UPS CNG Truck Fleet

Final Results

This is a Clean Air Natural Gas Vehicle

Produced for the U.S. Department of Energy (DOE) by the National Renewable Energy Laboratory (NREL), a DOE national laboratory

Alternative Fuel Truck Evaluation Project

UNITED PARCEL SERVICE (UPS) CNG TRUCK FLEET: FINAL RESULTS

DOE/NREL Truck Evaluation Project

By

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Executive Summary

United Parcel Service (UPS) is the world's largest express carrier and package delivery company. It delivers more than 3 billion packages and documents every year to more than 200 countries and territories. In 1989, UPS began testing compressed natural gas (CNG) to assess its viability and benefits as an alternative fuel. Today, UPS has the largest private fleet of CNG vehicles in the United States—more than 1,000 package delivery vehicles operating in 16 states.

In cooperation with UPS, a selection of Freightliner CNG delivery vehicles from the company's original 1996 order were evaluated as part of the U.S. Department of Energy/National Renewable Energy Laboratory (DOE/NREL) Truck Evaluation Project. The plan for this evaluation was to test as many as 15 CNG package delivery cars and 3 diesel package delivery cars operating in the Hartford, Connecticut, area from UPS's Waterbury, Hartford, and Windsor facilities.

This report includes a technical review of data collected for the UPS CNG package delivery car operations in Hartford and Waterbury, Connecticut, compared with UPS diesel truck operations in Windsor, Connecticut.

Objective

The objective of this project was to provide transportation professionals with quantitative, unbiased information on the cost, maintenance, operational, and emissions characteristics of CNG as one alternative to conventional diesel fuel for heavy-duty trucking applications.

Method

Data were collected for the UPS CNG truck operations in Hartford and Waterbury, and included comparisons in

- Operations
- Maintenance
- Performance
- Emission characteristics

In general, these data were already collected as part of normal business operations.

Results

The results presented in this report reflect the performance of early production and pre-production equipment. Since 1995 and 1996, when this equipment was new, many natural gas vehicle/engine and compressor technologies have improved. The early adoption of natural gas delivery vehicles has allowed for a longer-term perspective on the operation of some early technologies.

UPS started converting package delivery vehicles to operate on CNG during the 1980s using aftermarket (retrofit) kits. The engines in these trucks had to be converted to operate on natural gas (usually by adding fuel intake hardware and computer equipment for fuel injection). In addition, CNG fuel storage cylinders had to be attached to the vehicles. Fuel is delivered from the cylinders to the engine in stainless steel tubing. Although CNG conversions usually effectively reduce emissions, original equipment manufacturer (OEM)-designed and built engines and vehicles have even lower emissions and better engineering for long-term operation.

In Hartford, the CNG conversion vehicles started operating in 1995, after a CNG compressor station was installed. The station was an early design for vehicle operations and had problems with oil carryover into the vehicles' fuel systems.

This required that all the CNG vehicles at Hartford have the fuel filters changed at each oil change (rather than only once or twice a year) and has caused problems with the fuel regulators. Also, the CNG compressor at the Hartford facility can fill vehicles only as high as 3,000 psi, which reduces the range compared to 3,600 psi fuel fills. The station at Waterbury was built later, and can provide fuel fills to 3,600 psi without the oil carryover problem.

This evaluation concerns trucks that were part of UPS's first purchase of OEM CNG package delivery vehicles from Freightliner Custom Chassis and Cummins Engine Company. These vehicles were built in 1996 and have operated from the Hartford and Waterbury sites since April 1997. The evaluation uses data obtained from January 1997 through October 2000.

Conclusions

- UPS operates CNG trucks, which run every working day with no major complaints.
- The CNG truck engine was upgraded to a slightly higher horsepower and torque rating than similar diesel vehicles, which helped overcome the difference in the vehicles.
- The CNG engine and fuel systems are early production models that had problems with spark plugs, spark wires, and fuel regulators. Cummins and Freightliner continue to support these products.
- The energy equivalent fuel economy of the CNG trucks was 27%-29% lower than that of the diesel trucks. Newer technology has a fuel economy penalty as low as 10%-15% compared with diesel technology.
- Maintenance costs for CNG trucks at Hartford were 29% higher than for diesel trucks because of troubleshooting, replacement of spark plugs and wires, and clutch and transmission repairs. At Waterbury, the CNG costs were 6% lower because of greater use and longer preventive maintenance inspection cycles.
- Total operating costs for the CNG trucks at Hartford were 19% higher than for the diesel trucks; at Waterbury they were 2% lower.
- Tests at West Virginia University's mobile chassis dynamometer laboratory indicated that CNG trucks had much lower emissions than diesel trucks: carbon monoxide 75% lower; oxides of nitrogen 49% lower; hydrocarbons and nonmethane hydrocarbons 4% lower; and carbon dioxide 7% lower.

Lessons Learned

- **Preparation is essential.** Before starting a project, solidify the company's commitment to the environment, meet with managers to gain their support for purchasing or retrofitting vehicles, and notify employees about the company's plan. Also, research available incentives, acquire parts and supplies, and develop methods to measure performance and maintenance needs.
- **Keep abreast of ongoing activities.** Analyze the required ranges and routes of the fleet and locations of publicly available fueling stations, integrate alternative fuels information into training programs, install on-site fueling facilities (or share installation costs with another organization), stay current on technologies, and identify and consult with companies that participate in similar projects.
- **Develop long-term strategies.** Determine real costs, provide regular updates to those concerned about alternative fuels, and communicate regularly with stakeholders about the company's activities and objectives.

Future CNG Operations at UPS

UPS continues to use CNG package delivery vehicles. The company has no current requests for CNG fleet vehicles, but continues to demonstrate, evaluate, and watch the economics of new technology vehicles.

Overview

United Parcel Service (UPS) is the world's largest express carrier and package delivery company. It delivers more than 3 billion packages and documents every year to more than 200 countries and territories. More than 80,000 of the familiar brown trucks deliver more than 13 million packages and documents a day to 7.9 million regular customers in thousands of cities. With its international service, UPS can reach more than 4 billion potential customers. The company employs more than 370,000 people and invests more than $300 million per year in employee training and learning programs. The company's annual revenues in 2001 were $30.6 billion.

UPS has a long history of using new technologies. In the 1970s and 1980s, UPS evaluated methanol-powered vehicles and an engine to run on multiple alternative fuels. In the late 1970s, UPS's Canadian subsidiary converted 735 delivery vehicles to propane. In 1989, UPS began testing compressed natural gas (CNG) to assess its viability and benefits as an alternative fuel. Today, UPS has the largest private fleet of CNG vehicles in the United States—more than 1,000 package delivery vehicles in 16 states. In addition, in late 2001 UPS deployed a hybrid electric vehicle into its fleet in Huntsville, Alabama, and will add liquefied natural gas (LNG) tractors to its fleet in late 2002.

Between January 1997 and October 2000, data on selected CNG and diesel trucks from UPS were collected as part of the U.S. Department of Energy/National Renewable Energy Laboratory (DOE/NREL) Truck Evaluation Project.

The purpose of this report is to provide transportation professionals with summary information on the cost, maintenance, operational, and emission characteristics of CNG as one alternative to conventional diesel for heavy-duty trucking applications.

