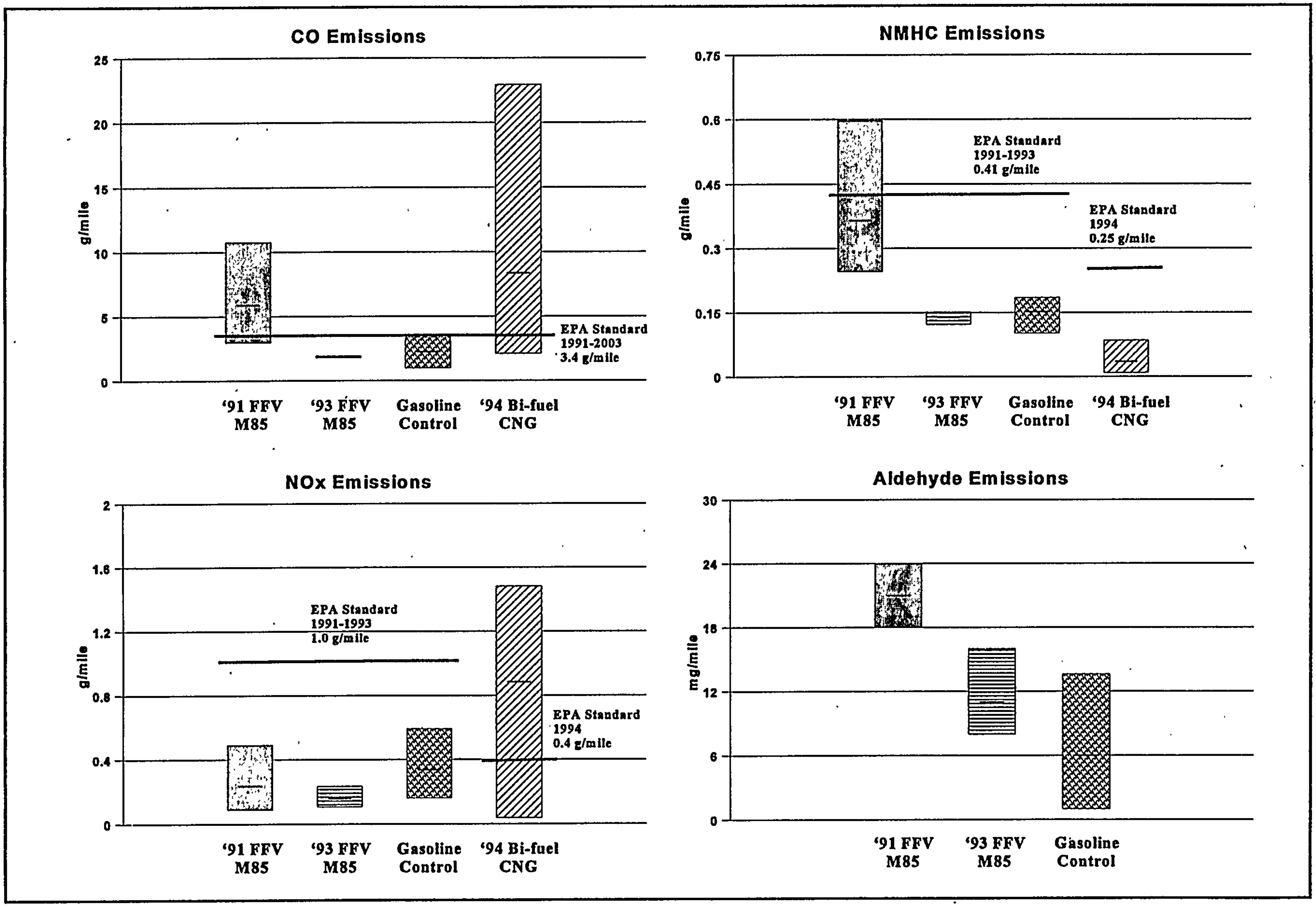

Figure 12. City Cycle Laboratory Emissions

Discussion of Emissions Results

Flexible Fuel Vehicles:

Both the 1991 and 1993 FFVs were evaluated on the EPA City Cycle for emissions. The 1991 Ford Taurus FFV was built and sold by Ford as an experimental vehicle and was not required to meet EPA standards for its model year. The 1993 Ford Taurus FFV was sold as a production vehicle in full compliance with EPA requirements. Results of emissions tests on these two vehicle types indicate that 1991 vehicles did, in fact, exceed EPA emissions limits for CO and HC emissions while the 1993 FFVs were able to satisfy EPA emissions about as well as the gasoline baseline vehicles.

The 1993 Ford Taurus is an upgraded version of its earlier M85 flexible fuel design. This model benefitted from the experience gained on the earlier model Ford FFVs such as the ones used by Monroe County. Results of the emissions tests on these vehicles indicate a significant reduction in the CO and HC emissions when tested on the City Cycle. Some improvements are also seen in NO_x and aldehyde emissions.

The 1993 Ford Taurus FFVs had aldehyde emissions of 11 mg/mile with M85 fuel and 13 mg/mile when using gasoline. Recent data on 1996 Ford Taurus FFVs[1] report lower values of aldehyde emissions: 3.9 gm/mile on M85 and 0.8 gm/mile on gasoline. Use of close-coupled light-off catalysts in the 1996 Ford Taurus FFVs is a primary reason for this reduction. Significant emissions reductions were also reported for CO, NO_x and HC emissions with the 1996 Ford FFV relative to the 1993 Ford FFV (both using M85).

CNG Vehicles:

The converted 1994 Ford Taurus CNG bi-fuel vehicles were also emissions tested. Data varied significantly from vehicle to vehicle and were in excess of EPA emissions requirements for CO and NOx. This result is not uncommon for CNG conversion systems using first generation closed-loop fuel system technology.

To reduce the variability and average level of emissions from these vehicles, it may be necessary to calibrate the fuel system with the vehicle installed on a chassis dynamometer - a procedure that is not feasible for typical fleets. When properly adjusted the converted CNG bi-fuel vehicles can be as clean as the same model gasoline vehicle. However, emissions testing of OEM dedicated CNG vehicles (such as the Dodge CNG minivans) demonstrate that such vehicles can have lower emissions than their gasoline counterparts.[2]

SUMMARY

This project demonstrated successful operation of CNG bi-fuel, M85 flexible fuel and gasoline control vehicles in fleet use in Monroe County, New York. Extensive data on fuel consumption, mileage accumulation, laboratory emissions testing and maintenance were collected. Refueling and maintenance facilities were modified or constructed and then operated based on specific requirements for either M85 or CNG fuel. Each vehicle type was evaluated on a variety of criteria, such as fuel economy, emissions, acceleration and maintenance. Important conclusions based upon the experience gained during this fleet operation are summarized below.

- Both FFV and CNG bi-fuel vehicles were adequate to meet the operating needs of Monroe County.
- The FFVs required the most maintenance among these Tauruses (FFV, CNG bi-fuel, and gasoline) due to cold-start problems and fuel system component failures.
- The FFVs experienced cold-start problems in very cold weather relative to the gasoline and CNG bi-fuel Tauruses.
- All the vehicles had acceptable driveability.
- The CNG bi-fuel Tauruses had significantly slower acceleration compared to the gasoline and FFV Tauruses.
- The energy economies for the FFVs on M85 were higher than those on gasoline for both, dedicated gasoline vehicles and the FFVs. Also, the energy economy for operation on gasoline is higher than for operation on CNG.
- Early 1990's models of CNG bi-fuel vehicles and FFVs were not effective at reducing emissions levels relative to conventional gasoline fueled vehicles. More recent FFVs and CNG vehicles have lower emissions.
- Facility changes for M85 are normally not required because the fuel is a liquid and contains gasoline. Training must be given to mechanics so that safe and proper procedures are used. Depending on the age and condition of the garage facility some facility changes may be needed for CNG service operation. Changes were needed for existing Monroe County garage facilities and more training was required for mechanics to safely service CNG vehicles.

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THERMAL MANAGEMENT OF AN ETHANOL FUELED FORD TAURUS CATALYTIC CONVERTER

Matt Keyser, National Renewable Energy Laboratory

(Presentation unavailable at time of publication)

SESSION 7

HEAVY DUTY ALTERNATIVE FUEL ENGINES
PRESENT AND FUTURE

Chair: Vinod Duggal, Cummins Engine Company, Inc.

Cummins Heavy Duty Natural Gas Engine Products

Don R. Welliver
Cummins Engine Company

1996 Windsor Workshop on Alternative Fuels
June 4, 1996
Toronto, Canada

Cummins Natural Gas Engines

- History
  - Gas engine development since mid 1980s
    - » Driven by 1991 transit bus particulate standard
  - Early work performed under contract to Ortech
  - Mechanical fuel management system chosen
    - » No existing technology for electronic controls
    - » Limited development time window
  - Other "off the shelf" components

Cummins Natural Gas Engines

- History
  - Significant field experience gained in late 1980s and early 1990s in fleets such at TTC and HSR
  - Natural Gas Bus Working Committee led by MTO provided industry focus
  - L10-240G CARB certified in August 1992
    - » Included complete deterioration factor testing

Cummins Natural Gas Engines

- Electronic Controls Development
  - Mechanical fuel control system delivered good air fuel ratio response
    - » Sensitive to fuel composition due to volumetric characteristics
    - » Difficult to shape torque curve
  - 1994 L10G improved with electronic waste gate control giving altitude compensation
    - » Allowed uprating to 260 hp

