Evaluation of Bi-Fueled Vehicles as an Alternative for Work-Trip and Business Commutes

Report 2

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16. Abstract

In 1998 a research was initiated to gather field data and performance information on alternative fueled vehicles (Electric and Compressed Natural Gas Vehicles) to assist the State and Federal Officials in complying with the Energy Policy and Conservation Act of 1992. This report focuses on ConnDOT’s experience with a 1998 bi-fueled compressed natural gas (CNG) Chevy Cavalier sedan. The car was part of the state fleet. It was operated under various weather conditions, trip lengths, and fuel types to document the performance, practicality, and limitations of operating this type of vehicle in Connecticut. From November 1998 to May 2003, the Research staff accumulated 27,000 miles on the subject vehicle. Forty percent of the weekly mileage driven was well within the CNG tank capacity range. If the CNG tank was fueled prior to each individual trip, 90 percent of all trips recorded in the 55-month time frame were within the range of the CNG-tank’s capacity. A majority of the trips taken were less than 30 miles in length. Overall CNG fuel economy was 25.6 MPG. The automobile manufacturer made several changes to the standard Chevy Cavalier (reduction in both trunk and fuel tank sizes) to equip this vehicle with the bi-fuel system and improve its fuel efficiency over the years. Production of the bi-fuel Chevy Cavalier was discontinued after the 2004 model year.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

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Background

The Department of Administrative Services (DAS) is charged with the responsibility of providing vehicles to all the state agencies in Connecticut. In 2005, the State fleet size was 4,041 vehicles. The Department of Transportation (Department) was assigned 221 fleet vehicles which consist of: 129 compact passenger cars, 1 compact sport utility vehicle (SUV), 13 compact trucks, 43 midsize passenger cars, 17 midsize SUVs, 9 minivans, 6 midsize wagons, 2 full size trucks and 1 full size passenger car. /1/

In addition to the fleet vehicles provided by DAS, the DOT owned and operated an additional 2,099 specialty vehicles consisting of: 528 buses; 713 dump trucks; 344 pickups; 251 specialty vehicles; 172 vans (cargo and passenger vans); 72 sport utility vehicles (SUV's) and Suburbans; and 19 cars in order to provide its mandated services. /2/

Both DAS and the Department are required to comply with U.S. Department of Energy (DOE) regulations delineated in the 1992 Energy Policy and Conservation Act (EPACT) 10 CFR Part 490. In states failing to meet certain air quality standards, the law requires government agencies with vehicle fleets, to purchase specified minimum percentages of cars and light trucks each year that operate on fuel other than gasoline or diesel. EPACT excluded emergency vehicles. The primary goal of this alternative-fueled vehicle acquisition requirement is to reduce dependency on foreign oil and thereby strengthen US energy security. Further legislation mandated by the Environmental Protection Agency (EPA) regarding fleet acquisition programs also address the alternative fuel subject, to reduce emissions of pollutants, thus improving the nation’s air quality in identified ozone or carbon monoxide non attainment areas. In 1996, DOE regulations were modified to 1) shift the initial model year up one year; 2) create a state alternative plan exemption process; 3) refine the acquisition requirements for alternative fuel provider; 4) add biodiesel to the list of alternative fuels; and 5) address provisions for allocation of credits. In 1998, DAS purchased 70 dual-fuel compressed natural gas (CNG)/gasoline four-door sedans to meet the 15 percent requirement. /1/ DAS purchased additional dual-fuel CNG/gasoline four-door sedans in 1999 and 2000 to comply with the 25 and 50 percent requirements of EPACT. After 2000, EPACT requirements were met with a combination of dual-fuel CNG/gasoline vehicles and flex-fuel vehicles capable of running on an E85 Ethanol/gasoline blend.

Nationally, in 2000, alternative-fuel consumption was 0.2 percent of fuels consumed in the US. CNG represented 29.5 percent of estimated consumption of alternative fuels in the US. /5/

In 1998, the Department initiated research project SPR-2223, titled “Evaluation of Alternative Fuel Light Trucks and Automobiles,” to gather field data and performance information on vehicles operated in Connecticut that are powered from electricity and Compressed Natural Gas. Project reports inform State-fleet and Federal officials that are responsible for compliance with the Energy Policy and Conservation Act (Section 507 (o)) of 1992.

This report presents the results of an observational study on bi-fueled compressed natural gas (CNG) vehicles operated in Connecticut under various weather conditions, trip lengths, and fuel types to document the performance, practicality, and limitations of this type of vehicle. The driver’s experiences in operating this type of vehicle were documented. Vehicle-usage data were evaluated to derive the benefits of operating a CNG vehicle and develop findings to inform State-fleet officials.

Observational Study Approach

In November 1998, the Division of Research was assigned a bi-fueled Chevy Cavalier (1998 model year) sedan from DAS for this research project. At that time, the Cavalier was the lowest priced sedan available that operated on natural gas. /3/ The Chevy Cavalier, with 55,000 miles on the odometer, had never operated on natural gas prior to this study. The vehicle was driven on several trips utilizing CNG prior to collecting performance data for this study, to ensure the alternative fuel system was functioning properly. The Cavalier was parked nightly in an outside lot at the Department’s Research and Materials Testing Facility located in the Town of Rocky Hill. The vehicle was available to 36 employees for any business travel. For each business trip event, the driver recorded trip destination(s) by town name, beginning and ending mileage, amount and type of fuel obtained, and the corresponding vehicle mileage at the time of fueling. Drivers were instructed to record their observations, such as the fuel-type-switchover mileage point, whether the vehicle’s air conditioning was operating during the trip, and air temperature when filling the natural gas tank. Toward the end of the research-data collection period, controlled trips were conducted to measure the engine’s fuel efficiency for both fuel types (natural gas and unleaded gasoline). The research staff logged over 27,000 miles on this vehicle during the evaluation period from November 1998 to May 2003 (55 months), or about 490 miles per month. Data collection ended in May 2003, after a statewide vehicle usage study, conducted by DAS, concluded that all vehicles driven less than 1,000 miles per month would be returned to the State fleet and reassigned or sold.

In July 2004, prior to analyzing the data from 55 months of general usage, a second bi-fueled Chevy Cavalier was provided by the motor pool for one month of additional tests. The vehicle was utilized by the Principal Investigator (PI) to conduct a series of drives following a fixed course, for the purpose of solidifying the PI's understanding of the technology and operating characteristics of a bi-fuel vehicle. These trips were replicated three times. The data collected during these trips were used to characterize city and highway mileage, and the corresponding CNG range was observed on each trip. Additional fuel tank capacity data were collected to better understand the variability of CNG fuel-tank storage capacity in the Cavalier. Each trip length was defined by the distance driven to consume all CNG pumped into the tank just prior to the drive.

Photo 1 - Bi-fueled Chevy Cavalier

Photo 2 - CNG Bi-fuel System

Description of the Bi-fuel Chevrolet Cavalier

The Chevrolet Cavalier is powered by a 2.2 L, 4 cylinder engine equipped with an original-equipment manufacturer's alternative fuel system (bi-fuel option). The bi-fuel system allows the vehicle to function on either compressed natural gas (CNG) or unleaded gasoline. The engine automatically starts on natural gas if that fuel is present. The combustion system is designed to automatically switch over to gasoline when the natural gas tank is empty. A dash board light is provided to indicate which fuel the vehicle is using. Otherwise, dash board instrumentation is indistinguishable from a conventional Cavalier (Photo 3).