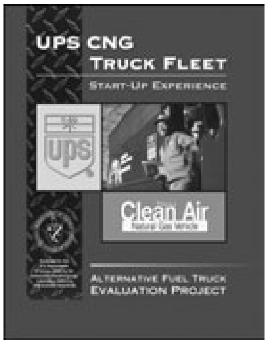
The report should also benefit decision makers by providing a real-world account of the obstacles overcome and the lessons learned in adapting alternative fuel trucks to a site previously geared toward diesel trucks.

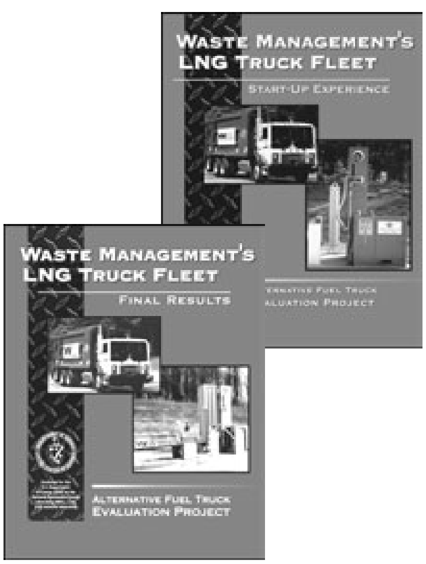
What Is Compressed Natural Gas?

CNG is one of several alternative fuels available. Natural gas is abundant and is used to heat homes throughout the United States. It is composed primarily of methane (more than 90%) and other hydrocarbon gases such as ethane, propane, butane, and pentane. Natural gas is colorless and odorless. An odorant called mercapton is added to natural gas to warn of leaks. CNG used in vehicle engines is stored and used at high pressure—up to 3,600 pounds per square inch.

A natural gas vehicle (NGV) can operate on CNG instead of gasoline or diesel fuel. The primary differences between an NGV and a gasoline-powered vehicle are in the on-board fuel storage and intake systems. NGVs carry their fuel in high-pressure cylinders, which are usually secured to the bottom of the vehicle. From there, the CNG travels along a high-pressure fuel line leading to the engine. A CNG-powered vehicle's mileage in "gasoline gallon equivalent" is about the same as a conventional gasoline vehicle, which can be retrofitted to operate on CNG, but may lose 5%-10% of its power.

CNG fueling stations are few and public access may be limited. Most are operated by natural gas utility companies, some of which allow public access. Increasingly, gasoline service stations are contracting with utilities to install CNG fueling dispensers. Companies with commercial fleets often install their own CNG fast-fill compressor facilities to ensure access to consistent supplies.





This report summarizes the results of the CNG study at UPS. Further technical background, research methods, extensive original data, and detailed discussions are presented in a companion document (*UPS CNG Truck Fleet Final Data Report*, NREL, September 2001).

Alternative Fuel Projects at DOE and NREL

NREL managed the data collection, analysis, and reporting activities for the UPS CNG truck evaluation. One of NREL's missions is to assess the performance and economics of alternative fuel vehicles (AFVs) objectively so that

- Fleet managers can make informed decisions when purchasing AFVs.
- AFVs can be used more widely and successfully to reduce U.S. consumption of imported petroleum and to benefit users and the environment.

Alternative fuels evaluated by NREL and participating companies across the United States include LNG, CNG, biodiesel, ethanol, methanol, and propane.

The Truck Evaluation Project

The overall objective of the ongoing DOE/NREL Truck Evaluation Project is to compare heavy-duty trucks using an alternative fuel advanced vehicle technology with those using conventional diesel fuel. Specifically, the program seeks to provide comprehensive, unbiased evaluations of the newest generation of alternative fuel engine and vehicle technologies. Heavy-duty alternative fuel trucks have been evaluated across the United States through data collection and analysis since 1996.

The truck program includes five demonstration sites. Other evaluation sites are

- Raley's (Sacramento, California)
- Orange County Sanitation District (Fountain Valley, California)
- Waste Management (Washington, Pennsylvania)
- Ralphs Grocery (Riverside, California)

Sites are selected according to the alternative fuel technologies in use, the types of trucks and engines, the availability of diesel comparison ("control") vehicles, and the host sites' interest in using alternative fuels.

The data collection and evaluation efforts are subject to peer review and DOE approval. The results of the evaluation at each site are published separately.

Host Site Profile: UPS in Hartford and Waterbury, Connecticut

The Hartford facility houses and operates 135 vehicles, of which 101 run on CNG. In 2000, UPS moved some of its CNG vehicle operations from Massachusetts into the Hartford and Waterbury facilities to provide better access to the fuel. The Waterbury facility operates about 180 vehicles, 85 of which run on CNG.

UPS's CNG Trucks

The similarity of the AFVs and control vehicles is determined by comparing the truck chassis and engine model used. The same truck chassis (Freightliner Custom Chassis) is used for the control and study vehicles. However, the diesel trucks have a Union City body, and the CNG trucks have a

Grumman Olson body. The body sizes are essentially the same in weight and aerodynamic profile; no fuel economy differences are expected. A Fuller FS-4205B standard transmission is used in the diesel and CNG trucks. The diesel trucks are equipped with a Cummins B5.9 diesel engine; the CNG study vehicles have the natural gas equivalent model, the B5.9G. The CNG trucks have a slightly higher peak torque and peak horsepower rating than the diesel trucks.

The CNG trucks are one year newer than the diesel control trucks. All the diesel trucks were built in 1995 and started operating in 1996. The CNG trucks were built in 1996 and started operating in 1997. The CNG trucks were ordered at the same time as the diesel trucks, but took longer to prepare and put into service. To help ensure comparability, all back maintenance data for the diesel trucks were collected, allowing comparisons of similar vehicle lifetimes for the test fleets. Table 1 summarizes the vehicle system descriptions for the CNG and diesel trucks (see Figure 1).

Table 1. Vehicle System Descriptions

Description	Diesel Control	CNG
Chassis Manufacturer	Freightliner	Freightliner
Chassis Model Year	1996	1997
Body Manufacturer/Model	Union City/MT14FD	Grumman Olson/MT45
Engine Manufacturer/Model	Cummins/B5.9	Cummins/B5.9G
Engine Ratings		
Maximum Horsepower	160 hp @ 2,500 rpm	195 hp @ 2,800 rpm
Maximum Torque	400 lb-ft @ 1,700 rpm	420 lb-ft @ 1,600 rpm
Fuel System Storage Capacity	35 gallons	15.3 diesel gallon equivalent usable – 2 CNG tanks from NGV Systems
Transmission Manufacturer/ Model	Fuller/FS-4205B, 5-speed standard	Fuller/FS-4205B, 5-speed standard
Catalytic Converter Used?	No	Yes
Vehicle Cost Compared to Diesel	-	+ $15,000

Battelle/PIX 08637

Figure 1. Package delivery cars using CNG display UPS's commitment to clean air.

Project Design and Data Collection

Data collection for vehicle operations includes each fuel fill (amount of fuel, odometer reading, and date) and fuel prices. Vehicle operations data collection also includes engine oil consumption and changes. Each engine oil addition and oil change is recorded. UPS did not collect detailed engine oil addition information. Maintenance data include preventive maintenance inspections (PMIs), unscheduled maintenance, and road calls. Along with fuel and engine oil consumption costs, maintenance data are used to estimate operating costs and indicate reliability problems.