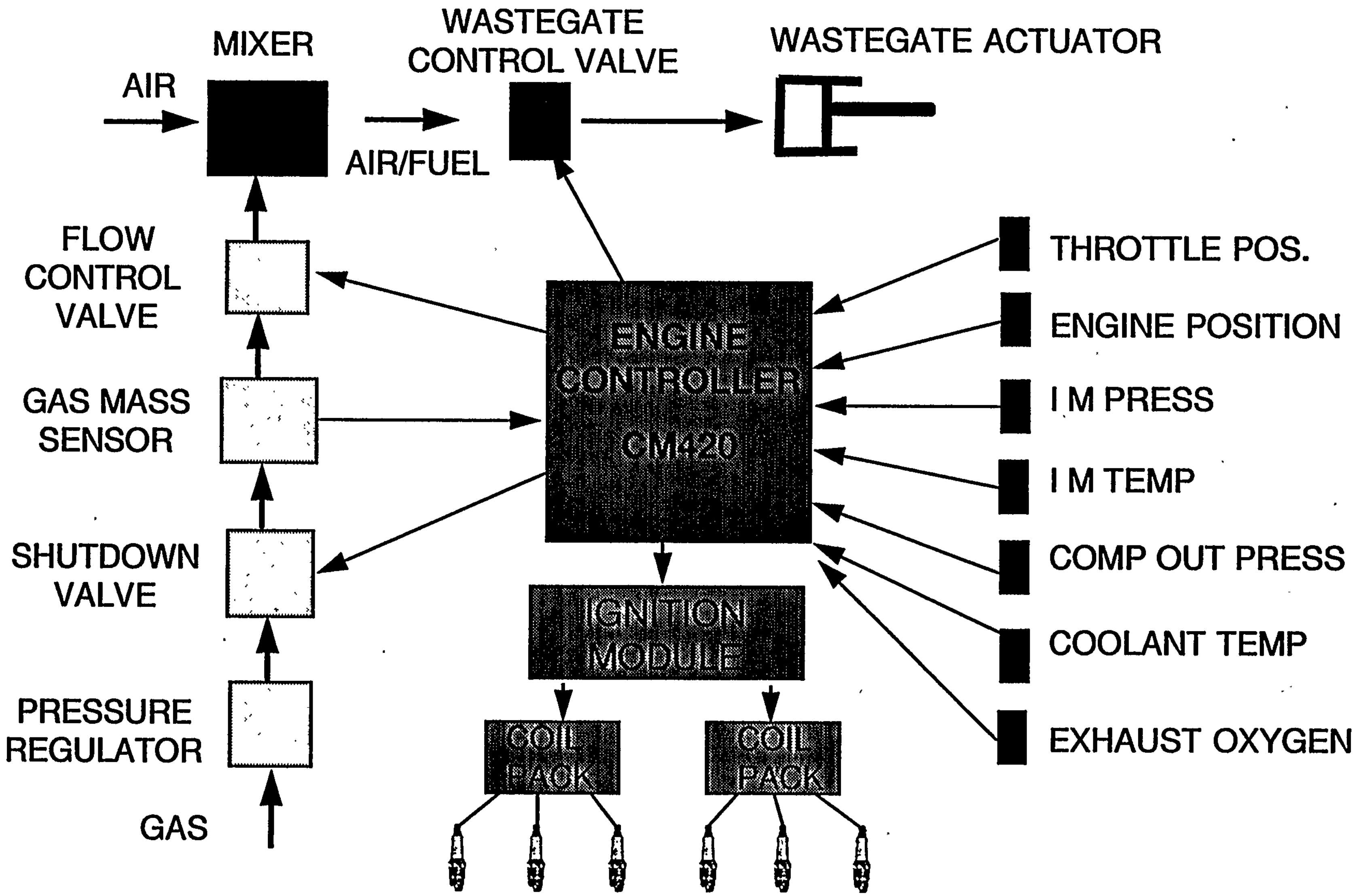
Cummins Natural Gas Engines

- B6G Engine Development
  - B6G platform developed next with specific development goals
    - » Electronic fuel delivery usable on all platforms
    - » In house design and development for all major subsystems
  - Required new skills
    - » Spark ignited engine controls
    - » Ignition systems

Cummins Natural Gas Engines

- B6G Engine Development
  - Several new subsystems developed
    - » Lean EGO sensor
    - » Gas mass sensor
    - » Engine controls
    - » Ignition control module
    - » Sensors and actuators

B6G Controls



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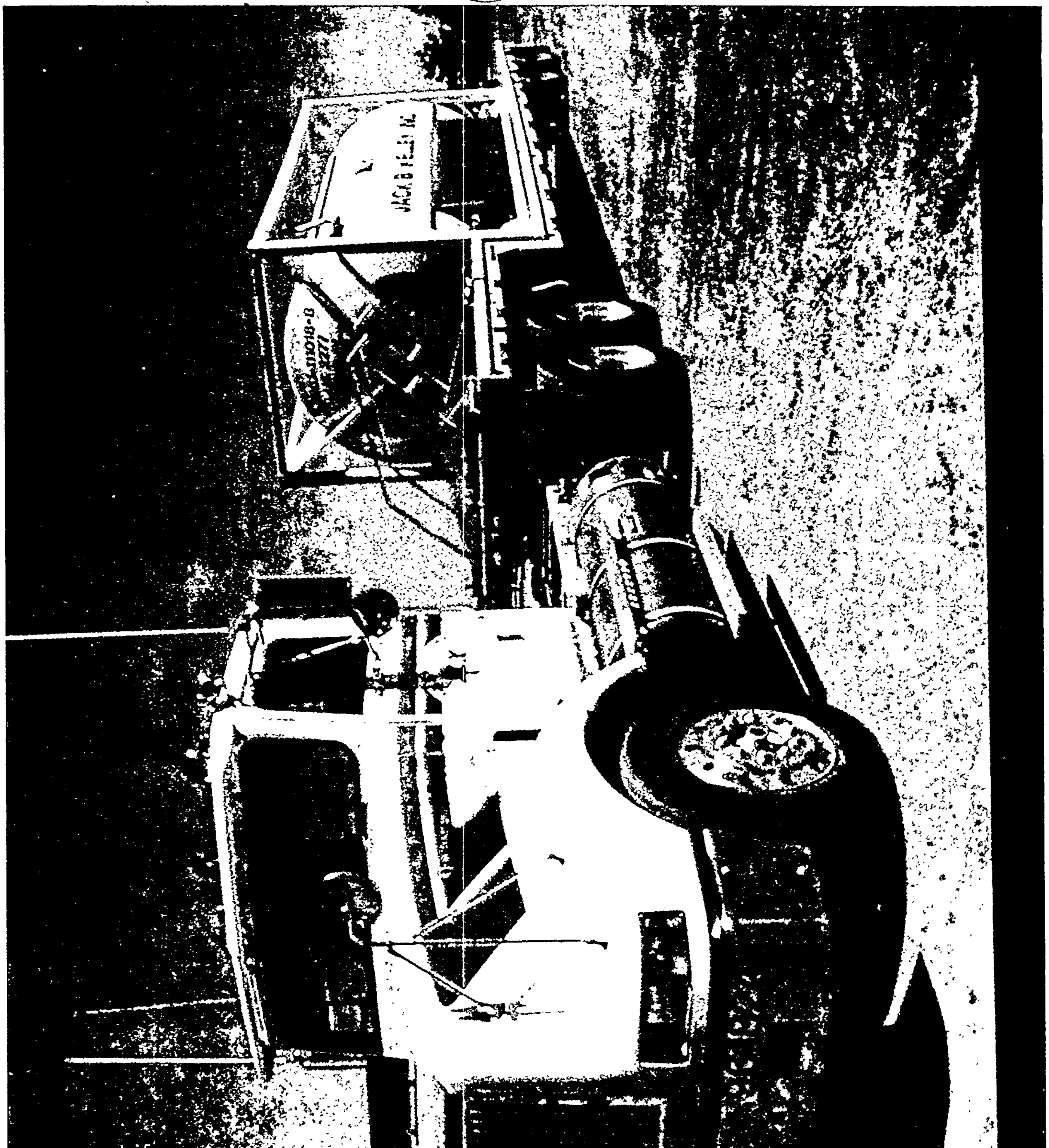
Cummins Natural Gas Engines

- B6G Engine Development
  - Released in December 1994
  - 195hp and 150 hp ratings with 420 lb-ft peak torque
  - 300+ engines built to date
    - » School and shuttle bus
    - » Package delivery vehicles
    - » Yard spotter
    - » Street sweeper

Cummins Natural Gas Engines

- 1996 L10G Engine Development
  - Applied B6G component and control technology to the L10G
  - Retained the existing governor
    - » Capacity of current ECM not enough to provide speed control
      - Single service tool downloads both modules as a single calibration and reads both module's diagnostics
  - Uprated to 300 hp, 900 lb-ft peak torque



Cummins Natural Gas Engines

- 1996 L10G Engine Development
  - Available as of January 1996
  - Engineered in several trucks and buses
  - About 60 units operating to date

Cummins Natural Gas Engines

- C8.3G Engine Development
  - Recently released for limited production
  - Advances state of the art in several areas
    - » New gas mass sensor design allows same sensor to be used across multiple platforms
    - » Coil on plug technology
    - » Multiple spark discharge

Cummins Natural Gas Engines

- C8.3G Engine Development
  - 250 hp with 750 lb-ft peak torque
  - 275 hp uprate available in January 1997
  - Eleven vehicles in operation
    - » School bus
    - » Transit bus
    - » Delivery truck

Cummins Natural Gas Engines

- M11G Engine Development
  - Uses M11 diesel carcass as platform
  - Lead platform for several new technologies
    - Full authority engine control module
    - Coil on plug (under valve cover)
    - Ignition control module with diagnostic and prognostic capabilities
    - Wide band EGO sensor
    - New fuel metering concept

Cummins Natural Gas Engines

- ◆ M11G Engine Development
  - – 340 hp with 1050 lb-ft peak torque
  - – Available in early 1998

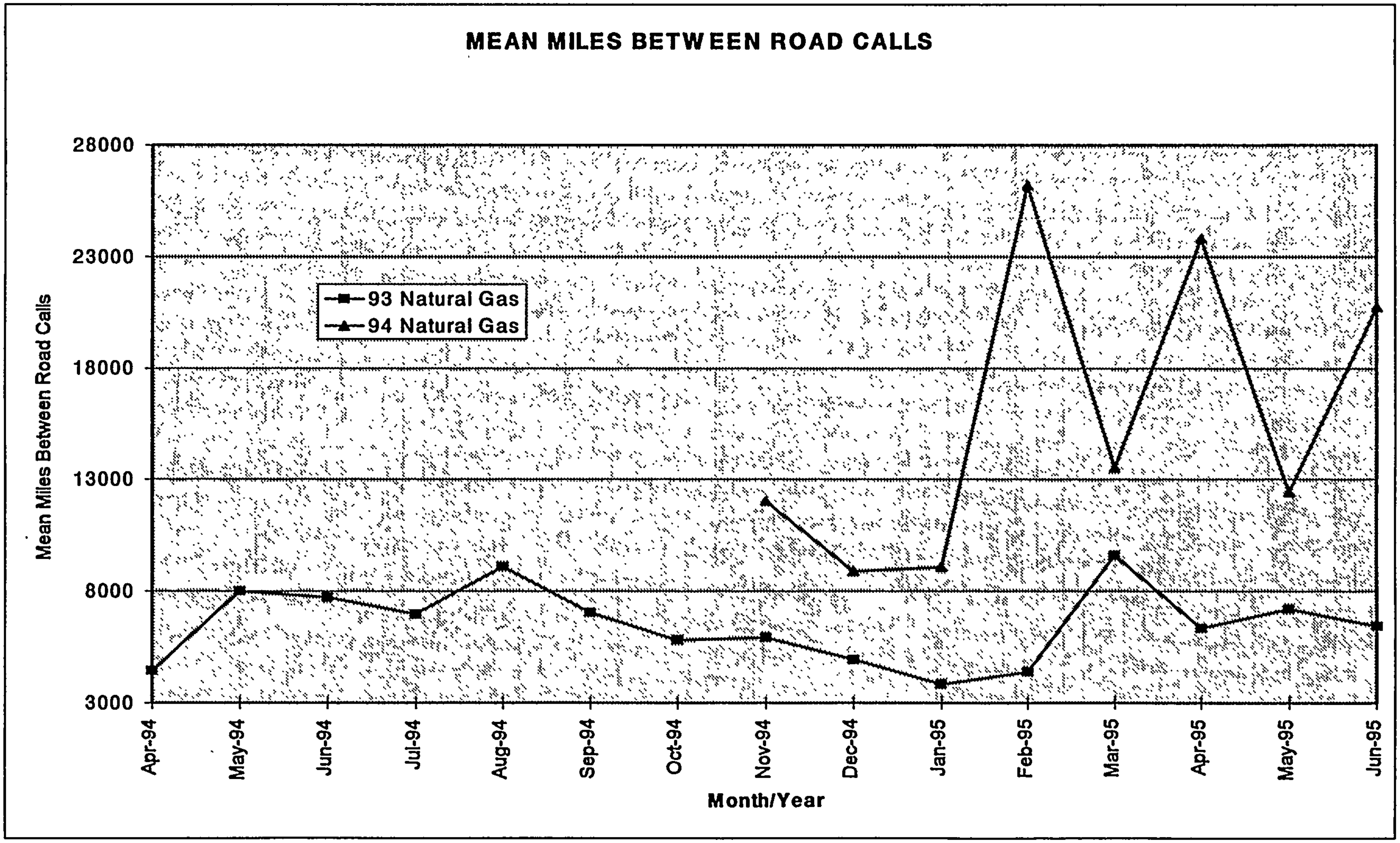
Cummins Natural Gas Engines

- Summary
  - Cummins has more than 1200 vehicles in operation with over 100 million miles
  - Twenty OEMs offer our engines, over 60 fleets are operating them
  - Market philosophy has been initial conservative ratings, increasing BMEP levels as field experience is gained
  - All major subsystem design performed in house