The vehicle's CNG fuel tank is located in the trunk. The maximum capacity of the tank is 6.99 GGE (Gasoline Gallon Equivalent) at 3,600 psi pump pressure and air temperature of 70°F. The automotive industry has developed the GGE unit of measure to allow for easy comparison of alternative fuels with gasoline. By definition, one equivalent gallon of gasoline is equal to 121.5 cubic feet of CNG (www.fueleconomy.gov).

The vehicle’s unleaded gasoline fuel was stored in a standard 15.2 gallon fuel tank.

The 2.2L engine provides 130 lbs-ft torque at 4,000 rpm when burning CNG Fuel, and 150 lbs-ft of torque at the same rpm when utilizing gasoline. No special maintenance or repairs were performed on the vehicle’s alternative fuel system during this evaluation period.

Photo 3 - View of the CNG Cavalier’s Dashboard Instrument Panel

A. General Observations:

SAE International reported that the 1998 Cavalier CNG bi-fuel sedan, while operating on CNG, was observed to emit lower non-methane organic gases, carbon monoxide, nitric oxide emissions than when running on gasoline. The fuel economy difference on an energy equivalence basis was found to be small. /6/

We observed that while operating in CNG mode, it was difficult for the driver to know how far the car could be driven on CNG. As seen in Photo 3, the Cavalier’s dashboard provides a single dual-purpose fuel gage to inform the driver. Tank capacity for CNG is 6.2 GGE, however, two other variables determine how much CNG can be pumped into the tank, making it difficult to estimate remaining range on CNG based on fuel gauge readings (full, 3/4, 1/2, and 1/4). This same fuel gage scale, while operating on gasoline, indicates the level of gasoline remaining in the 15.5 gallon tank.

Table 1 - Fuel display for CNG and remaining distance vehicle can be driven on CNG

Driver Display Gauge	Remaining CNG "Gallons" (GGE) @ 3600 psi, 70°F	Remaining Range @ 17 mpg (city)	Remaining Range (highway) @ 30 mpg
0	0.5	9	15
¼	1.9	32	57
½	3.4 gal	58	102
¾	4.8	82	144
Full	6.2	105	186

At the moment when the primary fuel (CNG) is depleted as indicated by the fuel gage, the vehicle will operate on CNG for an additional 6 to 10 miles. At that point, the engine's fuel system automatically switches over to function on the secondary fuel (unleaded gasoline). The switch over is accompanied by a distinct "pop" sound, followed by the fuel gage needle gradually rising to indicate the amount of gasoline in the gas tank. The car was driven three to four miles before the fuel-gauge adjustment was complete and the gauge then displayed the amount of gasoline remaining in the 15-gallon tank.

Photo(s) 4 and 5 - Views of the Cavalier's Trunk Space

The CNG fuel tank is mounted in the trunk of the bi-fuel Chevy Cavalier. The tank occupies approximately half the available cargo area, as compared to the trunk space in a standard Cavalier. The bi-fuel model's trunk provides a meager 6.6 cubic feet of cargo space (Photos 4 & 5). As can be seen in Photo 5, a full-size spare tire further reduces the cargo-carrying capacity of the trunk.

B. Refueling Observations:

Photos 6 and 7 - Views of CNG Fuel Port Connection Located Beneath Driver's Side Tail Light

The CNG pump-station hose is equipped with a positive-connect pressure fitting that locks onto the vehicle's fuel port. This type of fitting is relatively simple to manipulate (See Photos 6 & 7). To connect the pump station hose, you must pull back on the outer coupler while simultaneously pushing the fitting into the car's fuel port.

Once you release the outer coupler, the pressure fitting locks onto the fuel port. After filling, the process is reversed to remove the hose pressure fitting from the car’s fuel port. Directions are posted on the pump at every CNG fueling station.

Refueling at the same filling station, researchers observed that the CNG tank’s capacity varied by as much as 22 percent. From nine fuelings in July 2004, the storage capacity ranged from 3.89 to 4.77 GGE to fill an empty tank. The Cavalier’s CNG tank had an average capacity of 4.4 GGE, plus or minus 1/3 GGE.

The Chevrolet Cavalier owner’s manual states that CNG-fuel-tank capacity is dependant on three factors at the time of fueling, which are: station’s fuel pump pressure, fuel pumping speed and ambient air temperature at time of fueling. Standard CNG pump pressure is 3,600 psi. However, some gas stations provide 3,000 psi or 2,700 psi pressure at their pumps. Lower fuel pressure reduces vehicle range. For example, filling at 3,000 psi would reduce driving range by 15 percent. The rate of fuel delivery can either be fast or a slow. The fast speed delivery (similar to the traditional gas pump fueling time) of natural gas generates internal friction within the gas, raising its temperature. As temperature of CNG increases, its volume expands and can reduce the amount of CNG in the tank by as much as 15 percent. A slow fill process is defined as a fueling that typically requires six to twelve hours to refill the tank.

Ambient air temperature will influence that amount of CNG provided, but no guidance on the amount of reduction is provided by

Chevrolet. Today, modern fuel-pump-station equipment adjusts the delivery pressure to compensate for ambient temperature.

For all dedicated-fuel trips in July 2004, CNG fuel was obtained from the same distributor located on Brainard Road in Hartford. The same fuel pump was selected supplying the CNG at 3600 p.s.i. with a fast-fill delivery system.

Ambient air temperature was the only variable not held constant. The CNG tank's theoretical storage capacity for this 6.2 gallon CNG tank with the maximum reduction for fast speed fuel delivery is 5.27 GGE. The amount of CNG obtained varied from 3.89 to 4.77 GGE to fill an empty tank. The average amount obtained was 4.41 GGE. The amount of fuel obtained was from 10% to 22% less than the anticipated CNG storage tank capacity.

During July 2004, the CNG tank was filled twice from the same pump station on the same day. Between fillings, the ambient air temperature rose from 55 F to 80 F, resulting in a net reduction of 0.077 GGE supplied (1.87 % reduction). Based on this one observation, 25-degree change in ambient air temperature didn't have much effect on tank capacity, illustrating that the fuel-pump-station equipment is adjusting its delivery pressure to compensate for ambient temperatures.

In order for the CNG vehicle to be a viable alternative, public refueling stations must be readily available to the public. In 2001, the Department of Energy reported that there were approximately 600 public CNG refueling stations in the entire country. /4/ Availability of CNG public refueling stations in Connecticut is very limited. A search for alternative fuels stations within a 70 mile radius of the Rocky Hill Research Facility revealed there are 25 refueling stations (see appendix A Results from a Alternative Fuel Data Center Query). However, only three of these facilities are open to the general public. They are located in the towns of Hartford, East Norwalk, and Greenwich. There are seven additional fueling stations open to the public with restrictions, such as call ahead or card key requirements.

Purchasing a bi-fuel vehicle doesn’t guarantee it will be operating on CNG. Federal regulations only require the state to report the number of alternative fueled vehicles purchased for a given model year.