Warranty repairs are summarized based on work orders from the engine manufacturer. Costs for warranty repairs are generally not included in the operating cost calculations. Labor costs are included, depending on the mechanic who did the work and whether those hours were reimbursed by the original equipment manufacturer (OEM) under the warranty agreement. Warranty maintenance information was also collected for indications of reliability and operations costs outside the warranty period. A limited number of warranty data were collected for the CNG trucks at Hartford. Because of the vehicles' age, no other warranty information was available.

Any safety incidents with the vehicles, the fueling station, or in the maintenance facilities, including the nature of the incident or accident and the vehicles or facilities involved, were to be described. Any changes in procedures or hardware required to ensure that an incident is not repeated were to be documented. However, no safety incidents occurred during the data collection period.

UPS Facilities and Bulk Fuel Storage

Hartford

The Hartford facility (Figure 2) is at 90 Locust Street in Hartford, Connecticut. UPS houses and operates 135 vehicles at this facility, 101 of which run on CNG. In 2000, UPS moved some of its CNG vehicle operations from Massachusetts to the Hartford and Waterbury facilities to provide better access to the fuel. The Hartford CNG fueling station and a CNG dispenser are also shown in Figure 2. UPS owns this station, which was designed and constructed by Wilson Technologies. Installation was completed in 1995 at a cost of $500K. This facility is equipped with two compressors and provides fuel fills to 3,000 psi (versus 3,600 psi as normally allowed at CNG stations). This restricts the maximum range of the vehicles. Fill time for the CNG trucks is 3 to 5 minutes, compared to less than 3 minutes for the diesel trucks. The compressor allows compressor oil into the fuel stream, which dirties the fuel filters. Consequently, the filters must be changed at every PMI, which increases maintenance costs.

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Figure 2. UPS facility in Hartford, Connecticut, with fueling station and dispenser facility

Waterbury

The Waterbury facility (Figure 3) is at 8 Mountainview Road in Watertown, Connecticut. UPS operates about 180 vehicles from this site, 85 of which run on CNG. UPS owns the CNG fueling station, which was designed and built by IMW Atlas at a cost of $500K. The compressor station consists of two compressors and provides CNG at 3,600 psi. It was installed after the Hartford facility and does not have the compressor oil carryover problem. Fill time is generally 5 minutes or less. The fueling lanes are also shown in Figure 3.

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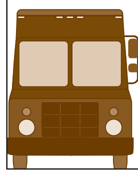
Figure 3. UPS facility in Waterbury, Connecticut, with fueling station and compressor station



Project Start-Up at UPS

UPS has a strong commitment to the environment, and a long list of environmental initiatives. It is no surprise then, that UPS volunteered to participate in a federal program to evaluate the potential benefits of using alternative fuels in commercial fleets, or that managers and staff at two UPS facilities in Connecticut enthusiastically supported the idea.

UPS's participation in an alternative fuel evaluation is not its first venture into this field—the company is a pioneer in alternative fuels. Since the 1930s, when it began using electric vehicles in New York City, UPS has researched and tested alternative fuels that could reduce vehicle emissions, dependence on fossil fuels, and operating costs.

During the 1970s and 1980s, UPS evaluated methanol-powered vehicles and a stratified-charge engine designed to run on multiple alternative fuels. In the late 1970s, UPS's Canadian subsidiary converted 735 delivery vehicles to propane fuel. In 1989, UPS began testing CNG to assess its viability and benefits.

"UPS began using new fuels 15 years ago," said Robert Hall, vice president of maintenance and engineering at UPS's corporate headquarters in Atlanta. "We have tried to keep current on the technologies and to be mindful of the environment and air quality issues."

During the 1980s, UPS evaluated various alternative fuels, found that natural gas had the best characteristics for its operations, and launched its first fleet of 10 CNG vehicles in New York City. The vehicles were fueled at the local gas company's CNG facility. During the next 10 years, UPS bought CNG vehicles or retrofitted older vehicles to use CNG.

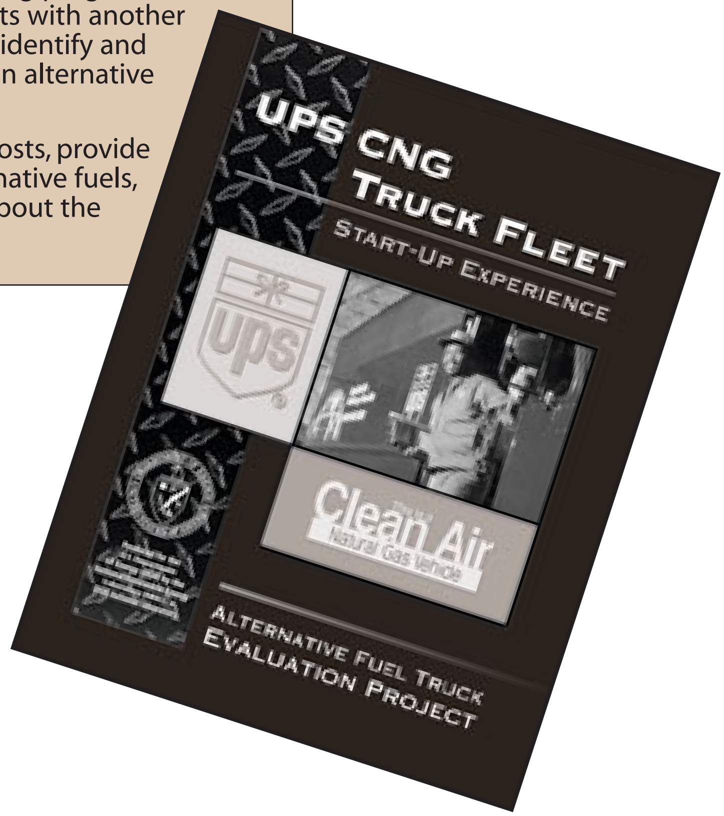
"We concluded that CNG was the best alternative fuel for our operations, and it had positive environmental qualities," said Hall. "Employees and customers recognized the company for those good neighbor efforts." UPS is also anticipating a cleaner-air future, and started testing hybrid electric vehicles in 2001.

"We value our leadership role in alternative fuels," said Hall, "and we find that customers and other stakeholders are generally positive." He also said that, because UPS has long been a part of the alternative fuels transformation process, it has direct experience, not just a theoretical response.

The UPS phase of data collection, which requires at least 12 months of operations data, began in 1999 and was completed in November 2000. Emissions data were collected at the Hartford, Waterbury, and Windsor facilities by a DOE-funded on-site mobile laboratory, which West Virginia University's (WVU) Department of Mechanical and Aerospace Engineering designed and constructed as a portable chassis dynamometer.

Lessons Learned

- **Preparation is essential.** Before starting a project, solidify the company's commitment to the environment, meet with managers to gain their support for purchasing or retrofitting vehicles, and notify employees about the company's plan. Research available incentives, acquire parts and supplies, and develop methods to measure performance and maintenance needs.
- **Keep abreast of ongoing activities.** Analyze the required range and routes of the fleet and locations of publicly available fueling stations, integrate alternative fuels information into training programs, install on-site fueling facilities (or share installation costs with another organization), stay current on technologies, and identify and consult with similar companies that participate in alternative fuel projects.
- **Develop long-term strategies.** Determine real costs, provide regular updates to those concerned about alternative fuels, and communicate regularly with stakeholders about the company's activities and objectives.