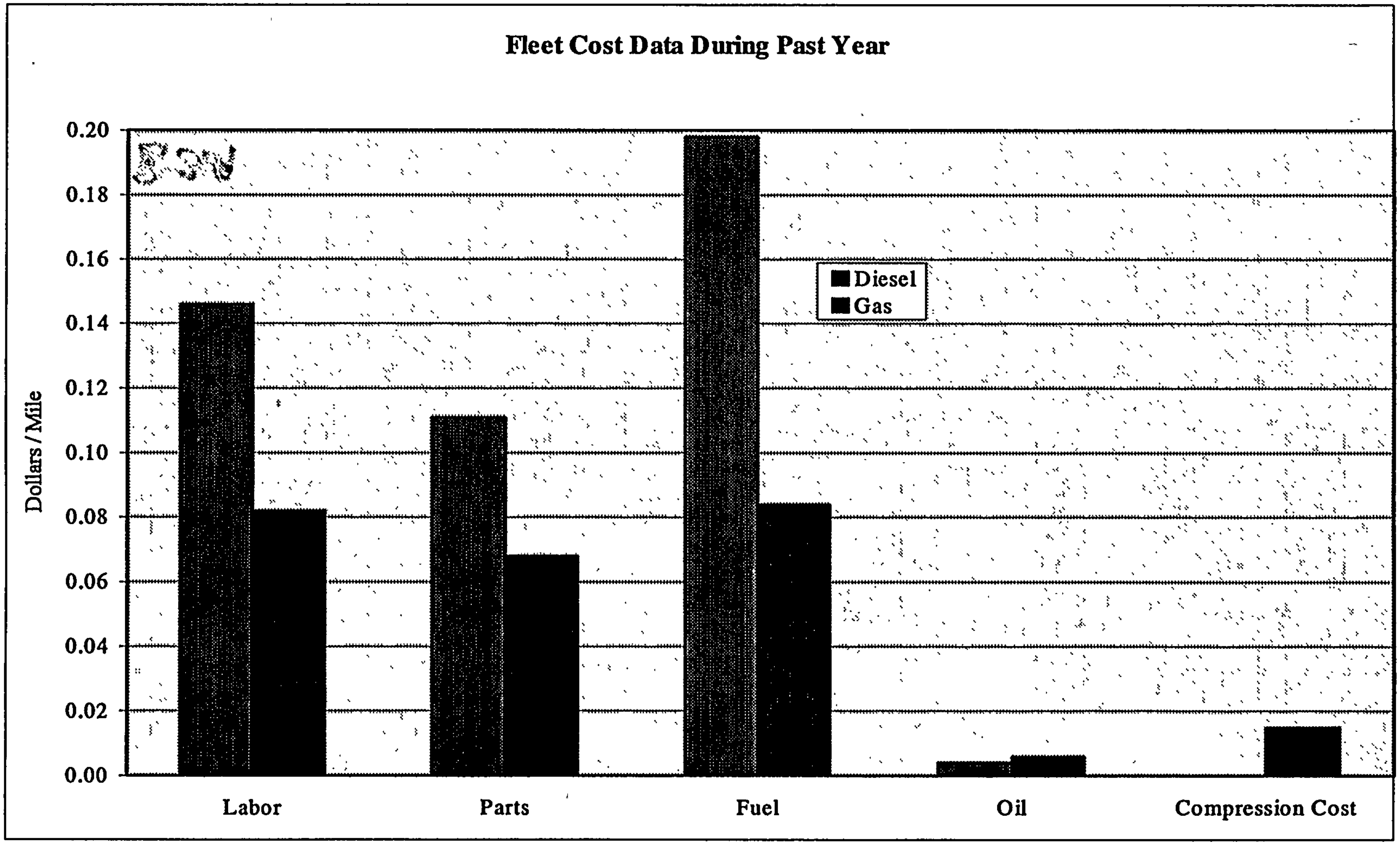
Cummins Natural Gas Engines

- Summary
  - Each new platform builds on learning from previous designs, thereby advancing the state of the art
  - As new technologies introduced, BMEP has risen from 185 psi in early 1990 to 225 psi today moving to 240 psi in 1998
  - This philosophy has provided advantages for our customers

Cummins Natural Gas Engines



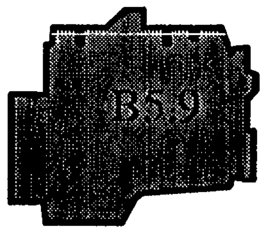
Cummins Natural Gas Engines

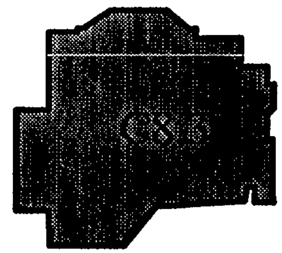


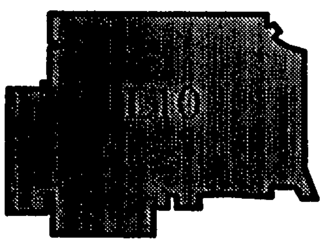
Cummins Natural Gas Engines

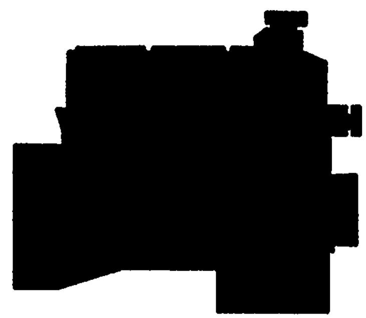
- Automotive Platforms

B3.9









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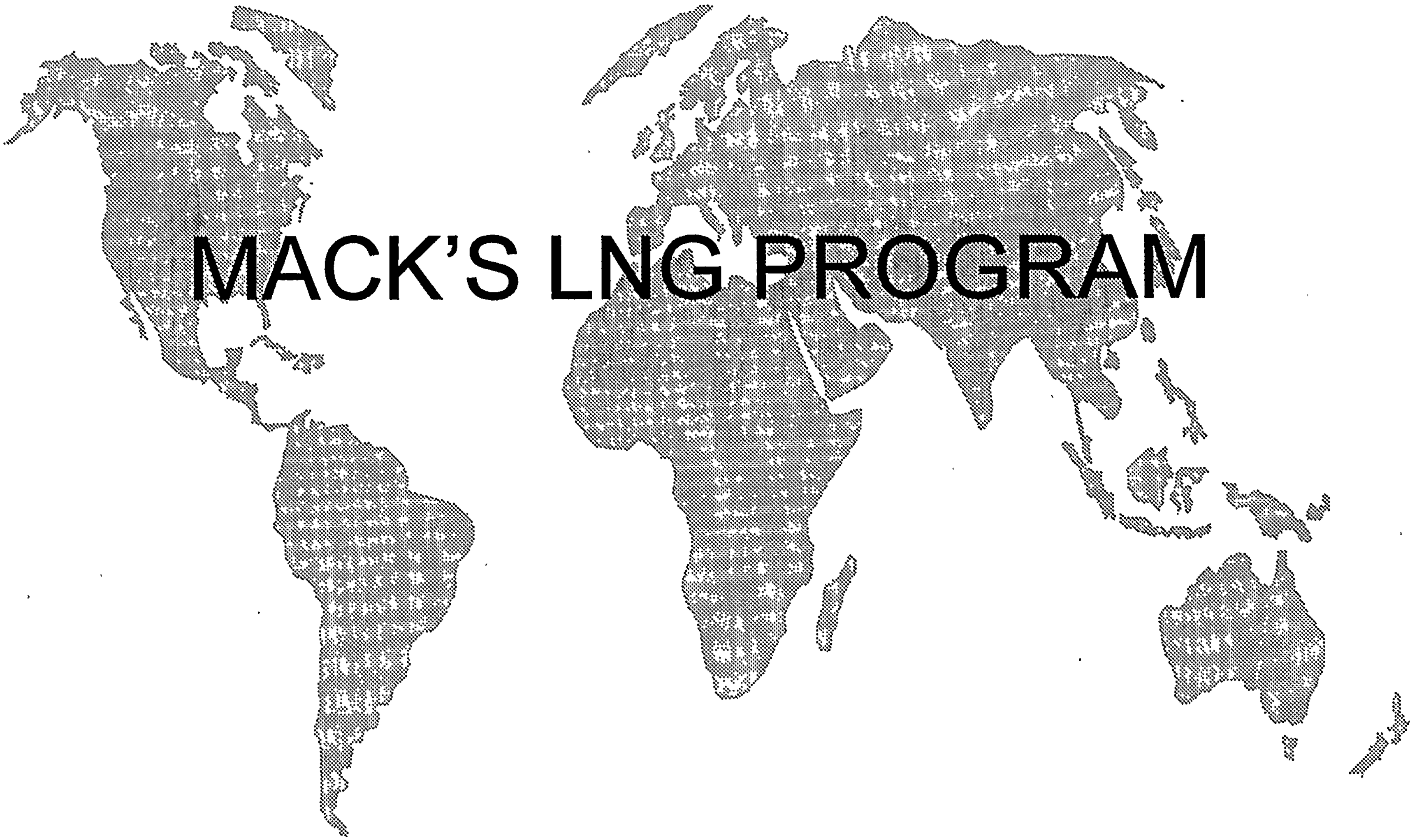
Cummins Natural Gas Engines

- Acknowledgments
  - Gas Research Institute
  - Columbia Gas
  - Consolidated Gas
  - SoCal Gas
  - New York Gas Group
  - Gas Technology Canada
  - NYSERDA


MACK'S LNG PROGRAM

CNG MR600 REFUSE TRUCK FOR BFI

- SwRI Performed All Engine & Vehicle Changes
- GRI Funded Program
- Purpose was to Demonstrate Feasibility of Natural Gas
- Operated for One Year in Boston During 1993/94

CNG PROGRAM CONCLUSIONS

- CNG Added 2000 lb. to the Vehicle
- Vehicle Range Needed to be Increased
- Part Load Fuel Consumption was Poor
- Engine Driveability Needed Improvement
- Natural Gas was Viable for Refuse Service

LNG MR600 REFUSE TRUCK

- The Truck was Moved From Boston to Atlanta in 1994
- BFI Replaced CNG with a LNG Fuel System by MVE
- Mack Replaced Original Engine with New Design in Late 1995