Vehicle Usage Observations for Period 1998 to 2003

In November 1998, the Division of Research received a 1998 bi-fuel Chevy Cavalier for use as a unit fleet vehicle. Over the next 55 months, the vehicle’s daily trip data and fuel consumption was documented by the staff (Normal Department Policy) while traveling on state business. For each trip, the driver was responsible for documenting the trip destination by town name, beginning and ending mileage, amount and type of fuel obtained, and the vehicle’s odometer reading at the time of fueling. This information was compiled and examined to document the vehicle’s performance and determine if this type of alternative fuel vehicle could meet the unit’s operational needs.

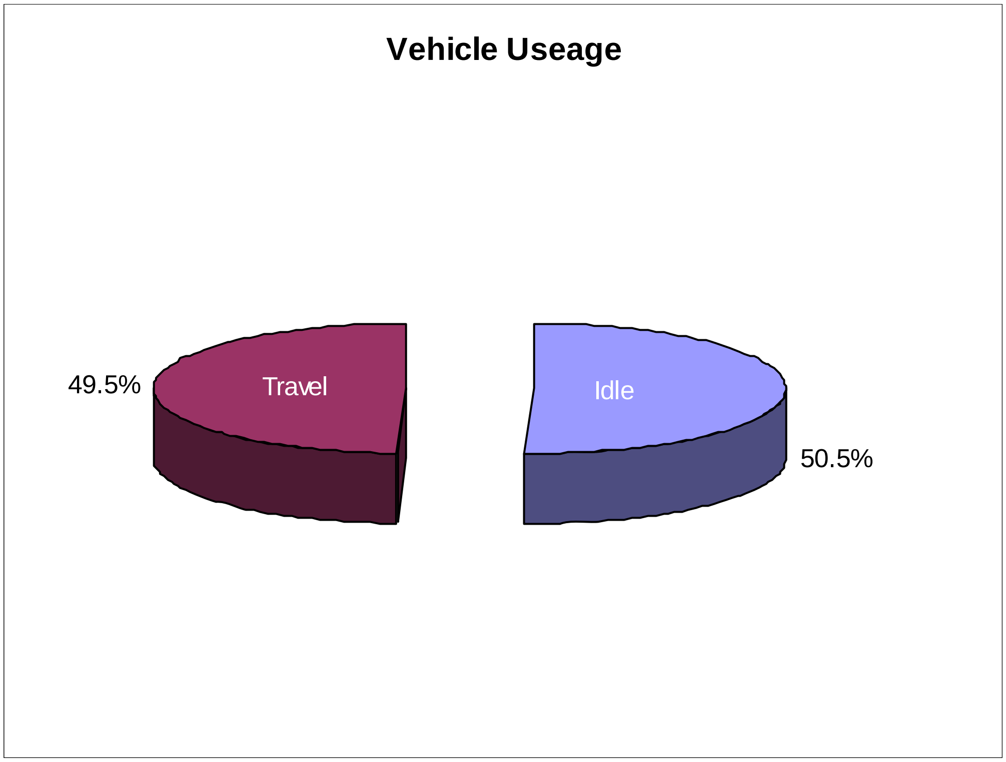

Figure 1 CNG vehicle was driven on half of the days, over the 55-month study

During the study period, November 1998 to May 2003, the vehicle was utilized on 553 business days for at least one trip each day, which represents 49.5 percent of the State business days during the study period. For the remaining 50.5% of the State business days, the vehicle was parked in the facility’s outdoor parking lot. Of the 553 days, there were only 73 days when the vehicle was driven by a different driver for a second trip on a particular day. On 34 occasions, the vehicle was signed out for three separate business trips on the same day. Predominately the vehicle was utilized for one trip per day. The amount of vehicle usage may have been influenced by four factors as part of this study. Firstly, the drivers volunteered to drive this vehicle and provide comments regarding their experience. Secondly, the 36 Office of Research and Materials (ORM) employees had five other fleet vehicles to select from, and so could avoid driving the ‘study vehicle.’ Thirdly, examination of the Cavalier’s log book indicates extremely low vehicle usage for many individuals. There were nineteen staff members who signed out this vehicle for fewer than 10 occasions, which can be interpreted to mean either that staff members may have been reluctant to operate this type of vehicle or had few business travel needs during the study period. Fifty percent of the mileage accumulated on the study vehicle was the result of three personnel operating this vehicle for state business. ORM’s fleet vehicle usage records were not examined to determine the impact on usage of other vehicles after the study vehicle was added to the pool. A fourth factor may have been the lack of mandatory training on how to operate and re-fuel a dual-fuel CNG/gasoline automobile.

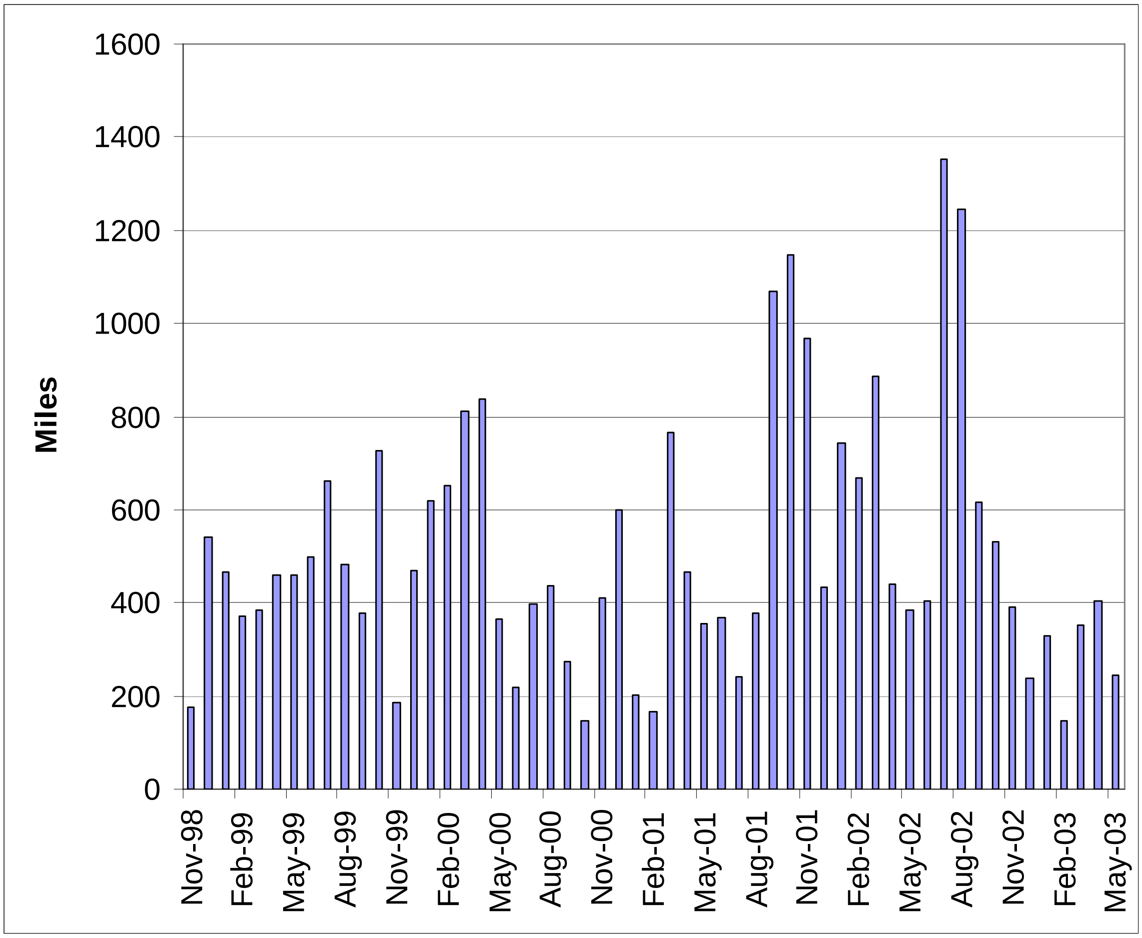

Figure 2 Monthly distances driven for 657 business trips in Cavalier, from November 1998 to May 2003.