The corporate commitment to the environment is clearly shared by managers at the Hartford area facilities. They believe questions such as, "Should we be using cleaner fuels?" or "Can the AFVs perform as well as conventional vehicles?" are being answered every day, based on their experience with the CNG-powered vehicles they have used since the late 1990s.

"From the beginning of discussions about using cleaner fuels—in 1996—I was psyched," said Steve Mitchell, plant engineer at the Waterbury facility, referring to the opportunity to use CNG. Having support from the state to encourage switching to cleaner fuels "really sealed the deal," he added.

Accommodating the CNG fueling station was not a problem at the Waterbury site, Mitchell recalled. "We already had a large central fueling island, so we just added the CNG tanks alongside the diesel tanks."

David Hooke, fleet supervisor at the Hartford facility, was also involved at the beginning of UPS's move to CNG. "At the Hartford facility, 101 of our 135 package cars now use CNG; the other 34 are powered by gasoline or diesel."

"These CNG cars roll in and out of here all day and we expect to keep them going for about 20 years," said Tom Robinson, the district automotive fleet manager. Each UPS driver delivers as many as 500 packages a day, which requires careful planning and teamwork. At each UPS sorting facility, packages are loaded into the package cars in the same order in which they are to be delivered. The facility is designed to sort tens of thousands of packages per hour.

Mitchell and Hooke agree with the corporate staff in Atlanta that too few publicly accessible CNG fueling stations are available. "That's hurting us because it limits the vehicle's range and adds to the driver's anxiety," Mitchell said. "At the time we installed our CNG fueling station, it was the largest in the area," Robinson added.

Even with on-site CNG fueling stations and careful route planning at Hartford and Waterbury, some eventualities cannot be covered. UPS offers an on-call courtesy pickup along the routes, and cannot anticipate the number of calls for this service. So sometimes the vehicles run out of fuel trying to meet this commitment, causing major delays and usually requiring a tow to the UPS facility.

Running low on fuel is a concern at both Hartford-area hubs, but it is more likely to occur in Waterbury. The CNG vehicles normally go 80 to 90 miles on a full tank in Hartford, which has fairly flat terrain. But in Waterbury, the many hilly routes reduce the miles per fillup and a car can run low on fuel far from its home base. If a Hartford-based car runs low on CNG near the municipal airport, it can be refueled at the CNG station near Windsor.

The need for publicly accessible fuel supply stations is a nationwide issue for government and private sector leaders committed to promoting the use of alternative fuels.

Evaluation Results

The analyses in this report cover 13 CNG trucks and 3 diesel trucks that operated during the 28-month focus periods (see Table 2). These periods were chosen to analyze each vehicle over a similar range of accumulated mileage.

Actual Truck Use in Service

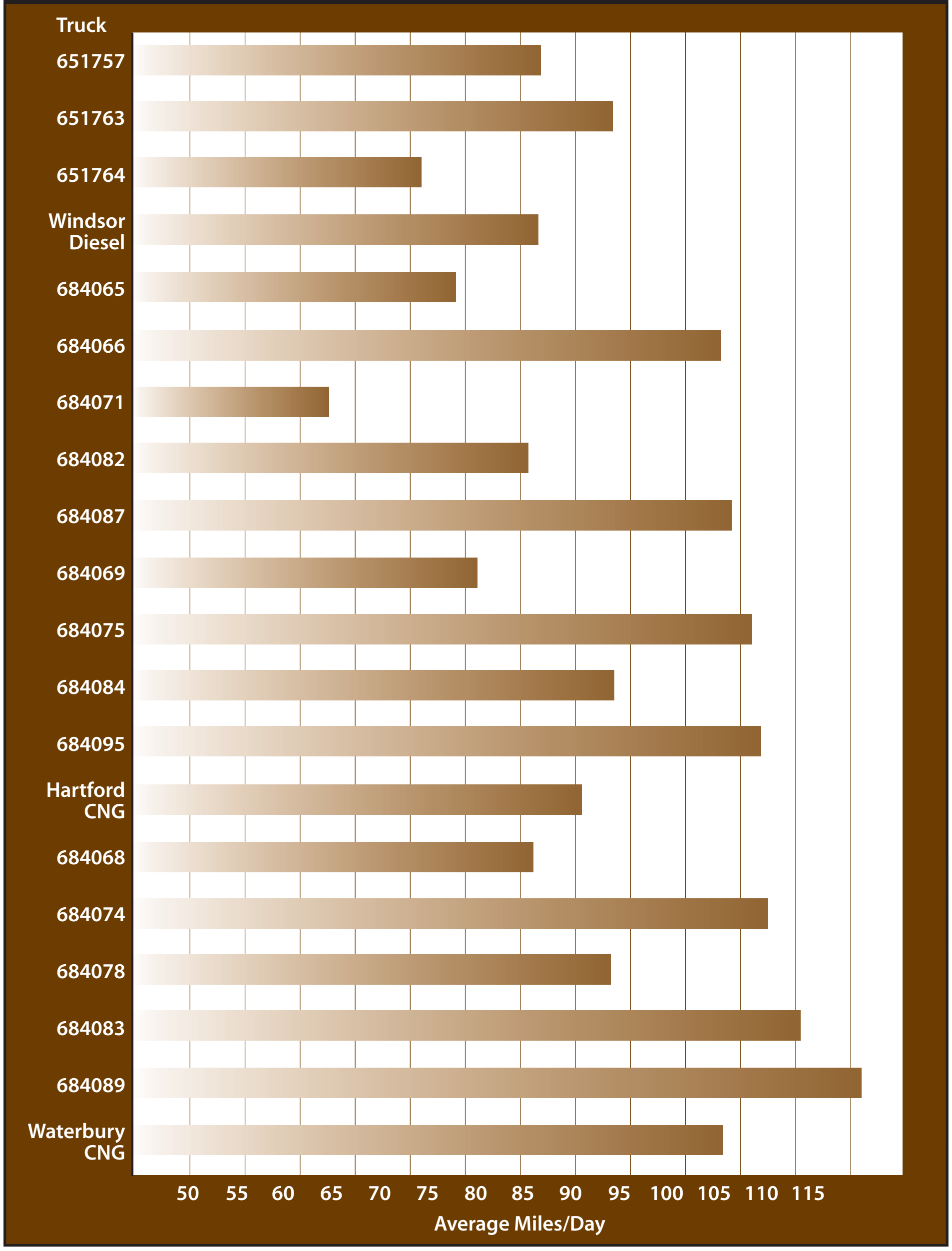
The CNG and diesel delivery trucks at Hartford, Waterbury, and Windsor operate for as long as 12 hours a day, 6 days per week. During the course of the day, the vehicles make both pickups and deliveries on routes that are carefully planned with mapping software. The diesel trucks have a 350- to 400-mile range when fully fueled. The CNG trucks have about a 125-mile range when fueled at 3,600 psi and a 110 mile range at 3,000 psi.