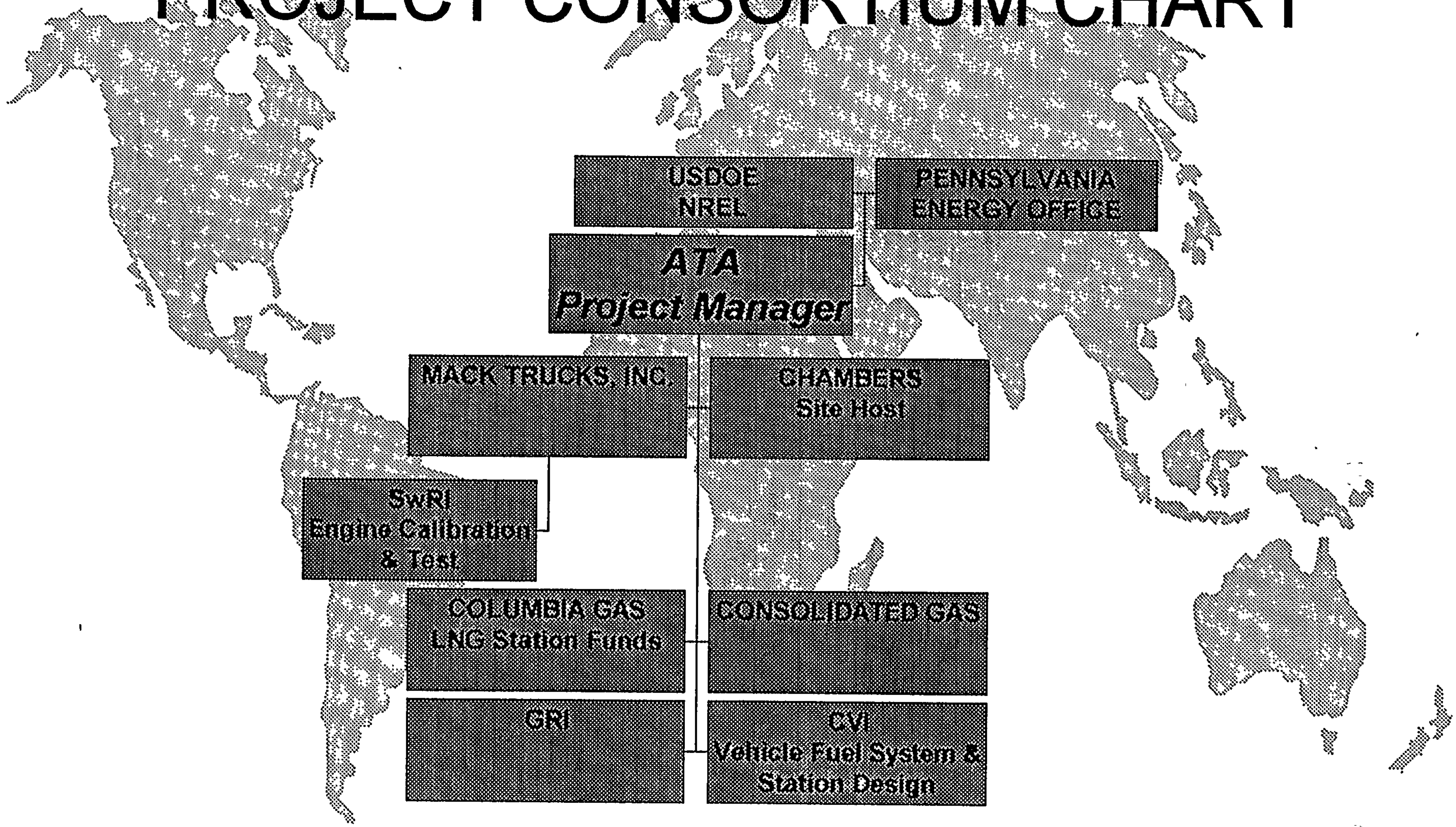
CHAMBERS LNG PROJECT

- Provide 7 LNG Fueled LE Refuse Trucks
- Install Underground LNG Refueling Station
- Improve Engine's Part-Load Efficiency
- Field Test for 3 Years
- Maximize Tank's Holding Time in the Vehicle
  - Non-Metallic Trunnion Joint

CHAMBERS LNG PROJECT - CONT.

- Perform Thorough Testing of Tanks & Supports
  - Mack's Bump Test
  - 30 ft. Drop Test
  - 10 ft. Filler Neck Drop Test
  - 30 mph Crash Test Simulation

PROJECT CONSORTIUM CHART



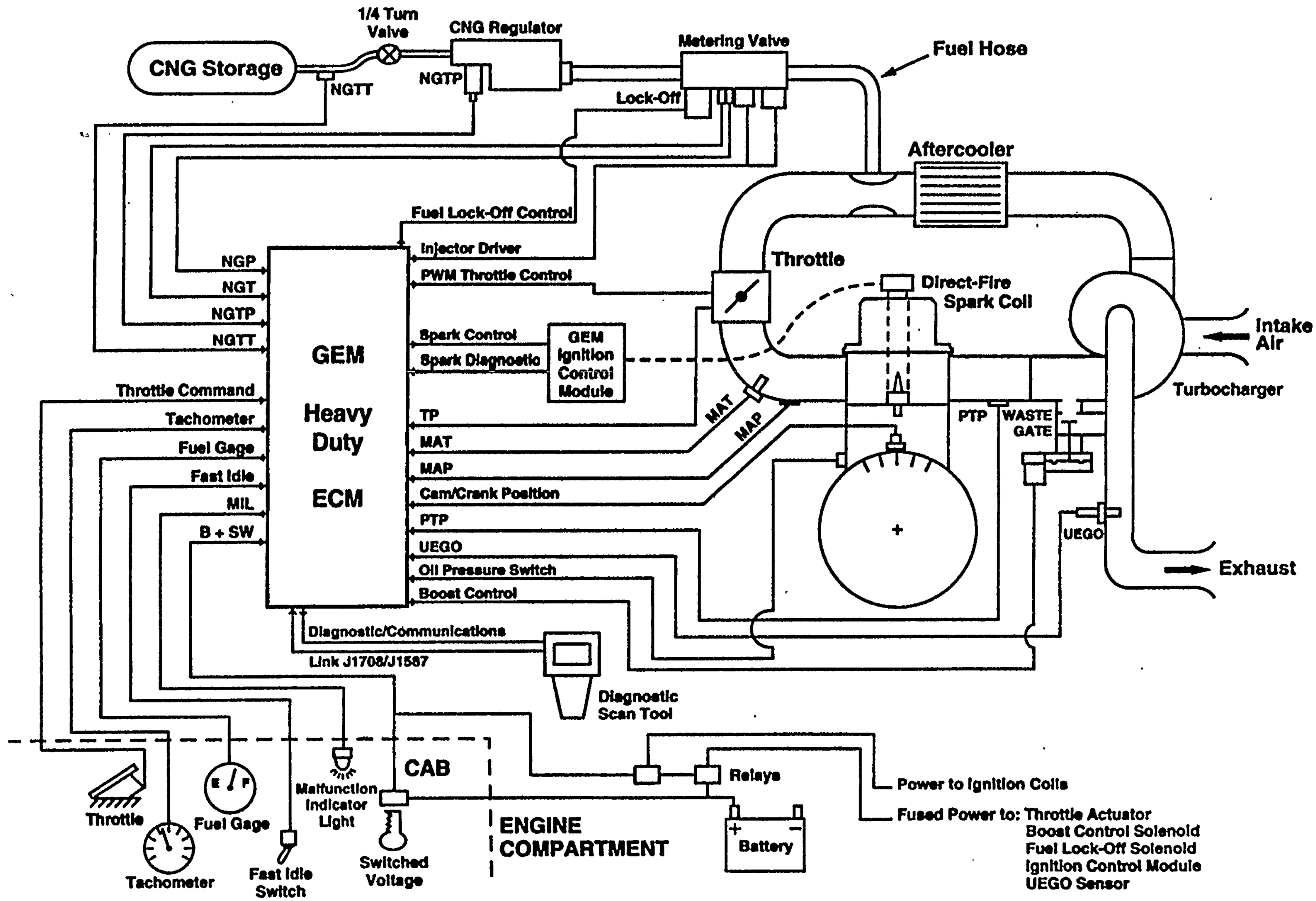
E7G 12L ENGINE GOALS

- Two Power Ratings:
  - 325 hp @ 1950 rpm; 1160 ft.lbs. P.T.
  - 350 hp @ 1800 rpm; 1260 ft.lbs. P.T.
- Good Part Load Efficiency for Refuse Industry
  - *3 Mpg D.E. in Service, Front Loader*
- Low Emissions W/O Catalyst
  - *1.9 gr/hp hr NOx SwRI Prediction*
  - *2.0 gr/hp hr THC SwRI Prediction*
  - < .05 gr/hp hr PM Goal
- Excellent Driveability
- Diesel-Like Reliability & Durability

WOODWARD/MESA ELECTRONIC FUEL SYSTEM

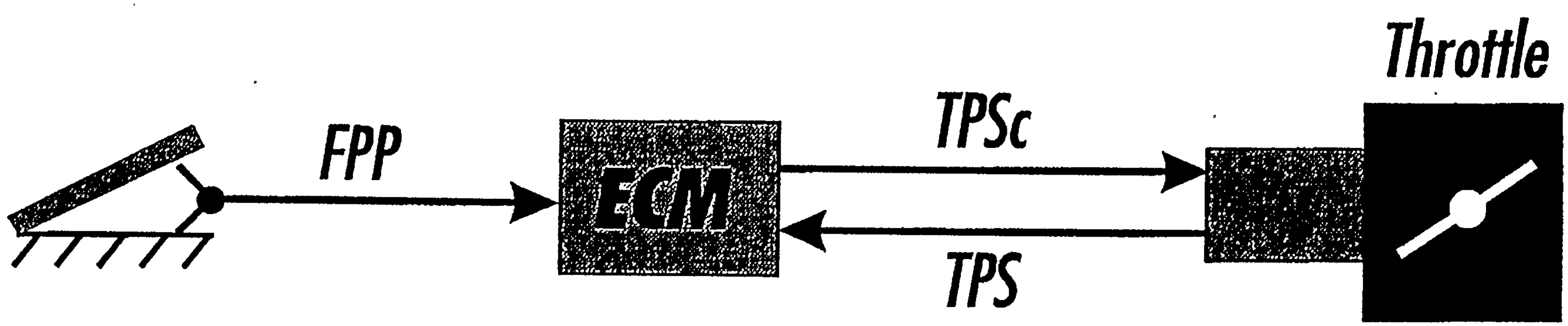
- State-of-the-Art Speed Density Control Strategy
- Closed-Loop Lean-Burn Operation with Adaptive Learn
- Advanced "Turbo-Lag" Compensation
- Full Authority Electronic Throttle
- NGK UEGO Sensor
- Electronic Wastegate Control
- High Energy Inductive Ignition System
- Full Diagnostics
- Reduced Power Engine Protection