As previously stated, on average the vehicle was driven about 500 miles per month. The maximum mileage accumulated in one month was 1,352 miles in July 2002. For the month of February 2003, only 147 miles were recorded. In charting the monthly mileage (Figure 2), no pattern is evident through the course of a year, probably due to the nature of work assigned to ORM staff. On only two occasions was the Cavalier driven more than 100 miles (November 2001 and August 2002) on a single trip. These were the result of commuter trips arranged for this research project, where the vehicle was driven between Rocky Hill and Stamford. In total, these dedicated-fuel runs to Stamford were conducted on seven separate work weeks compiling a grand total of 5,320 miles. Overall, the monthly mileage usage during the evaluation period shows that 40 percent of weekly mileage was less than one hundred miles. Traveling less than one hundred miles is within the vehicle's operating range for its natural gas fuel tank capacity, so the vehicle only required one refueling per week for 40 percent of the 55-month study.

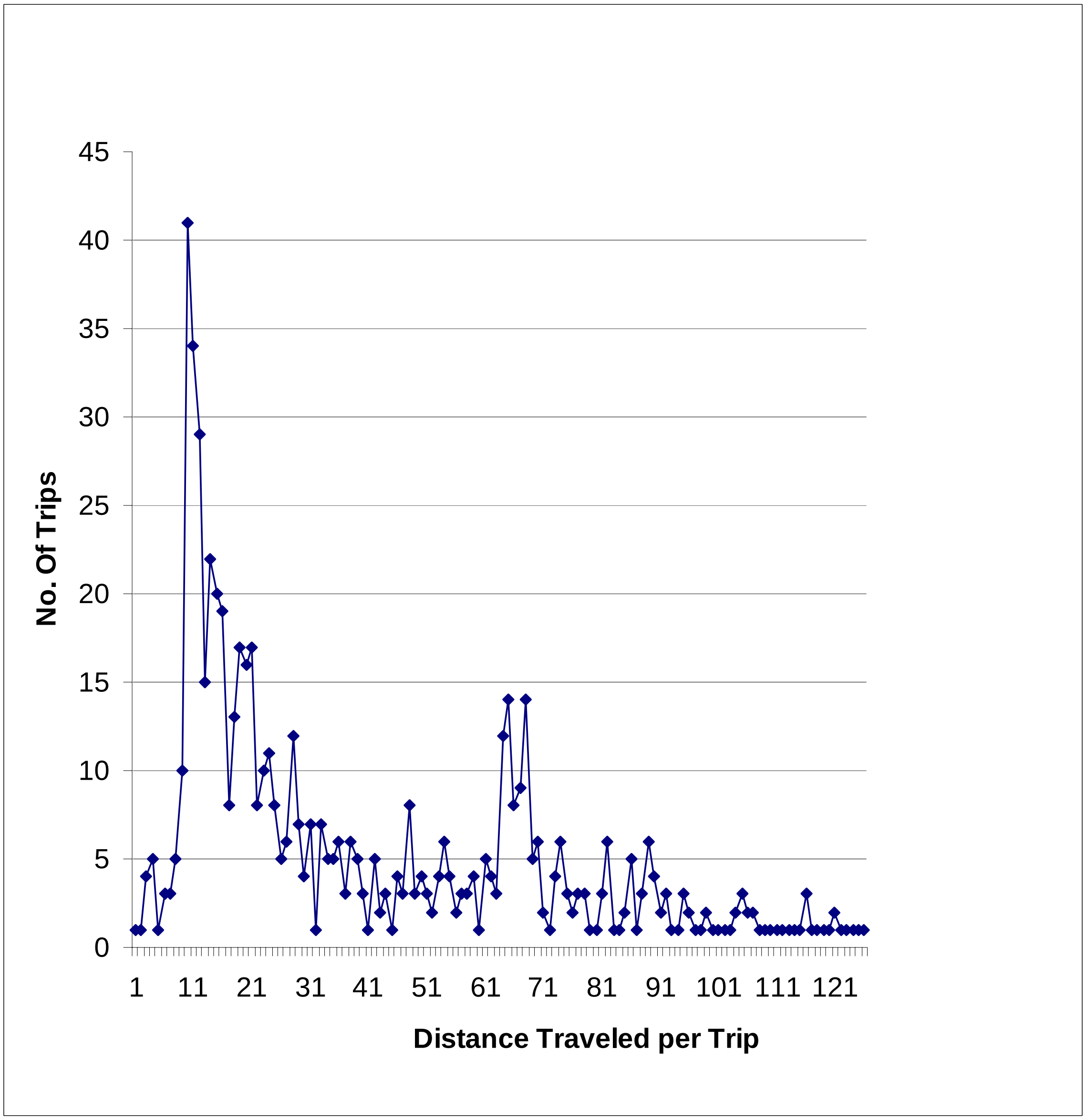

Figure 3 Trip length distribution of the 657 individual trips taken over the 55-month study

Charting all 657 individual trip distances traveled reveals that a majority of individual trips were within the automobile manufacturer's advertised natural gas tank's mileage range of 130 miles. The average distance traveled per trip was 42 miles. The longest trip recorded for one day was 212 miles. For that particular trip, an employee drove the vehicle to a neighboring state to attend a meeting in July 1999. One driver recorded the shortest distance traveled, one mile, in August 2000. We observed that the bi-fuel vehicle functioned much like a traditional gasoline powered engine. In fact, one driver who signed out this vehicle, on three separate occasions in 1999, was not even aware he was operating a bi-fueled vehicle. Dedicated fuel trips did impact the trip length distribution chart. A spike shown on the histogram at 60 miles per trip is a direct result of an effort made to document the dedicated-fuel range on CNG (Figure 4).