The vehicles analyzed for this study operate on a variety of terrains. The Windsor and Hartford areas

Table 2. Start of Operation Date, Fuel Data Period, and Maintenance Data Period for Each Study Truck

Fuel Type	Truck Number	Facility	Month of Start	Fuel Data Period	Maintenance Data Period
Diesel	651757	Windsor	4/96	12/98-6/99; 5/00-10/00	1/97-4/99
Diesel	651763	Windsor	4/96	12/98-6/99; 5/00-10/00	1/97-3/99
Diesel	651764	Windsor	4/96	5/00-10/00	1/97-7/99
CNG	684065	Hartford	4/97	9/98-6/99; 5/00-10/00	1/98-5/00
CNG	684066	Hartford	4/97	9/98-6/99; 5/00-10/00	11/97-4/00
CNG	684071	Hartford	4/97	9/98-6/99; 5/00-10/00	11/97-6/00
CNG	684075	Hartford	4/97	5/00-10/00	2/98-7/00
CNG	684082	Hartford	4/97	9/98-6/99; 5/00-10/00	11/97-1/00
CNG	684087	Hartford	4/97	9/98-6/99; 5/00-10/00	11/97-2/00
CNG	684069	Hartford	4/97	5/00-10/00	1/98-6/00
CNG	684084	Hartford	4/97	5/00-10/00	2/98-5/00
CNG	684068	Waterbury	4/97	9/98-6/99; 5/00-10/00	1/98-9/00
CNG	684074	Waterbury	4/97	9/98-6/99; 5/00-10/00	10/97-12/99
CNG	684078	Waterbury	4/97	9/98-6/99; 5/00-10/00	12/97-7/00
CNG	684083	Waterbury	4/97	9/98-6/99; 5/00-10/00	12/97-12/99
CNG	684089	Waterbury	4/97	9/98-6/99; 5/00-10/00	12/97-3/00

Figure 4. Average daily use (May 1997-September 2000)



have flat terrains in primarily urban settings. Waterbury has a hilly terrain and the trucks run on longer routes.

Figure 4 shows average daily use of the trucks evaluated in this study. The CNG trucks at Hartford had 4% higher average daily mileage than the diesel trucks. The CNG trucks at Waterbury had about 19% higher average daily mileage than the diesel trucks at Windsor.

Figure 5 shows average monthly mileage by vehicle. The data are for all vehicles through September 2000. The CNG trucks in Hartford have essentially the same average monthly mileage as the diesel trucks at Windsor. The CNG trucks in Waterbury have 19% higher monthly mileage than the diesel trucks in Windsor, which is consistent with the average daily mileage shown in Figure 4.

Figure 6 shows the average monthly mileage by truck for each group.

Figure 5. Average monthly mileage by vehicle

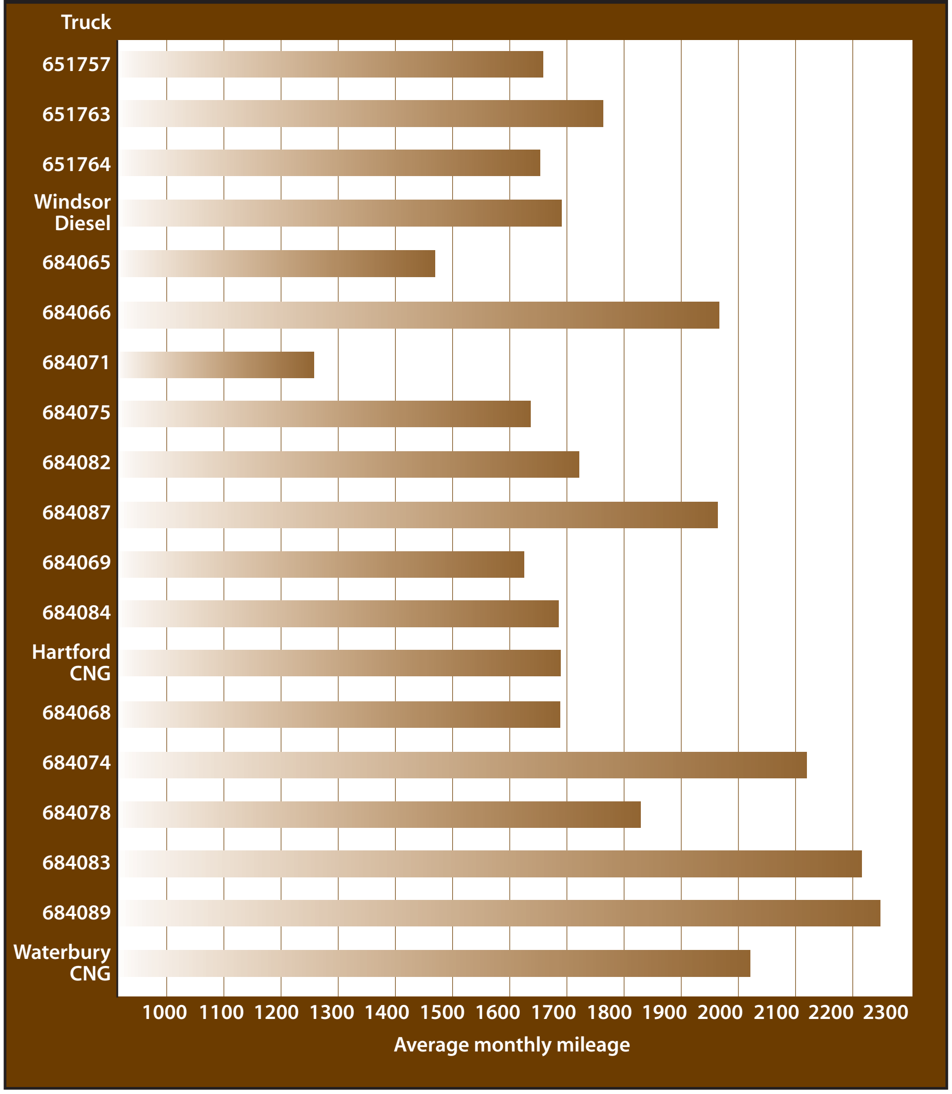
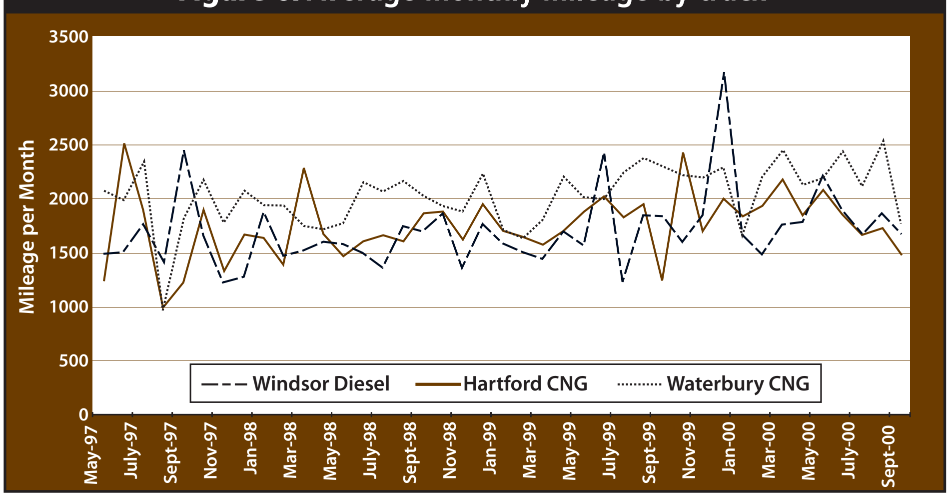


Figure 6. Average monthly mileage by truck



Fuel Consumption, Economy, and Cost

Fuel consumption data were collected during two calendar periods: September 1, 1998, through June 11, 1999; and May 1 through October 24, 2000. Per-truck and per-fleet fuel consumption and economy are shown in Table 3. The fuel economies are 27% lower for the CNG trucks at Hartford and 28% lower at Waterbury than for the diesel control trucks (based on diesel energy equivalent gallons). The CNG dispensers at Hartford and Waterbury have readouts in GGE, the amount of CNG that has the same energy content as one gallon of gasoline. To calculate diesel energy equivalent gallons, the GGE was multiplied by 0.9, which is based on the energy content difference between gasoline and diesel. (See Figure 7.)