GEM HEAVY DUTY CONTROL SYSTEM

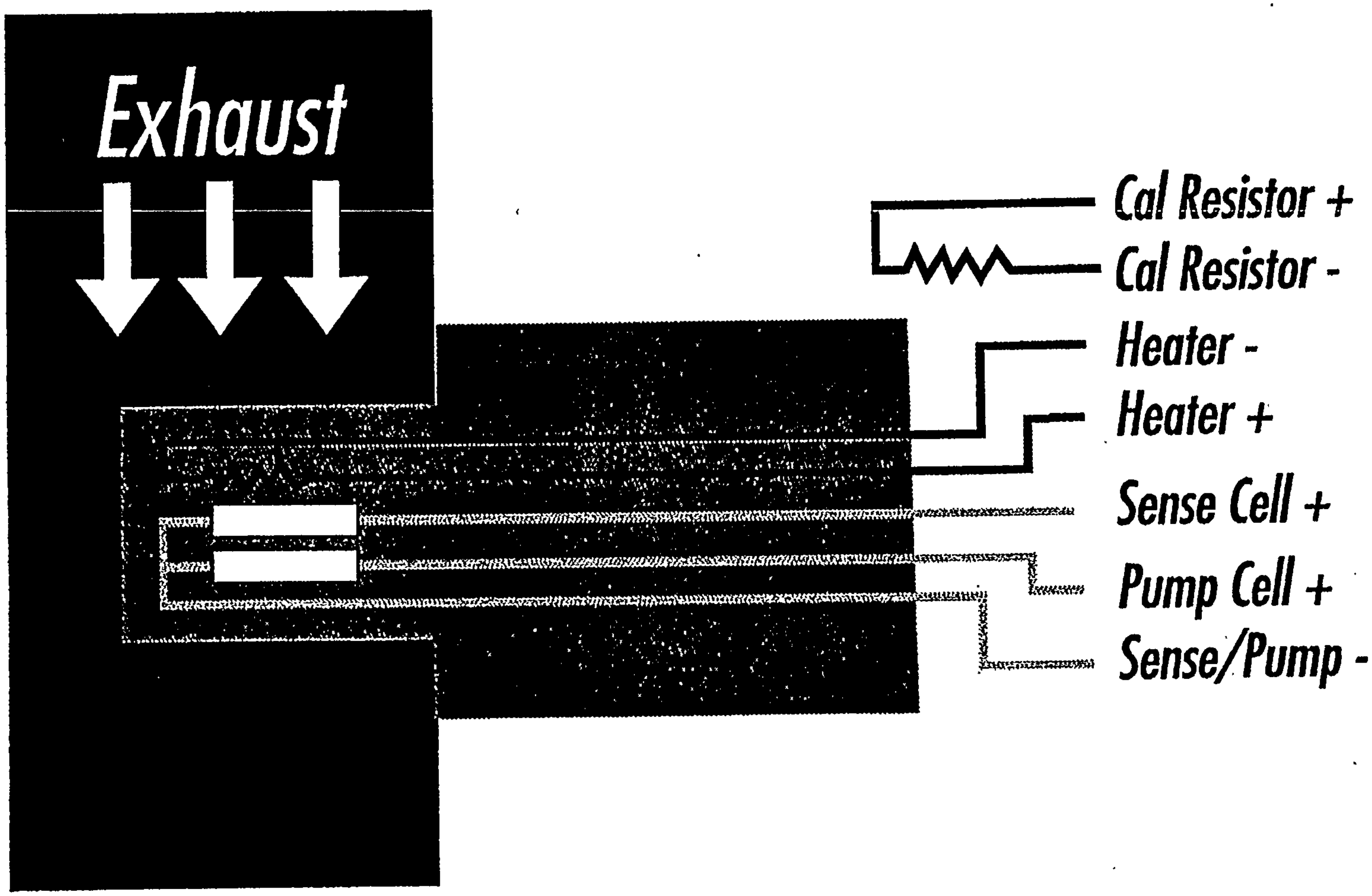


DRIVE-BY-WIRE THROTTLE SYSTEM

- Full-Authority DBW Throttle Control
- Command Signal from FPP Sensor
- Min / Max Governing
- Controlled by ECM
- Woodward Digital Throttle
- Extensive Diagnostics Provided

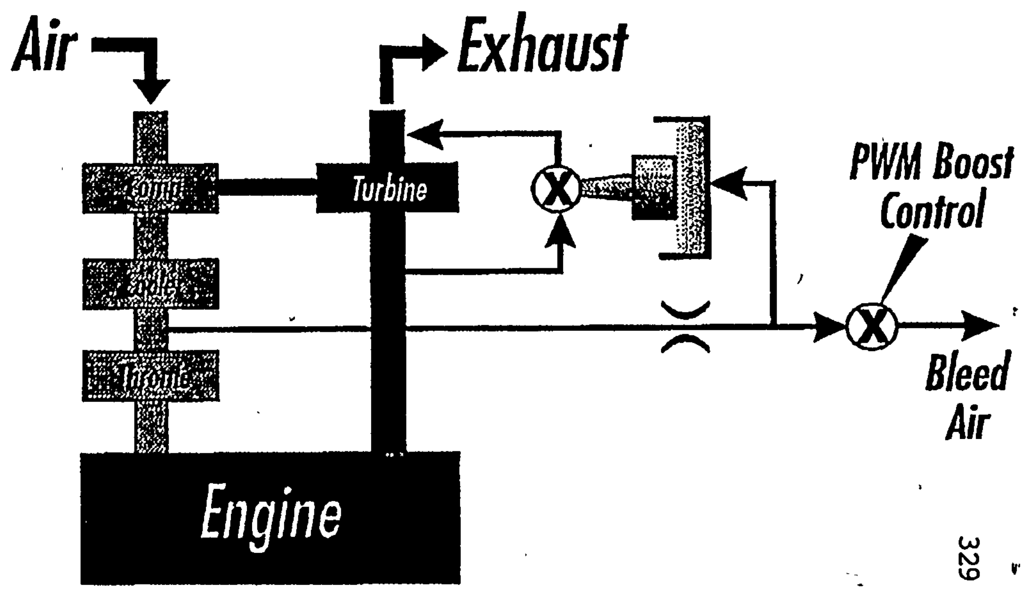


NGK UEGO SENSOR



BOOST CONTROL

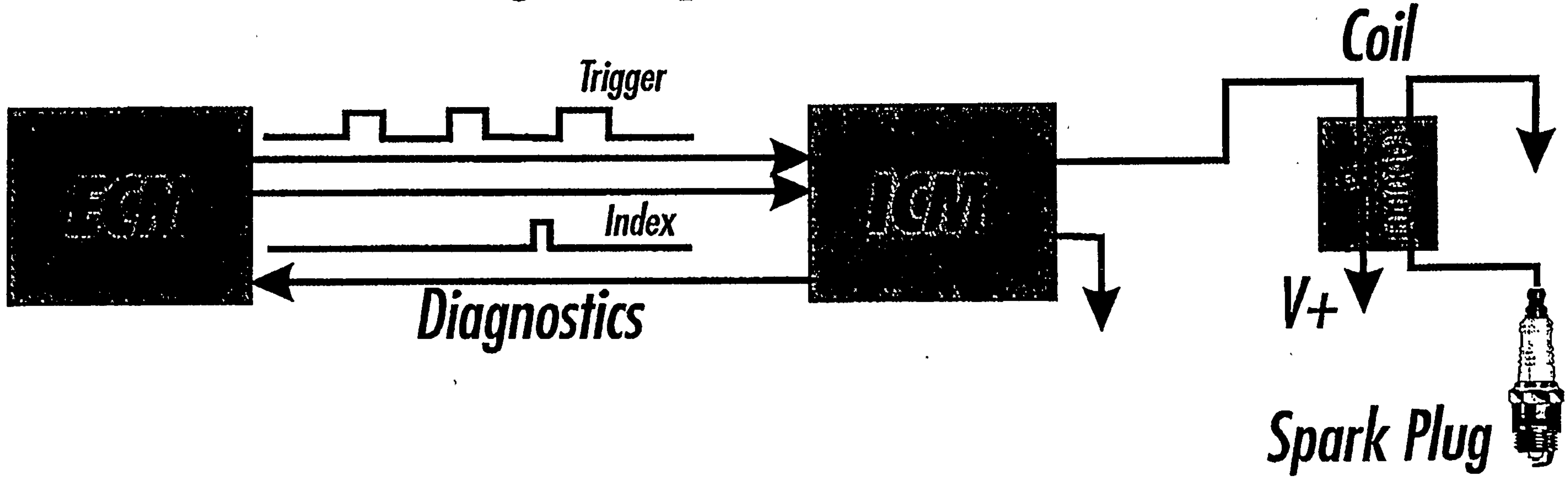
- **Electronic Wastegate Control**
  - torque curve shaping
  - electronic delta-P wastegate control improves part-load efficiency
- **MAP Setpoint Based on RPM and FPP**
- **"Turbo Lag Compensation" Quickly Spools Turbo**
  - 50% reduction in spool-up time
  - Based on spark and fuel control
  - Zero emissions penalty



IGNITION SYSTEM

- **Inductive, Direct-fire Ignition System**
  - one coil per cylinder
  - longer spark duration than CD, extends LML

- **ECM Spark Timing and Dwell Control**
  - based on RPM and MAP
  - separate ignition control module with drivers
  - ICM diagnostics provided



FUTURE PLANS

- Continue with Current Programs
- Progress to Production on LE Model with the E7G Engine for Late 1997
- Evaluate Potential for a Natural Gas Highway Tractor; the CH
- Work with Renault V.I. on European Applications of E7G Engine
- Continue to Incorporate New Technologies to:
  - Improve Performance
  - Reduce Cost

GEORGETOWN UNIVERSITY
Advanced Vehicle Development

Fuel Options For Fuel Cell Powered Transit Buses

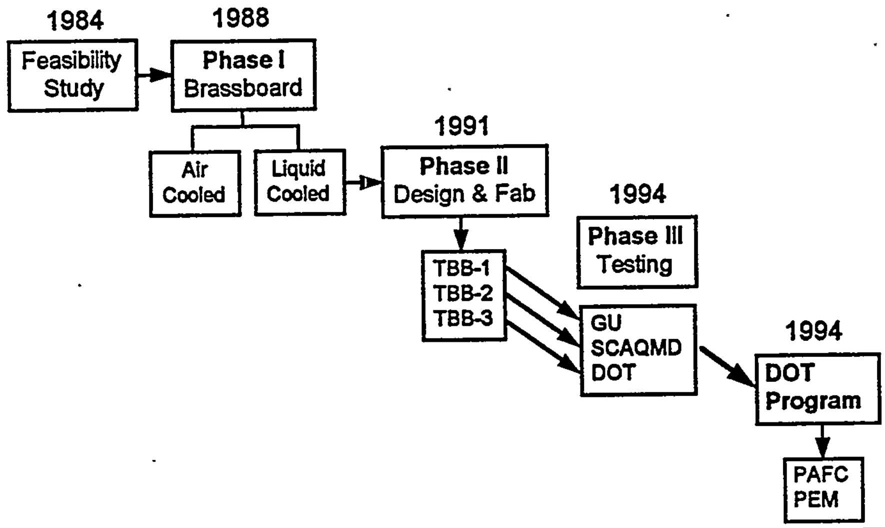
Robert R. Wimmer
Project Manager

Windsor Workshop on Alternative Fuels
Toronto, Canada
June 4, 1996

GEORGETOWN UNIVERSITY FUEL CELL POWERED TRANSIT BUS PROGRAMS

- Georgetown University (GU) has been working on Fuel Cell (FC) powered transit buses since 1983
- We are presently working on two FC bus projects
  - The 30 ft FC Powered Test Bed Bus Program
  - The 40 ft FC Powered Bus Commercialization Program
- Both buses are hybrid electric (two power sources)
  - The fuel cell provides the "average" power or energy
  - The battery pack provides the "peak" power
- This presentation will discuss FC and reformer technology, and fuel selection for the transit bus application

PROGRAM HISTORY

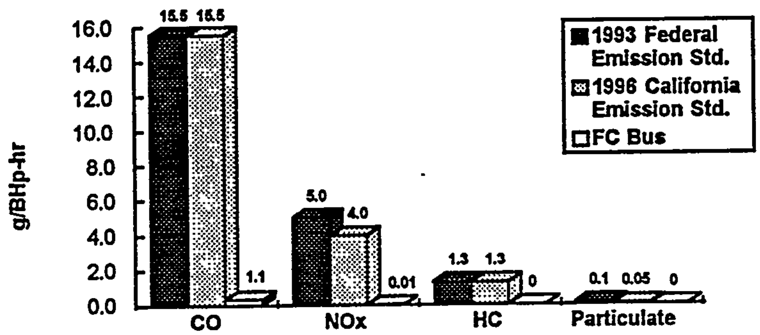


PROGRAM GOALS

- Demonstrate that FC systems can supply 100% of the energy required to successfully operate a transit bus
- Demonstrate benefits as compared to present buses
  - Higher efficiency; ie, better mileage resulting in lower fuel costs
  - Lower emissions and noise
- Develop a vehicle that meets the needs of the operator
  - No loss of performance
  - Minimum effect on present fueling infrastructure
- Demonstrate commercial viability

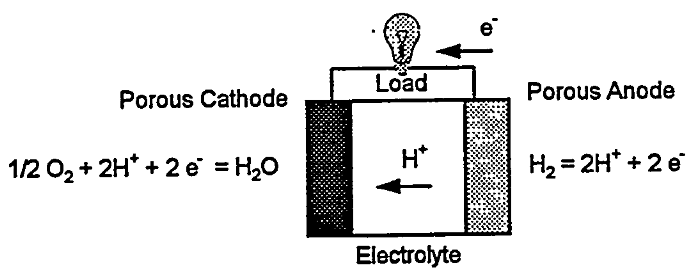
EMISSION COMPARISON

- Tested emissions for 50 kW PAFC system



WHAT IS A FUEL CELL?