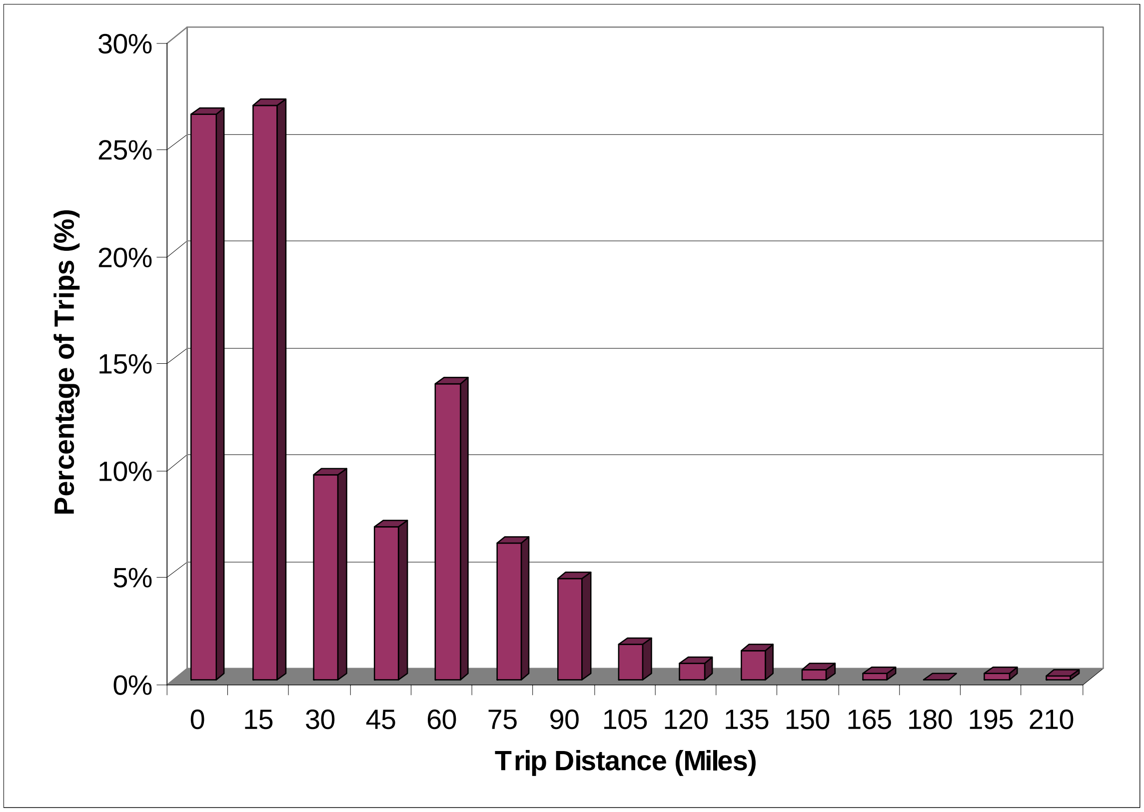

Figure 4 Trip distance frequency histogram

In Figure 4, the relative-trip-length frequency is a reflection of the nature of research's work assignments, where 53% of the trips taken were less than 30 miles. Only 17 percent of the trips required the vehicle to be driven between 30 and 60 miles. If the CNG tank was fueled prior to each individual trip, 90 percent of all trips recorded in the 55 month time frame were within the range of the CNG-tank's capacity. Special dedicated fuel runs to Stamford artificially raised the relative frequency of the 60-mile trip lengths taken.

Performance Observations for July 2004

To gain a better understanding of the technology and the operating characteristics of a bi-fuel vehicle, the principal investigator drove a series of dedicated pre-defined trips, running on both fuels (gasoline and CNG). The following performance observations are based on this experience.

Firstly, my initial experience operating the vehicle during the fuel switchover was stressful. Traveling for miles on the interstate highway with the fuel gage reading empty (CNG), waiting for the switchover to occur (to gasoline) was the source of the stress. I did not know how much gasoline was in the tank. The anticipation of hearing the distinctive “pop” reported by others created anxiety about the likelihood of running out of fuel. After experiencing this event a few times, subsequent switchovers between fuels became routine as I developed an understanding and comfort-level about the dual-fuel system.

Secondly, while operating on CNG at highway speeds, engine speed seemed to be sensitive to the amount of pressure applied to the fuel pedal. Engine speed was observed to quickly change, rising from 2,200 to 5,000 rpm, in response to light pressure on the accelerator pedal, as compared to when the engine was functioning on gasoline. The manufacturer’s literature for this vehicle indicates that operating on CNG results in less horsepower at engine speeds of 4,000 and 5,200 rpm, as compared to the gasoline mode. This may explain the fuel pedal sensitivity I experienced on hilly highways.

Thirdly, while conducting dedicated CNG city trips on hot July days (air temperatures well over 90 F) with air conditioning turned on, the engine idled cyclically. Engine speeds cycled from 500 to 1,500 revolutions per minute (RPM) when the car was stopped at intersections.

Efficiency Observations:

According to the U.S. EPA, the 2000-model year Chevrolet Bi-Fuel Cavalier's fuel economy rating was 22 MPG (city) 28 MPG (highway) when running on gasoline, and 20 MPG (city) 27 (highway) when operating on CNG. The vehicle's CNG tank capacity was estimated to provide a nominal 130 mile travel range per tank. The fuel efficiency for the 1998 model year of the Bi-fuel Chevy Cavalier is not reported by the EPA. The 2004 Cavalier model's fuel efficiency showed improvement over the 2000 model year, getting an additional 3 to 5 MPG respectively. The manufacturer reduced the tank size for both fuels types in the 2004 model, as compared to the 1998 model studied. The CNG tank size was reduced from 6.9 to 6.2 GGE and the regular gasoline tank size was reduced from 15.5 to 11.7 gallons.

The automobile manufacturer stated that improved fuel efficiency was accomplished by implementing changes that affect the Cavalier's tire rolling resistance, internal friction sources, and aerodynamic drag.

Of course, the engine's fuel efficiency is dependent on how, when and where the vehicle is driven. Vehicle operator's driving behavior and expectations are human factors that also influence the vehicle's real-world fuel efficiency. One goal of this study was to analyze the study vehicle's trip data to determine if a bi-fuel CNG vehicle of this type is a suitable alternative to conventional vehicles in Connecticut.

Traditionally fuel efficiency is defined by dividing the miles traveled by the amount of fuel required to refill after the trip is completed. To calculate CNG fuel economy, it made more sense to record miles traveled as defined by the vehicle mileage observed and recorded at the moment the engine switched to regular gasoline. The operator can hear a “pop” sound) at the point where the vehicle automatically switches from CNG to gasoline. CNG-trip length was then calculated by subtracting the vehicle’s mileage at the initial fueling from the mileage at switchover. To determine the vehicle’s fuel economy while operating on CNG, the miles traveled were divided by the initial fuel amount acquired just prior to the trip. Due to the variability in fueling capacity, this procedure produced more accurate results.

Data were also collected while driving pre-defined routes for each type of trip (city and highway). Three drives were made on CNG and one drive was on unleaded gasoline (87 Octane). The engine’s fuel performance measurements based on these drives is shown in Table 1:

Table 2 Fuel Economy Information Collected in July 2004, on pre-defined city and highway routes.

Fuel Type	City Driving		Highway Driving	
	CNG	Gasoline	CNG	Gasoline
Average Miles per Gallon (MPG)	17.3	21.5	29.8	31.5
Range of MPG	16.5 to 18.6	N/A	26.7 to 32.9	N/A
Average distance driven on tank of CNG (miles)	78		130	
Range of CNG Tank (in miles)	75 to 81	N/A	113 to 142	N/A
Number of Trips per Fuel Type	3	1	3	1
Average Number of Stops (traffic signals, etc.)	212	211	2	2
Average Trip Speed (MPH)	17	17	58.6	58.7
Average Fuel Operating Costs per Mile	$0.10	$0.12	$0.06	$0.06
Fuel-cost per gallon	1.80	2.00	1.80	2.00

During these dedicated trips in July 2004, the vehicle seemed to have trouble maintaining it’s idle with the air conditioner operating. While operating on CNG, the engine idled cyclically at stops where engine speed cycled from 500 to 1,500 RPM. This situation may have reduced fuel efficiency for CNG in the city. While burning gasoline, the engine idle only varied 300 rpm under the same operating conditions.