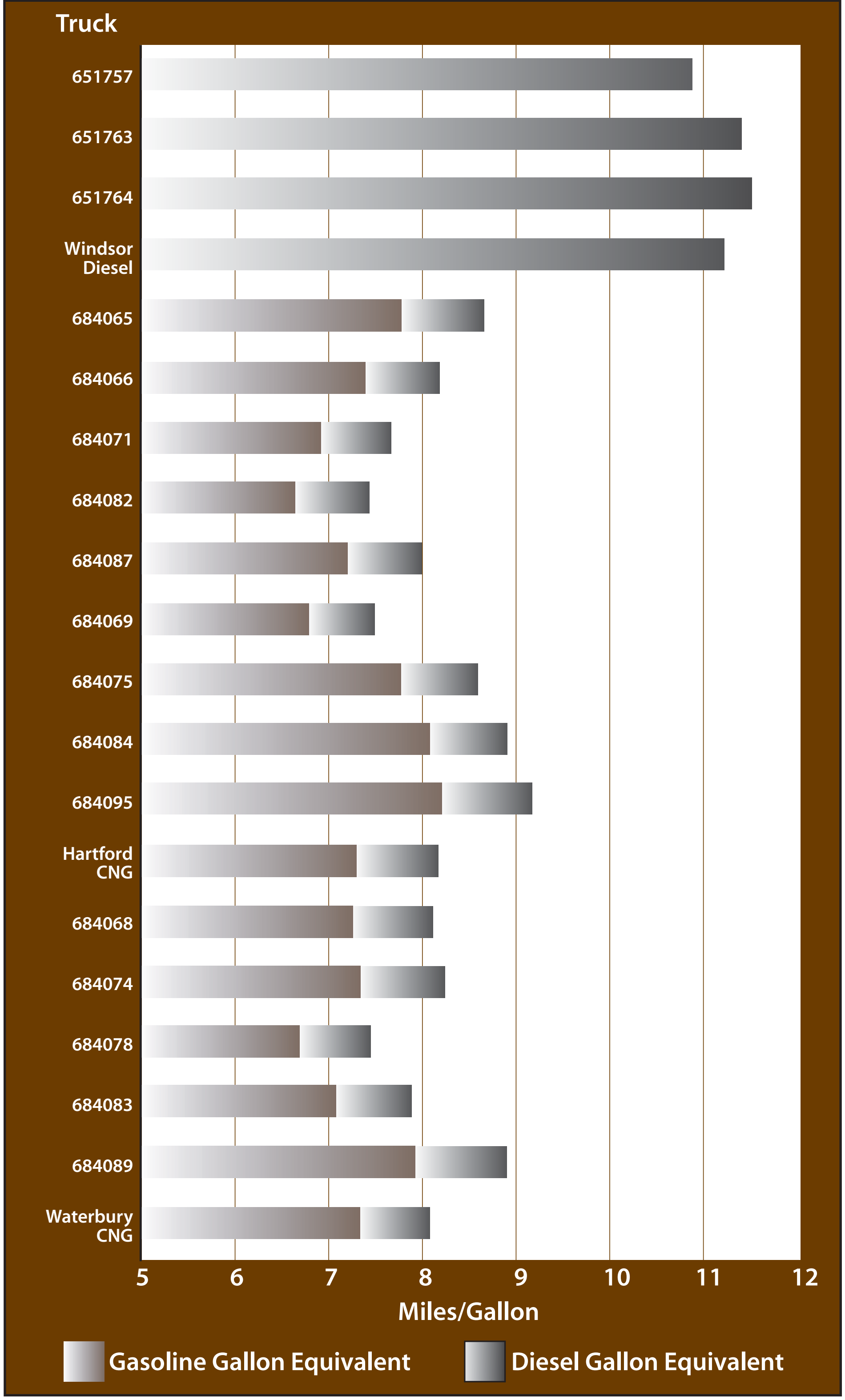
Table 3. Fuel Consumption and Economy

Vehicle	Mileage (Fuel Base)	CNG Gallons	Miles/ GGE	Diesel Energy Equivalent Gallon*	MPEG**
651757	21,865	-	-	2,009	10.88
651763	20,612	-	-	1,796	11.48
51764	8,412	-	-	730	11.52
Windsor Diesel	**50,889**	**-**	**-**	**4,535**	**11.22**
684065	22,149	2,843	7.79	2,559	8.66
684066	28,775	3,903	7.37	3,513	8.19
684071	17,946	2,595	6.92	2,336	7.68
684082	24,152	3,612	6.69	3,251	7.43
684087	22,545	3,133	7.20	2,820	8.00
684069	9,441	1,390	6.79	1,251	7.55
684075	12,315	1,584	7.77	1,426	8.64
684084	9,170	1,142	8.03	1,028	8.92
684095	12,774	1,547	8.26	1,392	9.17
Hartford CNG	**159,267**	**21,749**	**7.32**	**19,574**	**8.14**
684068	24,246	3,340	7.26	3,006	8.07
684074	34,284	4,681	7.32	4,213	8.14
684078	24,528	3,648	6.72	3,283	7.47
684083	31,099	4,411	7.05	3,970	7.83
684089	33,659	4,230	7.96	3,807	8.84
Waterbury CNG	**147,816**	**20,310**	**7.28**	**18,279**	**8.09**

Note: The mileage and gallons columns show the amount used in calculations, not the total used in service.
*Diesel energy equivalent gallons are calculated by GGE 0.9.
**MPEG—miles per equivalent gallon.

The diesel fuel costs reported during the data collection were $1.02/gal (1998) to $1.25/gal (2000), including federal and state taxes. CNG fuel cost was $0.39/standard cubic foot (scf) to $0.60/scf, plus federal tax and state tax. The fuel costs used for operating cost comparisons were $1.20/diesel gal and $0.60/scf for CNG. The federal tax for CNG use is $0.4854/Mcf (1,000 ft^3), which translates into $0.0605/GGE or $0.0675/diesel gallon equivalent. (The cost of natural gas has fluctuated significantly since the end of the data collection period.) The fuel consumption data provided in this report could easily be used to recalculate the fuel cost based on other fuel prices.

Figure 7. Fuel consumption and economy



Engine Oil Consumption and Cost

Engine oil consumption is measured by recording the volume of engine oil added between oil changes. For most engines, a certain level of engine oil consumption is expected, but higher-than-expected engine oil consumption is a precursor to engine problems. Engine oil consumption data were not available for the data collection period.

The cost of engine oil for the diesel trucks was $0.69/quart. Oil was $1.19/quart for the CNG trucks because it had to be very low ash and was purchased in low volume.