- In its simplest form, a fuel cell is a solid state electrochemical device that combines H_2 & O_2 to form water and electricity



$H_2 + 1/2\, O_2 = H_2O$

THE FUEL CELL REACTANTS

- In land based FC systems, air provides the oxygen required for the electrochemical reaction
- The hydrogen required for FC operation can be stored as a gas, liquid, hydride or bound in a compound
- These hydrogen containing compounds include methane (natural gas), alcohols, hydrocarbons and ammonia
- A "Reformer" is used to break-down these compounds

REFORMERS

- The reformer liberates hydrogen by heating the compound, possibly in the presence of a catalyst, until it cracks into simpler molecules (H_2, CO_2 & CO)
- Each fuel has unique reforming requirements
  - Temperature
  - Type of catalyst
  - Dwell time in reformer
- These variables effect system design and control
  - Efficiency over the full range of outputs
  - Control of a reformer during vehicle transients

FUEL CELLS

- There are two primary types of FCs being considered for transportation applications
- The Phosphoric Acid Fuel Cell (PAFC)
  - Most developed (Over 75 utility systems in operation worldwide)
  - Proven systems (many with over 25,000 hrs)
  - Proven operation on reformed fuel (CO tolerant)
- The Proton Exchange Membrane Fuel Cell
  - Low temperature operation (quick start-up)
  - Simpler storage requirements
  - Less tolerant of CO

FUEL SELECTION

- GU initially reviewed fuel selection in the mid 80s for the 30 ft bus program and revisited many of the same issues in 1993 for the 40 ft bus program
- GU's broad knowledge of the transit and FC industries, reforming technology, and fuels allowed consideration of a variety of factors
  - Public policy
  - The customer's requirements (Transit Operators)
  - Storage and reformer technology
  - Fuel price and availability
- These issues were all considered in selecting a fuel

ISSUES THAT IMPACT FUEL SELECTION

- Public policy was determined by the funding agencies
  - Due to concerns for energy security and balance of payments, these agencies mandated the use of a domestically produced, alternative fuel
- The transit operators use centralized refueling allowing for greater flexibility in choosing a fuel
  - A trained fueling and maintenance staff
  - A controlled repeatable demand
  - Experience with many of the candidate fuels (biases)
- Refueling time and complexity must be minimized

ISSUES THAT IMPACT FUEL SELECTION

- The operators are sensitive to capital and operating costs
  - Fueling infrastructure cost
  - Zoning, above-ground equipment and noise
  - A fuel's cost per mile
- Impacts to the vehicles are also a concern
  - Increased weight
  - Decreased range
  - Changes in the vehicle's handling
  - Fuel systems that require special care (cryogenic or gaseous)

FUEL CHOICES - Hydrogen

- Direct H_2 FC systems are simpler, easier to control and more efficient than reformer based systems
- They also produce zero tailpipe emissions
- But hydrogen storage is problematic
  - Gaseous storage is heavy and requires excessive space
  - Current hydride storage technology is very heavy
  - Cryogenic storage raises cost, safety and boil-off concerns
- Limited fuel infrastructure

FUEL CHOICES - Reformed Fuels

- Candidate fuels for reforming are ammonia, natural gas, ethanol, and methanol
- Although ammonia is attractive from the storage and price standpoint, its hazardous nature will prevent use in mobile applications
- Natural gas is low cost, available throughout the country and well characterized as a reformer fuel
  - Requires a high temperature reformer and a heavy fuel storage system, which results in a significant weight penalty

FUEL CHOICES
- Reformed Fuels cont.

- Because of differences in their chemical bonds, some fuels require higher reforming temperatures than others

Low Temperature Catalytic Steam (450°F)	High Temperature Catalytic Steam (1300°F)	Partial Oxidation (>2000°F)
Methanol	Natural Gas Ethanol	Gasoline Diesel

- Typically, the higher the temperature, the more complex and less efficient the reforming process

FUEL CHOICES
- Reformed Fuels cont.

- High temperature reforming produces more CO than low temperature, requiring additional shift hardware
- Although low-temperature reforming requires the least hardware, maintaining reformer bed temperature during load transients is a system control challenge
- Due to excess heat, high temperature reforming requires a less complex control system to follow transient power demands
- This excess heat must be recovered for high efficiency

FUEL CHOICES
- Price and Availability

- H_2 price is difficult to asses
  - It is not sold as a commodity
  - Limited availability increases transportation costs
  - Compression or liquefaction requires additional energy
- Although ethanol contains 30% more energy than methanol, its market price is typically 1.5-3 times higher
  - Both liquid fuels are produced in various parts of the country and are easily transportable
  - Since both are commodities, their price fluctuates

SUMMARY OF FUEL SELECTION ISSUES

	H_2	Ethanol	Methanol
FC System Weight	○	●	⊙
Fuel System Weight	●	○	⊙
FC System Efficiency	○	●	⊙
Retraining (Transit)	●	⊙	⊙
Capital Cost (Transit)	●	○	⊙
Fuel Cost	⊙	●	⊙
Fuel Availability	●	⊙	⊙

Good ○ Fair ⊙ Major Concern ●

FUEL CELL BUS SYSTEMS - 30 ft Bus

- Three 30 ft test bed buses are being tested in different parts of the country to verify performance, emissions and fuel efficiency
- The bus design consists of
  - A Fuji Electric 50 kW oil-cooled PAFC
  - A low temperature steam reformer for methanol fuel
  - A 100 kW SAFT NiCd battery pack with 180 amp-hr capacity
  - A 120 kW (peak) DC electric motor
- Areas of concern include bus weight, FC response and system control algorithms

FUEL CELL BUS SYSTEMS - 40 ft Buses

- GU has received a grant from the Federal Transit Administration to design and fabricate two 40 ft FC powered hybrid transit buses
- Both buses will use a methanol fueled 100 kW FC system and a 125 kW battery pack
- The first bus will be a preproduction prototype
  - IFC 100 kW PAFC and compact high temperature steam reformer
  - Idle to 100% output in less then 5 seconds
  - Water recovery
  - Proven production utility-stack design (PC25)

FUEL CELL BUS SYSTEMS - 40 ft Buses cont.

- The second bus will be powered by a PEMFC system being designed by Ballard Power Corporation
- The PEMFC system will make use of existing technology being used on other projects
  - High power density stack
  - An oil-heated low temperature steam reformer
  - Hydrogen separation membrane technology for removal of CO
- Both PAFC and PEMFC systems are projected to be more than 38% efficient with significant improvements in power density compared to the 30 ft bus systems

SUMMARY

- For near-term commercialization of FC systems for transit buses, methanol continues to be the fuel of choice
  - It has none of the storage problems of gaseous fuels
  - It has minimal infrastructure impact on the transit operator
  - It has a price and ease of reforming advantage over ethanol

SESSION 8

PANEL DISCUSSION

CALIFORNIA ZEV COMMERCIALIZATION EFFORTS

Moderator: Juan Osborn
California Air Resources Board

Presentation - Lois Wright, Sacramento Municipal Utility District

(Other presentations unavailable at time of publication)

California's Clean Cities

ELECTRIC VEHICLE INCENTIVE PROGRAM

Lois Wright

Electric Transportation Department
Sacramento Municipal Utility District

Program Goals

- ➢ Accelerated introduction of electric vehicles
- ➢ Market-based approach
- ➢ Uniform level of incentive statewide
- ➢ Fuel diversity
- ➢ Energy security
- ➢ Air quality
- ➢ Economic development

Program Opportunity Notice

- $250,000 available (US Dept. of Energy)
- Proposals requested from local air districts
- Required elements
  - "Clean Cities" designation or application
  - 50:50 match
  - $5,000 incentive level

Air District Participants

➤ Sacramento	$50K
➤ San Francisco Bay Area	$50K
➤ Santa Barbara	$50K
➤ San Diego	$50K
➤ Ventura	$25K

- ➤ Note: Additional $25K reserved for first Air District to award all of its funds

Administrative Options

- Sale or lease is eligible
- $5,000 incentive is payable to
  - purchaser / consumer
  - retail dealership
  - auto manufacturer

Rebate vs. "Buy Down"

	Consumer	Manufacturer
EV Purchase Price	$30,000	$30,000
Buy Down	-	($5,000)
Sales Tax @ 8%	$2,400	$2,000
Federal Tax Credit	($3,000)	($2,500)
Rebate	($5,000)	-
Income Tax on Rebate @ 28%	$1,400	-
Net EV Cost	**$25,800**	**$24,500**

Vehicle Eligibility Requirements

- Light Duty (<8500 lbs. GVW)
- Certified as Zero Emission Vehicle (ZEV)
  - by the CA Air Resources Board
- Meet EV America performance goals
- Meet Federal Motor Vehicle Safety Standards (FMVSS)

EV America Performance Goals (at 50% state of charge)

- Acceleration: 0-50 mph in 13.5 seconds
- Minimum Top Speed: 70 mph
- Gradeability: 3% @ 55 mph; 6% @ 45 mph
- Gradeability: start & ascend a 25% grade
- Range: 50 mile minimum
- Heat Durability: 120 degrees F. ambient air
- Water Durability: 20 mph in 2” of water

Air District Responsibilities

- Publicize the program
- Verify customer's eligibility
- Verify vehicle's eligibility
- Collect data from selected EV customers

$642K: Funding Sources

- $250K US Dept. of Energy
- $250K Local air districts (matching funds)
- $112K Redirected CEC-SMUD contract
  - for Sacramento incentives
- $ 30K Separate allocation
  - by Yolo-Solano Air District for incentives

Term of program

- Incentives available as of July 1, 1996
- EV purchases must be completed and invoices submitted by June 30, 1997

Summary

- Promotes successful commercialization of EVs in CA
- Establishes uniform incentive level statewide
- Increases enthusiam of Clean Cities Stakeholders for EVs
- Leverages limited funds effectively