For trips driven using only gasoline, the vehicle was driven 78 miles in city driving and 148 miles in highway driving, before refilling.

At the time of this study, 87 Octane unleaded gasoline was priced at $2.00 per gallon at the pump, and CNG costs $1.80 per gallon (GGE). The cost for both includes state and federal taxes. A $0.04 per mile fuel cost savings would have been realized if the Cavalier achieved the fuel economy rating published by the EPA for natural gas fuel, compared to gasoline under city driving conditions.

Examination of the fueling data from the 55-month study period indicate this vehicle was fueled a total of 193 times over the 27,000 miles traveled. Either CNG, gasoline or a combination of both fuels were obtained at each refueling. These fueling events were categorized into three distinct fueling events (single, both, or unknown fuel). A single-fueling event for CNG was defined as the distance traveled after CNG fueling to the point where the switchover occurred to gasoline. Unfortunately, not many drivers noted the fuel switchover point. Consequently a second definition for the single-fuel event was defined as distance traveled where the vehicle was driven between 75 and 145 miles between CNG fueling and potentially achieved a calculated CNG efficiency of 16 to 32 MPG, but the driver(s) had not documented the switchover from CNG to gasoline. Fueling events labeled “unknown” refer to either 1) distance traveled on possible CNG failed to meet the stated criteria, or 2) driver’s notes lacked the mileage switchover point documentation. The label “both fuels” was used to establish common points throughout the study where both tanks (CNG and gasoline) were filled at about the same time (odometer reading). Information derived from these “both fuel type” fueling events was suitable for observations on seasonal variability and the overall fuel economy of the Cavalier. (See Figure 5)

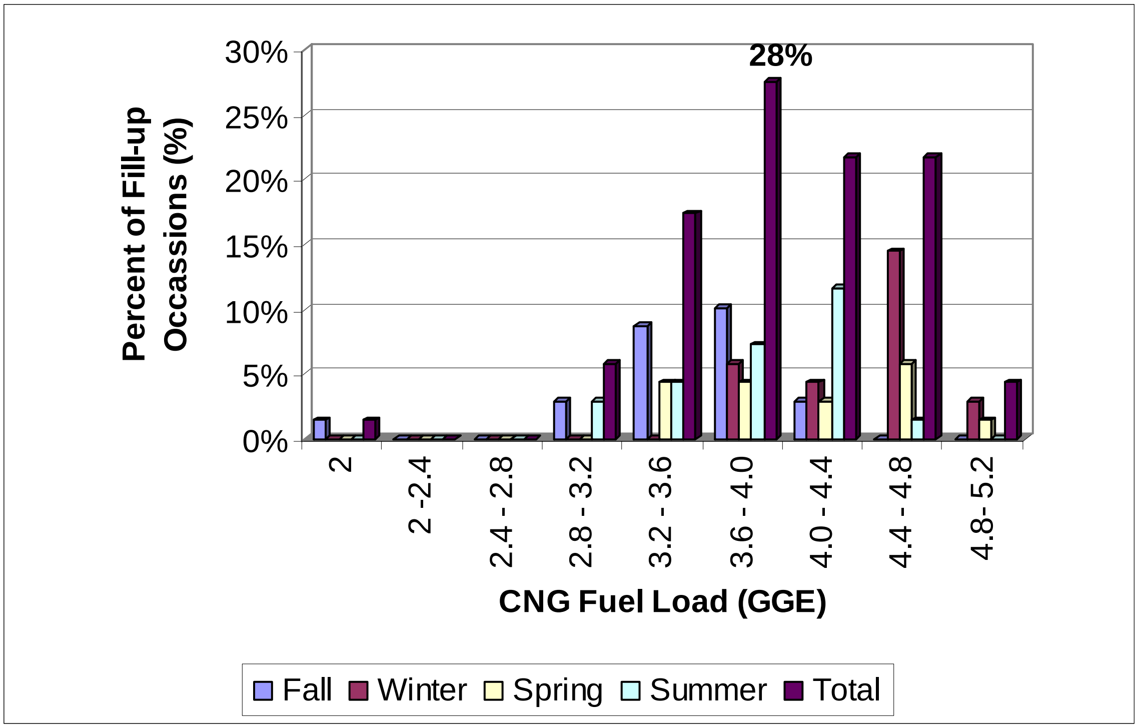

Figure 5 Seasonal variation of CNG fueling gasoline gallon equivalent (GGE) gallonage

For 108 out of the 193 total fueling events, CNG fuel was added to the vehicle. It is assumed the tank was completely empty prior to each fueling. The tank's storage capacity at the time of fillings is dependant on three variables: Pump Pressure, Speed of Fuel delivery, and Ambient Air Temperature. Fueling records indicate a large range in actual CNG tank's fuel load achieved (0.75 GGE to 5.18 GGE of natural gas per fill-up). The number of fueling occasions was fairly evenly distributed over the four seasons (winter, spring, summer, and fall). Overall, we observed 28% of CNG tank refills were between 3.6 to 4.0 gallons of fuel, independent of the time of year. The average gallons of CNG acquired at fillings was 3.8 GGE. Three quarters of all the refills were between 3.6 to 4.8 GGE of CNG fuel. During winter months, refills ranged from 4.4 to 4.8 GGE of natural gas. The vehicle operator could expect to obtain the least amount of fuel (3.6 to 4.0

GGE) in the fall months. However, there were a few occasions in the winter and spring seasons when 4.8 to 5.2 GGE of CNG was pumped into the tank. CNG fuel, obtained during the 55-month evaluation period, was purchased from different pumping equipment at two different suppliers (Texaco Station in Hartford and BP Station in Norwalk). The pumping equipment's pressure capabilities were not documented. It is likely that differences in pump-pressure and ambient temperature existed and affected the amount of CNG the tank could hold on fill ups.