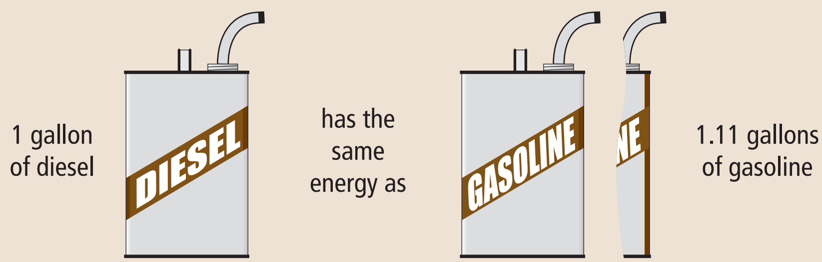
Maintenance, Maintenance Costs, and Warranty Work

All maintenance work orders and parts information were collected for the study trucks. The following analysis first covers total maintenance costs with no warranty work included. Next,

What Is a Diesel Equivalent Gallon?

1 gallon diesel	=	1.43 therm (90,000 Btu LHV CNG)
	=	139.3 scf (standard cubic feet)
	=	6.34 lb
	=	1.11 GGE (gasoline gallon equivalent)

Conversions are based on average energy content. Numbers change slightly based on energy content (varying amounts of methane) per volume.



the maintenance costs are broken down by system and discussed. Road calls are discussed; warranty costs and descriptions are provided after the maintenance costs by vehicle system.

The following discussions focus only on the results for similar vehicle lifetime comparisons, which nominally began about 9 months after the truck started operating for UPS and extended through about 28 months of operation. This period, which was chosen to evaluate similar vehicle lifetimes, was intended to start after the third PMI cycle and run for about 9 PMIs.

Total Maintenance Costs

Maintenance costs by vehicle and fleet show that labor costs are held constant at $50/hour. For the Hartford CNG trucks, the similar vehicle lifetime data show the average vehicle mileage is 4% higher than for the diesel trucks at Windsor. The parts costs are 28% higher, labor hours are 39% higher, and the overall cost per mile is 29% higher for the CNG trucks. Hartford costs included additional filter changes because of contaminated fuel.

For the Waterbury CNG trucks, the similar lifetime data show the average vehicle mileage is 21% higher than the diesel trucks at Windsor. The parts costs are 4% higher, labor hours are 21% higher, and the overall cost per mile is 6% lower for the CNG trucks. The comparison is in cost per mile, and the Waterbury CNG trucks have significantly higher mileage than the Hartford and Windsor trucks. This lowers the cost per mile for the Waterbury CNG trucks (see Table 4).

Figures 8 through 11 show total maintenance costs by vehicle and fleet.

Figure 12 shows maintenance costs per mile for each study truck group and all data collected from UPS. The x axis shows time in months from the start of operation (not calendar months) for each fleet. This chart shows clearly that the CNG trucks in Hartford have consistently been about 30% more costly to maintain than the diesel trucks or the CNG trucks in Waterbury.

Maintenance Costs by System

The following maintenance costs by vehicle system are included in this report (see Table 5):

- Cab, body, and accessories – includes body repairs, repairs following accidents, glass, and painting; cab and sheet

Figure 8. Maintenance costs

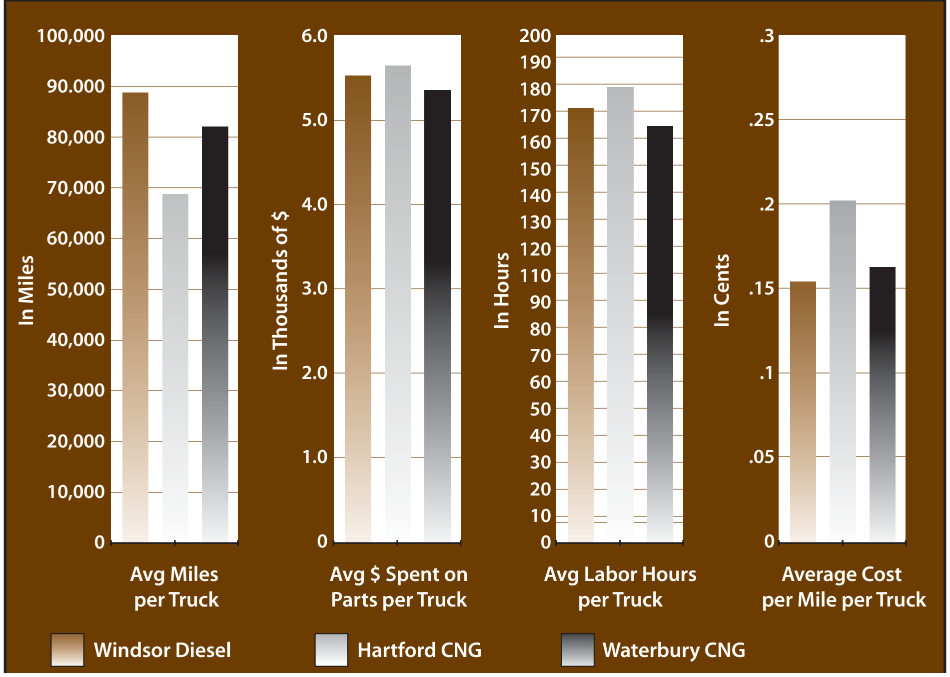


Figure 9. Maintenance cost per mile from start of operation

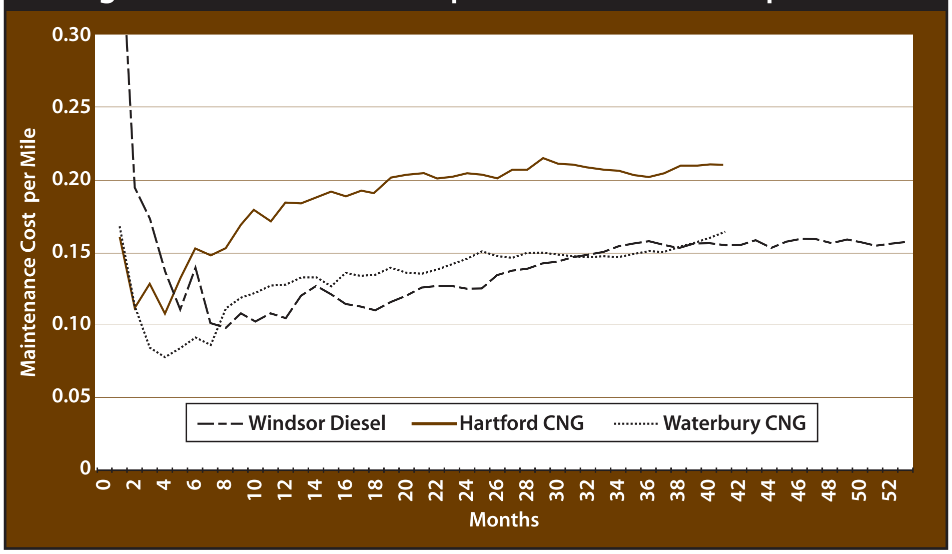
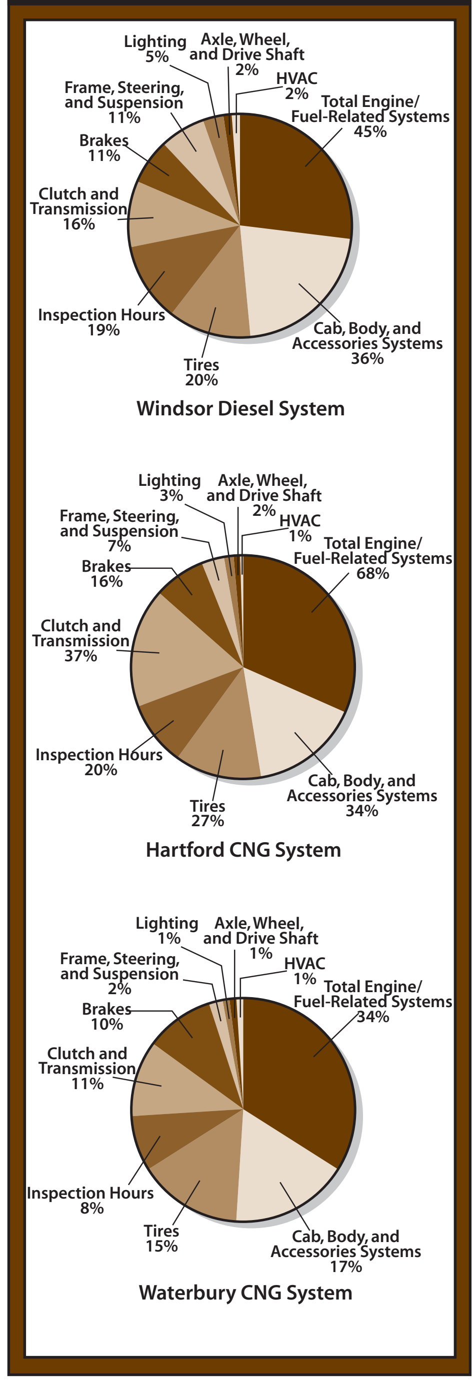