Future Activities

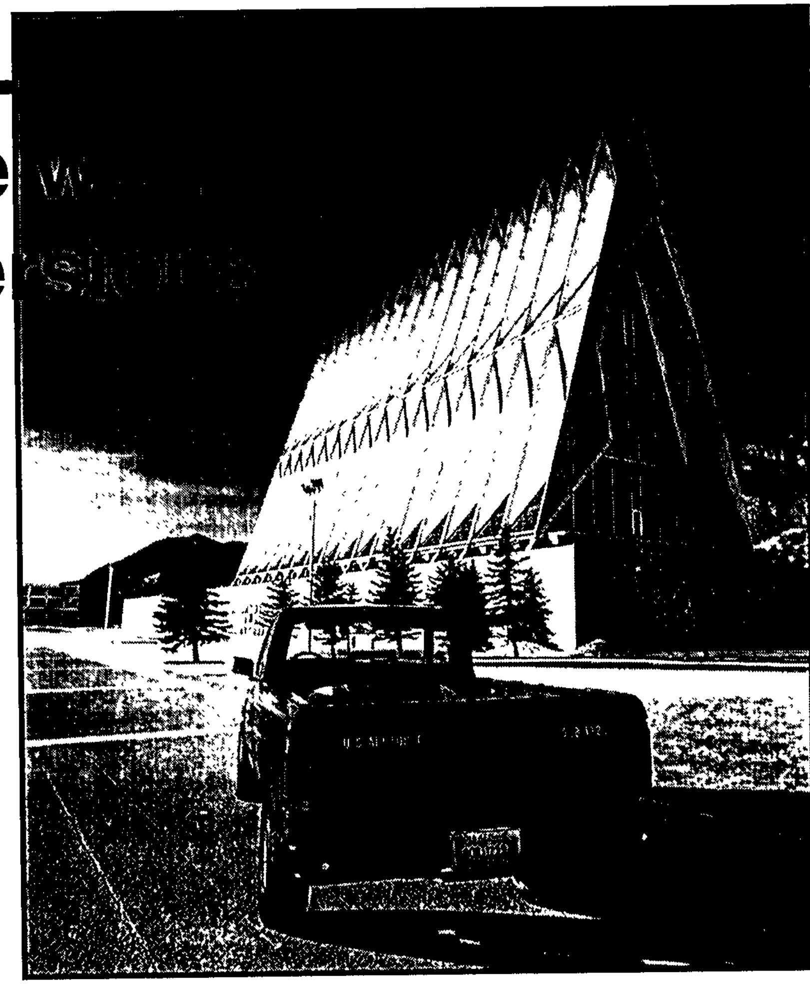
- Augment incentive program for EVs
- Develop incentive program for advanced batteries

SESSION 9

IN-USE EXPERIENCE

Chair: **Brent Bailey, National Renewable Energy Laboratory**

NREL's Experience
Aftermarket Conve



Robert C. Motta
Kenneth J. Kelly
William W. Warnock

Windsor Workshop
on Alternative Fuels

Toronto, Canada
June 3–5, 1996

SQP4-B119401

Center for Transportation Technologies and Systems

Sponsored by the U.S. Department of Energy Office of Transportation Technologies

SQP4-B119402

Presentation Overview

- Program objectives/basis
- Steps to high quality conversions
- Results
  - Meeting EPACT requirements
  - Evaluating performance
- Summary of conclusions

Objective

- Assist Federal government in meeting the alternative fuel vehicle purchase requirements of the Energy Policy Act (EPACT) of 1992
- Ensure high-quality equipment and installations
- Evaluate performance
  - Emissions tests
  - Driver surveys

Energy Policy Act of 1992

AFV Purchase Requirements

FY 1993	5,000
FY 1994	7,500
FY 1995	10,000
FY 1996	25%
FY 1997	33%
FY 1998	50%
FY 1999	75%

Typical annual Federal vehicle purchases

- 50,000 at the start of the program
- 35,000 after Federal downsizing

1992 OEM Vehicle Availability

Manufacturer	Model	Body Style	Fuel	Type
Chrysler-Dodge	Ram van/wagon	Full-size van	CNG	Dedicated
GM-Chevrolet	C1500/C2500	Full-size pickup	CNG	Bi-fuel
GM-Chevrolet	Lumina	Mid-size sedan	Ethanol	Flex-fuel
Ford	F700	Medium-duty truck	LPG	Dedicated

Two light-duty CNG models: one van and one pickup

Steps to High Quality Conversions

1. Conversion Company
2. Hardware Requirements (Equipment and Technology)
3. Installation Procedures
4. Warranty and Training
5. Emissions and Performance Requirements

SQP4-B119408

Center for Transportation Technologies and Systems

Steps to High Quality Conversions

Conversion Company

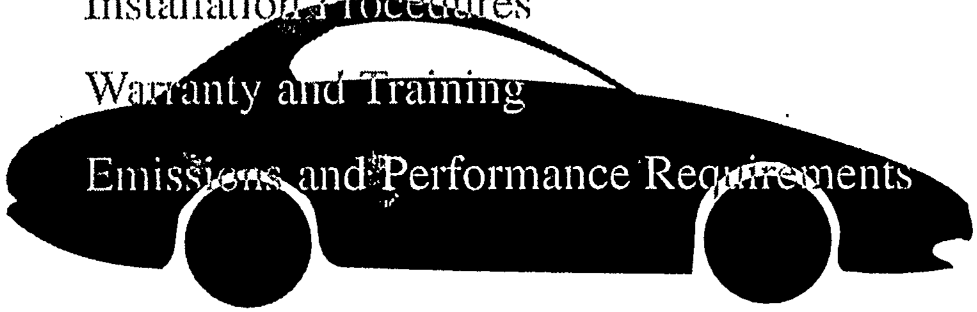
- **Competitive Procurement/Evaluation Criteria**
  - **70% Technical Merit**
  - **30% Cost**

Hardware Requirements (Equipment and Technology)

Installation Procedures

Warranty and Training

Emissions and Performance Requirements



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Steps to High Quality Conversions

Hardware Requirements (Equipment and Technology)

- **Closed loop feedback control**
- **AGA NGV2 Fuel cylinders - CNG**

Installation Procedures

Warranty and Training

Emissions and Performance Requirements

Conversion Company

Steps to High Quality Conversions

Installation Procedures

- **Best Industry Practice - NFPA Standards**
- **On-site inspection by NREL**

Warranty and Training

Emissions and Performance Requirements

Hardware Requirements (Equipment and Technology)

Conversion Company

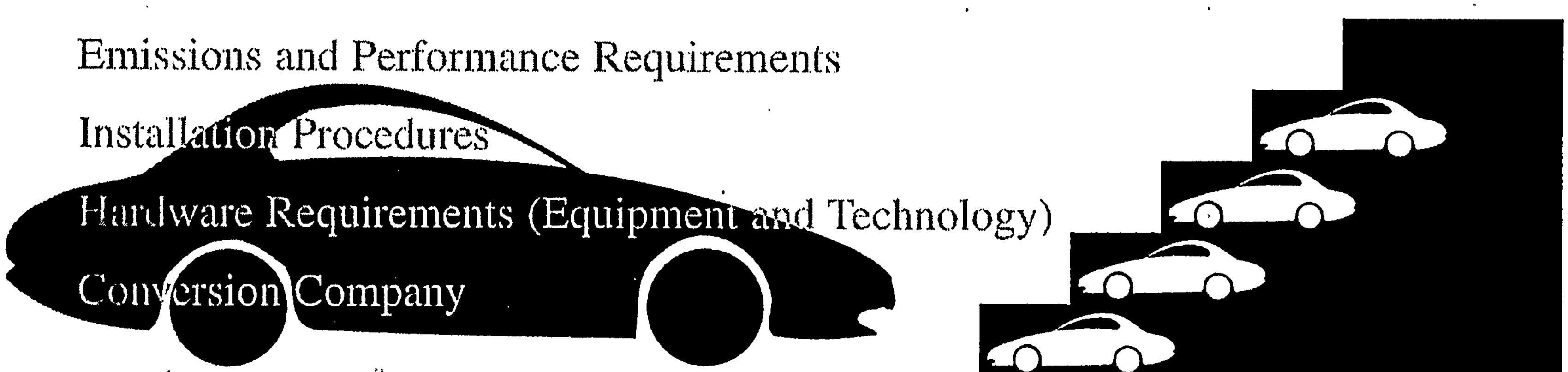
SQP4-B119411

Center for Transportation Technologies and Systems

Steps to High Quality Conversions

Warranty and Training

- **3 years/36,000 miles conversion system parts and labor**
- **Damages to OEM equipment**
- **Training site personnel**



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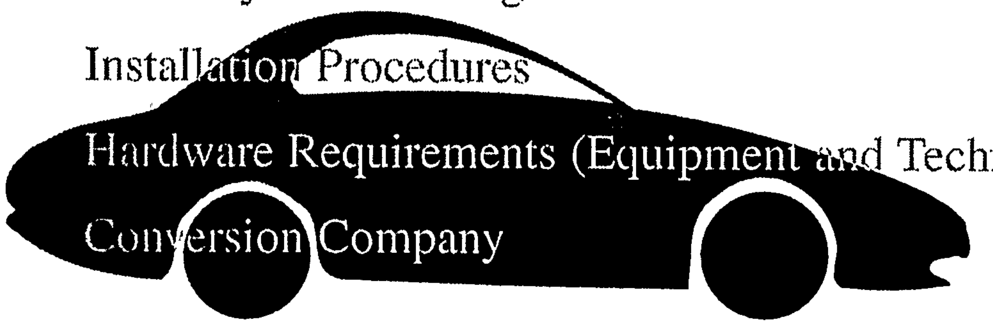
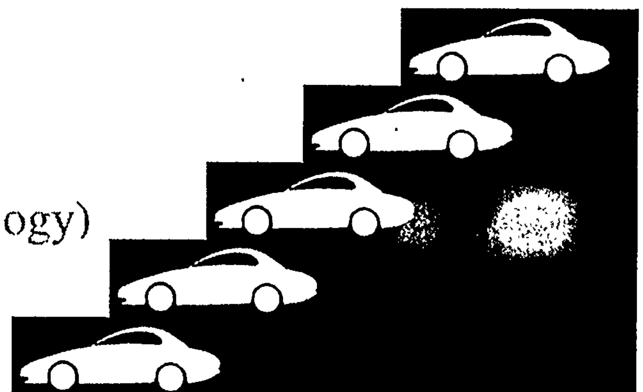
Steps to High Quality Conversions

Emissions and Performance Requirements

- Applicable emissions standards (EPA/CARB)
- CNG range > 70 miles; LPG range > 170 miles
- Initial conversions test driven by NREL
- Emissions tests and driver surveys