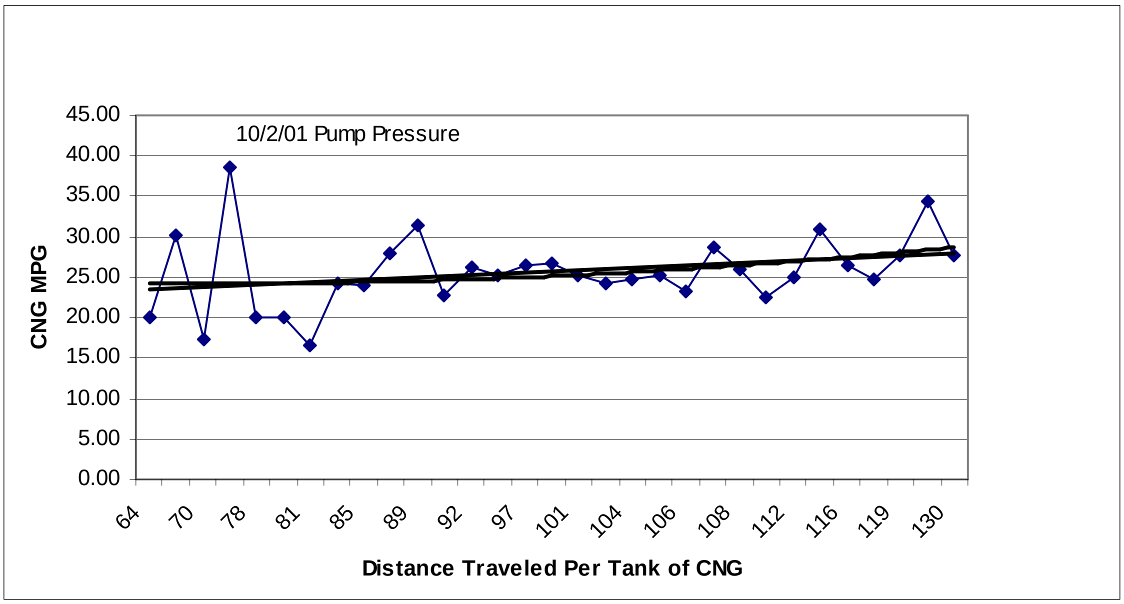

Figure 6 Fuel efficiency for trips made exclusively with CNG

The vehicle's CNG fuel efficiency was calculated from 30 drive-plus-refueling events, where the driver noted the vehicle's odometer reading at the point where the fuel switched over to gasoline. Fuel economy was calculated by dividing the distance traveled for these single-fuel trips by the fuel consumed (amount of CNG required to fill the empty tank prior to the drive). The total distance traveled for single-fuel (CNG) trips was 3,016 miles. The overall fuel economy was

25.6 MPG with a standard deviation of 4.6 MPG, independent of type of driving (city or highway). The fuel consumption ranged from 16.3 to 38.50 MPG for those trips labeled “CNG single fuel trips.” Sixty-seven percent of CNG single-fuel trips were driven on limited-access highways. For these trips fuel efficiency was 26.3 MPG with a standard deviation of 4.9 MPG.

As can be seen in Figure 6, CNG fuel efficiency gradually rises from 24.0 MPG at 64-mile distance traveled, to just under 30 MPG for trips over 130 miles. On October 2, 2001, abnormally high fuel economy was observed on a 78-mile drive (on CNG) before switching to gasoline for the remainder of the 130-mile trip. The definition of “Distance Traveled per Tank” shown on the chart (Figure 6) is the distance driven to consume all the CNG fuel and doesn’t infer the composition of trips (city/highway) or who drove.

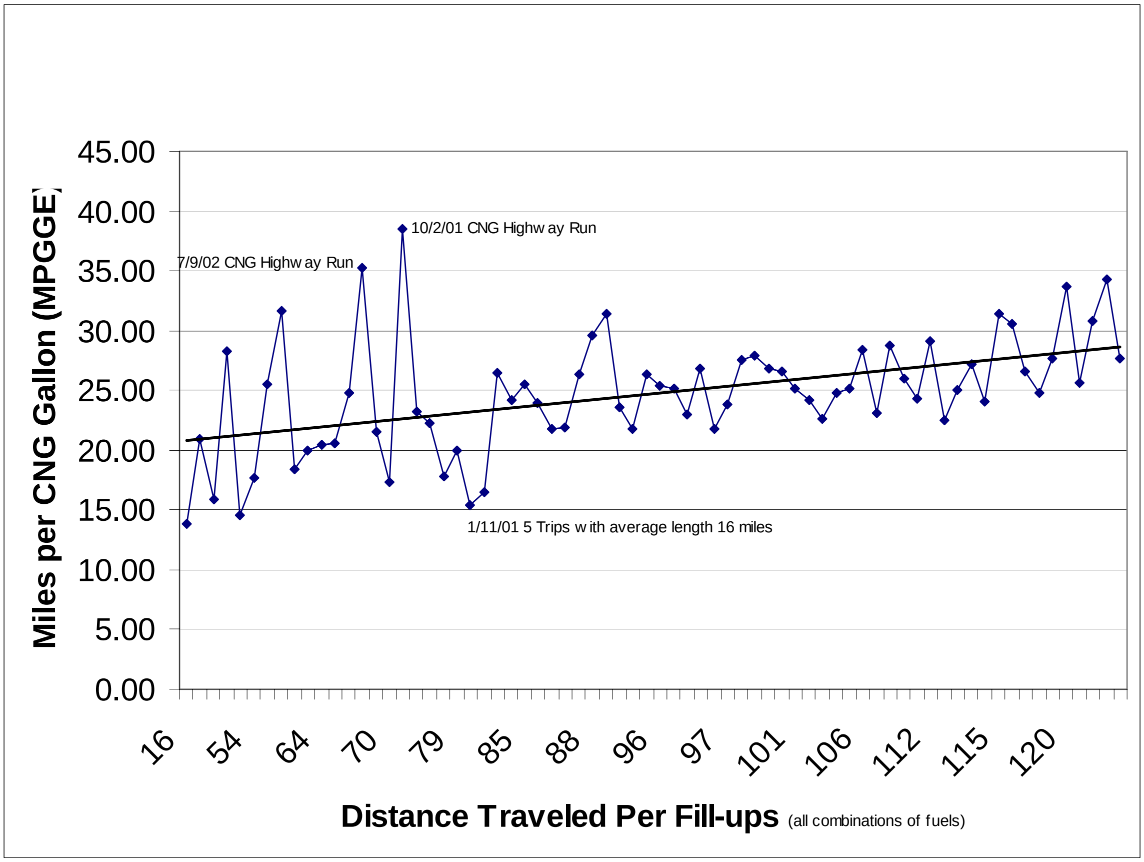

Figure 7 Fuel Efficiency of all CNG trips made for all trips and all combinations of fuels consumed.

Figure 7 shows a data set for the vehicle that includes trip events meeting the secondary criteria established for the single-fuel events. This adds 35 fueling events to the data set, and reduces the average CNG fuel efficiency to 24 mpg. The fuel efficiency (MPG) per distance traveled on one tank of fuel. In general, a driver could expect Cavalier economy to be from 20 to 28 miles per gallon while operating on CNG. Characteristics of the drives (trip length, and city/highway miles) were related to the vehicle's fuel efficiency, where longer drives generally achieved higher fuel economy, and highway drives were more economical than city driving conditions.

Summary and Conclusions

The Department initiated this research to gather field data and performance information on alternative fueled vehicles, both electric and compressed natural gas, to assist the State and Federal Officials with information about these options, which could be used to comply with the Energy Policy and Conservation Act of 1992, Section 507. The main purpose of this report is to document the Department's experience operating a bi-fuel compressed natural gas vehicle for business travel. A 1998 Chevy Cavalier Sedan, bi-fuel compressed natural gas vehicle, was selected and driven over 27,000 miles by Research personnel during a 55 month evaluation period. Based on data gathered during this evaluation period, November 1998 to May 2003, the following observations were made:

1) The benefits of powering a bi-fuel vehicle with natural gas in the State fleet have not been fully realized in Connecticut due to several factors: a) For employees, a lack of familiarity with CNG fueling may have discouraged usage of the vehicle by staff (less than 490 miles per month). b) Lack of conveniently located CNG refueling facilities in Connecticut discouraged CNG refueling. c) The fact that it was possible to operate the Chevy Cavalier exclusively on gasoline discouraged CNG refueling. d) Lack of meaningful price differential between CNG and gasoline in Connecticut discouraged CNG refueling. e) Under EPACT 1992, State Fleets are not required to report alternate-fuel usage, i.e. displacement of gasoline. The Act only requires equipment purchases.

2) There is limited trunk cargo space provided in the bi-fuel CNG Chevy Cavalier. Comparing the manufacturer’s specifications of the bi-fueled Cavalier’s trunk space to the standard Cavalier’s cargo space, approximately half the cargo room was eliminated due to placement of the CNG storage tank and spare tire.