SQP4-B119413

Center for Transportation Technologies and Systems

Results

880 High-Quality Conversions in the Federal Fleet

SQP4-B119414

Center for Transportation Technologies and Systems

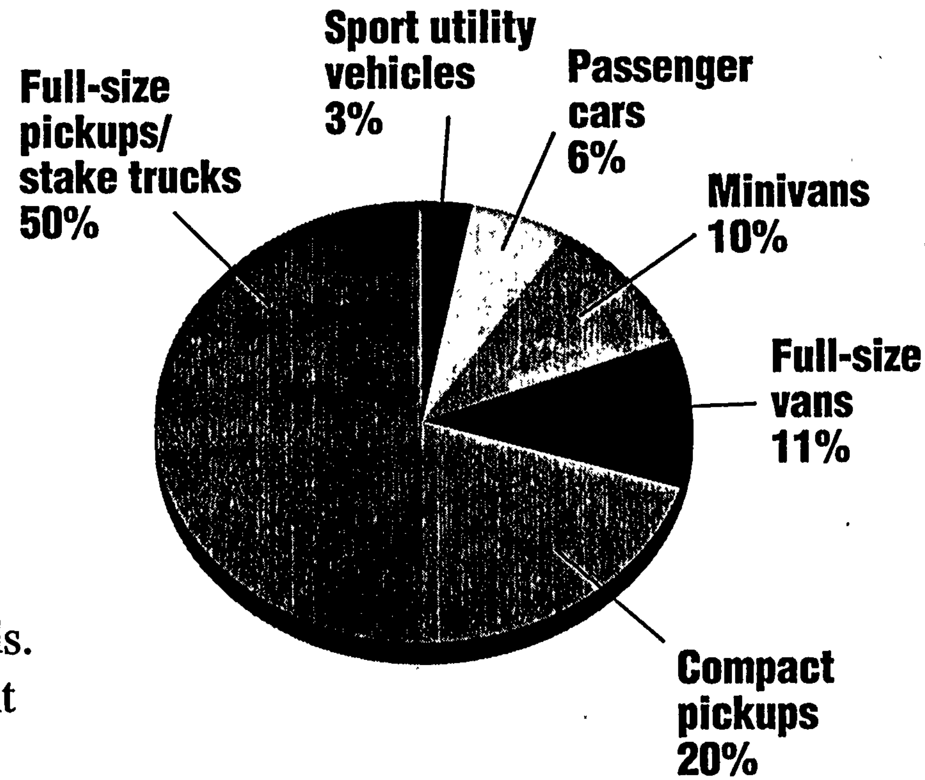
Results

- Conversion Kit Selections
  - CNG: GFI and IMPCO kits
  - LPG: IMPCO ADP kits
- Average System Cost
  - CNG: $4,500
  - LPG: $2,800

Results

90 % Vans or Pickups

90% Bi-fuel



Note: Type of vehicles converted was based on fleet demands. They closely follow current OEM availability

SQP4-B119416

Center for Transportation Technologies and Systems

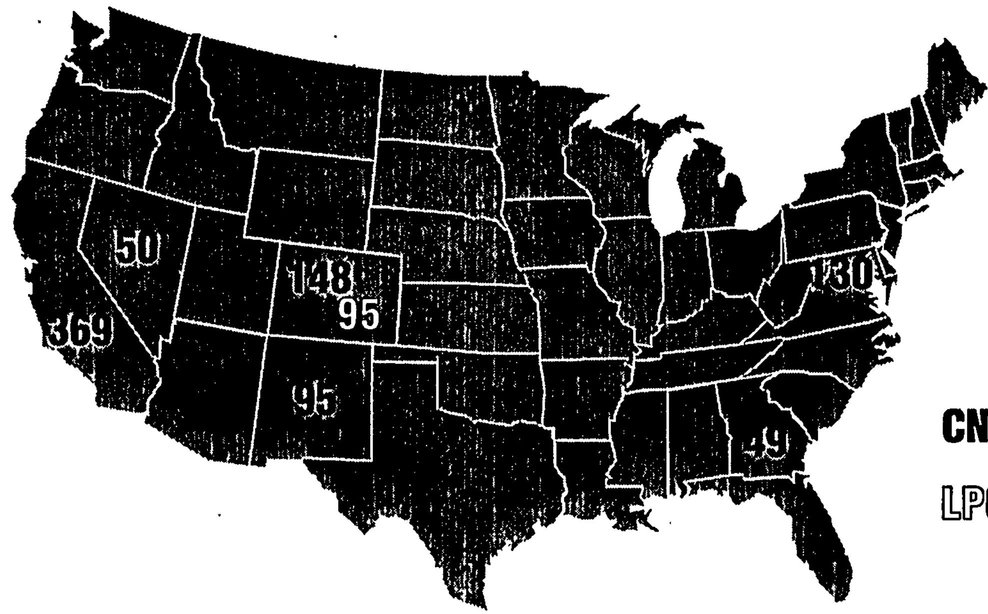
1996 OEM Vehicle Availability

Manufacturer	Model	Body Style	Fuel	Type
Chrysler-Dodge	Ram van/wagon	Full-size van	CNG	Dedicated
Chrysler-Dodge	Ram pickup	Full-size pickup	CNG	Dedicated
Chrysler-Dodge/ Plymouth	Caravan/Voyager	Minivan	CNG	Dedicated
Ford	Contour	Compact sedan	CNG	Bi-fuel
Ford	Taurus	Mid-size sedan	Methanol	Flex-fuel
Ford	Taurus	Mid-size sedan	Ethanol	Flex-fuel
Ford	Crown Victoria	Full-size sedan	CNG	Dedicated
Ford	F150/F250	Full-size pickup	CNG	Bi-fuel
Ford	Econoline	Full-size van	CNG	Bi-fuel
Ford	F150/F250	Full-size pickup	LPG	Bi-Fuel
Ford	F700	Medium-duty truck	LPG	Dedicated

Eight light-duty CNG/LPG models available

Results

Placement of CNG/LPG vehicles in six states Including nine Clean Cities



CNG Conversions

LPG Conversions

SQP4-B119418

Center for Transportation Technologies and Systems

Results

Variety of Federal Agencies

Agency	CNG	LPG	Total Vehicles
Air Force	368	0	368
Marines	219	0	219
Navy	97	0	97
National Institutes of Health	66	0	66
Forest Service	2	24	26
Other Federal Agencies	89	15	104
Totals	841	39	880

Emissions Testing

- Part of larger evaluation program
- 8 models/16 vehicles tested
- Specially blended test fuels
    - CNG—93% methane
    - LPG—HD5 transportation fuel
    - RFG—California Phase II reformulated gasoline
- EPA Federal Test Procedures
    - RFG before conversion
    - RFG shortly after conversion
    - CNG/LPG shortly after conversion

Importance of Evaluating Aftermarket Conversions

- 330,000 on the road
- 10,000 conversions per year

Emissions Results Legend

○	Large emissions decrease (>50%)
◒	Moderate emissions decrease (10%–50%)
NC	No change (<10%)
◓	Moderate emissions increase (10%–50%)
●	Large emissions increase (>50%)

Emissions Results:

Washington, D.C. CNG Conversion Vehicles—**Kit make: GFI**

Vehicle Model	Model Year	After Conversion (RFG) NO_X	After Conversion (RFG) CO	After Conversion (RFG) NMHC	After Conversion (CNG) NO_X	After Conversion (CNG) CO	After Conversion (CNG) NMHC
Acclaim	1992	NC	◒	◒	●	○	○
Acclaim	1992	NC	◓	NC	●	◒	◒
Astro	1992	◒	NC	NC	◒	●	◒
Caravan	1992	◒	●	◓	●	●	◒
Caravan	1992	◒	◒	NC	●	●	◒
Safari	1993	NC	◒	NC	◒	NC	○
Safari	1993	NC	◒	◒	◒	◒	○
Taurus	1994	◓	NC	◒	●	●	NC
Taurus	1994	NC	◓	◓	●	●	NC

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Emissions Results:

Denver. CNG Conversion Vehicles—**Kit make: GFI**

Vehicle Model	Model Year	After Conversion (RFG) NO_x	After Conversion (RFG) CO	After Conversion (RFG) NMHC	After Conversion (CNG) NO_x	After Conversion (CNG) CO	After Conversion (CNG) NMHC
B250	1994	NC	NC	NC	◒	◓	○
B250	1994	◒	NC	NC	◒	●	○
C1500	1994	NC	◒	NC	◒	●	○
C1500	1994	NC	NC	NC	◒	●	○

Emissions Results:

Denver LPG Conversion Vehicles—**Kit make and model: IMPCO ADP**

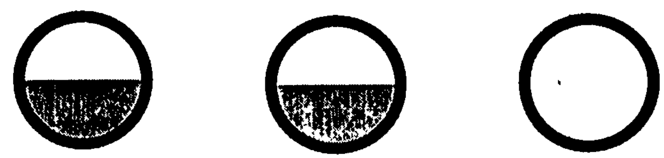
Vehicle Model	Model Year	After Conversion (RFG) NO_x	After Conversion (RFG) CO	After Conversion (RFG) NMHC	After Conversion (CNG) NO_x	After Conversion (CNG) CO	After Conversion (CNG) NMHC
F150 pkup	1994	◒	●	●	NC	○	●
F150 pkup	1994	NC	●	●	NC	○	●
Taurus	1994	NC	◒	NC	●	○	◓

OEM Results: Dodge B250 Van

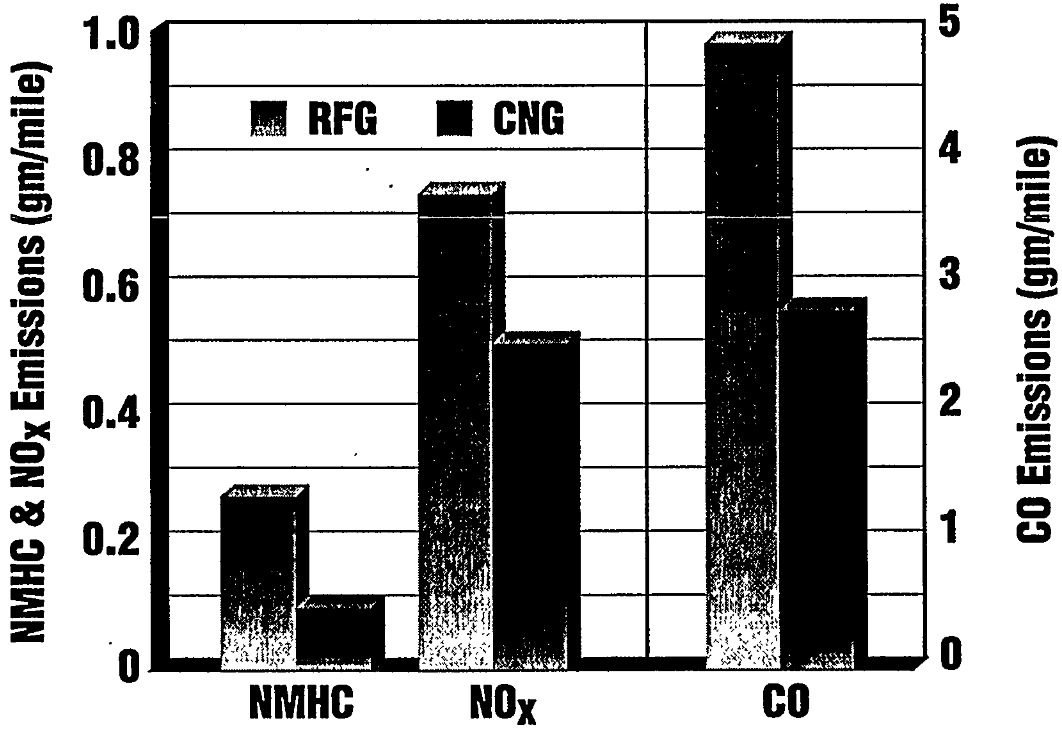
Dedicated CNG versus Standard Gasoline

Average of approximately 40 of each

NO_x	CO	NMHC
-30%	-40%	-70%



OEM Results: Dodge B250 Van



Emissions Test Results -
Other Considerations for Aftermarket Conversions

- Potential Positives
  - Ozone-forming potential
  - Exhaust toxics/particulate matter
  - Off-cycle emissions considerations
- Potential Negatives
  - Conversion of new, relatively clean (Tier 1) models
  - Use of less advanced kits (non-feedback)
  - Poor/untested installations
  - Deterioration

Conclusions

- Program was successful in helping to meet EPACT requirements
- Developed a systematic approach for fleets to ensure "high-quality" conversions
- Emissions results from conversions have raised some serious concerns
- OEM tests show emissions benefits "across the board"
- Fleets should require verification of emissions performance with FTP testing when considering aftermarket conversions
- Initial driver survey data are currently being tabulated