3) The actual amount of CNG-tank capacity is influenced by three factors: station’s fuel pump pressure, station’s fuel-pumping speed and ambient air temperature at time of fueling.

4) The CNG refilling station in Hartford did a good job of compensating for differences in ambient temperature. We observed that a 25°F rise in ambient temperature resulted in less than a two percent reduction in CNG tank capacity.

5) There is some driver confusion because the same fuel gage scale is utilized for both tanks: 6-gallon CNG and 15-gallon gasoline tanks. It was difficult for a driver to estimate the number of miles which can be driven on a full tank of CNG.

6) With only one fuel gage, drivers complained about the initial experience involving the fuel switchover process. During the fuel change, there were several miles in which the fuel gage would indicate the CNG tank is empty, but the engine would continued to function. This period of time until the gage reading switched to the other fuel (gasoline)was unnerving to some drivers. One question that came to mind when operating the vehicle in this gray zone was whether there was any gasoline in the other tank. Drivers generally didn’t read the manual and discover that a button on the

dash could be pressed that would display the fuel level in the 'other' tank.

7) CNG fuel economy of the study vehicle was on average 17.3 miles per gallon in the city and 29.8 miles per gallon on highways. The vehicle's range on CNG was from 75 to 81 miles in the city and 113 to 143 miles while traveling on the highway.

8) There is a limited number of CNG refueling stations in Connecticut. Only two CNG stations are available to the public operating within a 70 mile radius of the Rocky Hill Research Facility (Cities of Hartford and Norwalk).

9) After the 2004 model year, Chevrolet stopped manufacturing the Bi-Fueled Chevy Cavalier.

In conclusion, the bi-fuel CNG Chevy Cavalier did function as described by the automobile manufacturer's literature. The bi-fuel capability of this vehicle worked well and provided a means of operating fleet automobiles on an alternative fuel. However, the limited CNG supply infrastructure in Connecticut, together with no requirement to report the amount of CNG fuel consumed by fleet operations and the lack of price-differential incentives between the two fuels in Connecticut limited its acceptance in the State Fleet.

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3. Okabayashi, C., “General Motors 1999 Model Year Alternative Fuel Vehicles,” TRIS Accession Number 00811911, from “National Parks: Transportation Alternatives and Technologies for the 21st Century,” Conference Proceedings, 1999.

4. “Advanced Technology and Alternative Fuel Vehicles,” Energy Efficiency and Renewable Energy Clearinghouse, National Renewable Energy Laboratory, Department of Energy, Publication No. DOE/GO-102001-1142, FS143, August 2001.

5. Eudy, L., “field Operations Program – Overview of Advanced Technology Transportation, Update for CY2001,” National Renewable Energy Laboratory, U.S. Department of Energy, Contract No. DE-AC36-98-GO10337, Report No. MP-540-30187, April 2001.

6. Sun, B., Lutz, A., Vermiglio, E., Arlod, M., Wiedmann, T., “The Development of the General Motors 2.2l CNG Bi-Fuel Passenger Cars,” Document No. 982445, paper presented at “International Fall Fuels and Lubricants Meeting and Exposition,” October 1998.

Appendix A

Alternative Fuels Data Center – Query Results

Table 1A – 33 Compressed Natural Gas (CNG) Refueling Station(s)within 70-Mile Radius of 280 West Street, Rocky Hill, CT

Id	Name	Phone	Address	City	State	Zip	Type of Access
699	Town of Rocky Hill	860-258-2700	Old Forge Rd	Rocky Hill	CT	06067	N
566	Connecticut Natural Gas Corp.	203-869-6900	1376 Cromwell Ave	Rocky Hill	CT	06067	N
567	Connecticut Natural Gas Corp.	203-869-6900	76 Meadow St	Newington	CT	06111	N
105	Texaco	860-278-7044	130 Brainard Rd	Hartford	CT	06114	P
694	Town of Berlin	860-727-3264	27 Town Farm Ln	Berlin	CT	06037	PL
562	United States Postal Service	860-953-4920	121 Shield St	Elmwood	CT	06050	N
698	Town of Newington	860-665-8510	281 Milk Lane	Newington	CT	06111	PL
565	United Parcel Service	860-742-5877	90 Locust St	Hartford	CT	06114	N
563	United States Postal Service	860-223-3681	135 Chestnut St	New Britain	CT	06050	N
697	AAA	860-236-3261	112 Prospect St	Hartford	CT	06106	N
104	Connecticut Natural Gas Corporation	860-727-3204	100 Columbus Blvd	Hartford	CT	06103	PL
558	Raymonds Exxon	203-237-1460	1100 E Main St	Meriden	CT	06450	PR
555	Yankee Gas Services Company	203-639-4639	56 Cooper St	Meriden	CT	06451	PR
564	World Skate International	860-651-5400	1375 Hopmeadow St	Simsbury	CT	06070	N
556	Yankee Gas Services Company	203-639-4639	47 Eagle St	Waterbury	CT	06708	PR
571	U.S. Postal Service	203-782-7122	115 Peat Meadow Rd	New Haven	CT	06513	N
777	U.S. Postal Service	203-782-7000	50 Brewery St	New Haven	CT	06511	N
572	Regional Water Authority	203-624-6671	90 Sargent Dr	New Haven	CT	06519	N
525	Sackett Street Refueling Station	413-572-0214	30 Sacket St	Westfield	MA	01085	PL
739	Norwich Dept. of Public Utilities	860-823-4173	16 S Golden St	Norwich	CT	06360	PR
425	Southern Connecticut Gas Co Services Ctr	203-786-7600	60 Marsh Hill Rd	Orange	CT	06477	N
424	Southern Connecticut Gas Company	203-874-4159	76 Quirk Rd	Milford	CT	06460	N
695	Bridgeport Hydraulic Company	800-732-9676	600 Lindley St	Bridgeport	CT	06606	N
820	KeySpan Riverhead Service Center	516-545-4944	117 Doctors Path	Riverhead	NY	11901	PR
700	Town of Westport	203-341-6000	50 Jesup Rd	Westport	CT	06880	N
559	Performance Auto Sales	203-838-5155	211 East Ave	East Norwalk	CT	06855	P
837	University of Rhode Island	401-222-6200	9 Garage Rd	Kingston	RI	02881	G
926	RISEO	401-222-5161	1395 Pontiac Ave	Cranston	RI	02920	G
171	KeySpan Brentwood Service Center	516-545-4944	1650 Islip Ave	Brentwood	NY	11717	PR
344	New England Gas Co	401-272-5040 x2228	477 Dexter St	Providence	RI	02907	PL
696	Greenwich Exxon	203-869-7860	111 W Putnam Ave	Greenwich	CT	06830	P
343	Allens Avenue NGV Fueling Station	401-272-5040 x2247	670 Allens Ave	Providence	RI	20903	PR
727	New England Gas Co	401-525-5548	1595 Mendon Rd	Cumberland	RI	02864	PR

Type of Access

N: Private Station – Limited access

P: Public access – no restriction (3)

PL: Public Limited time – call ahead (3)

PR: Public with Restrictions – card key required (4)

G: Government personnel only

Note: Lack of conveniently located public fueling.

Online Reference: http://afdcmap.nrel.gov