Figure 10. Share of maintenance costs across major systems



metal repairs including seats, sun visor, and doors; and accessory repairs

- Engine- and fuel-related systems – exhaust, fuel, engine, non-lighting electrical, air intake, and cooling repairs
- PMIs – labor for inspections during preventive maintenance
- Brakes
- Lighting
- Frame, steering, and suspension – includes bumper, steering, and suspension repairs such as springs, power steering system, and shock absorbers
- HVAC – heating, ventilation, and air conditioning repairs
- Clutch and transmission
- Tires
- Axle, wheel, and drive shaft assemblies.

Figure 11. Overall operating costs, based on mileage

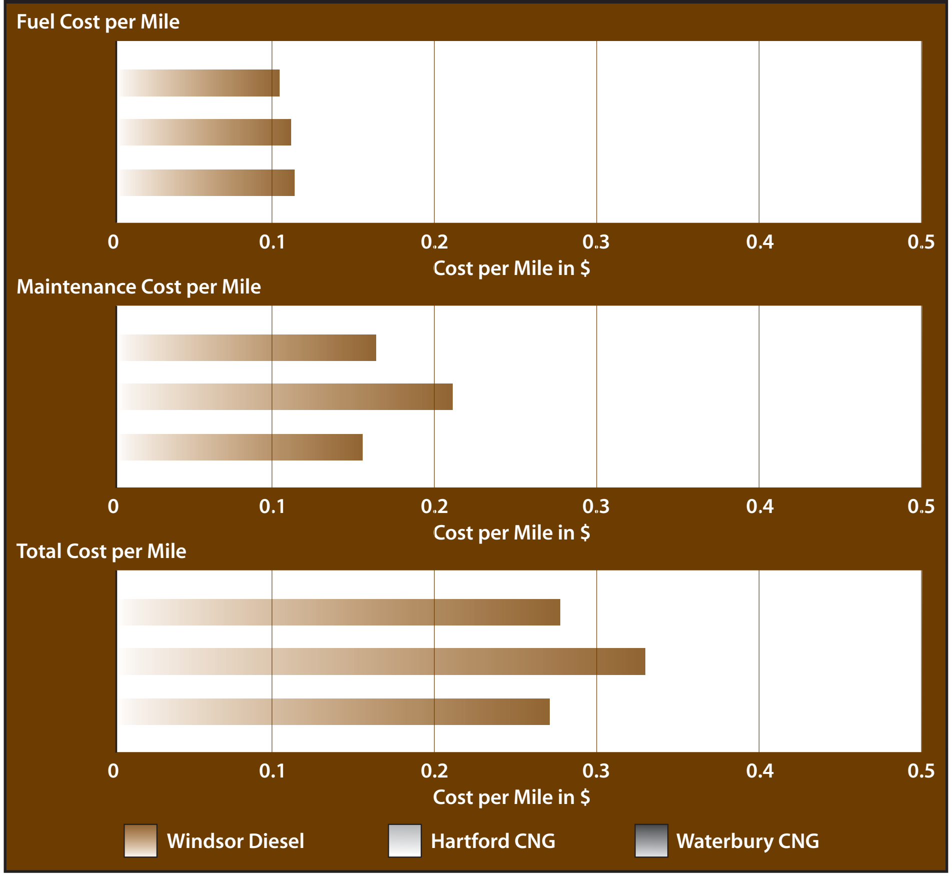
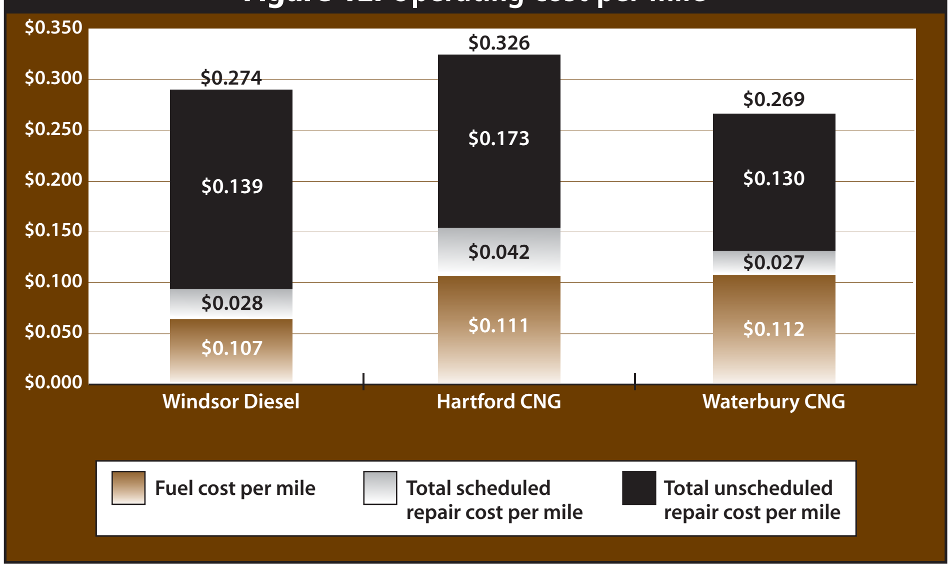


Figure 12. Operating cost per mile



The top five cost categories are nearly the same for all three groups:

1. Total engine- and fuel-related systems
2. Cab, body, and accessories
3. Tires
4. Inspection hours
5. Clutch and transmission

Tables 4 and 5 show maintenance costs by vehicle system for diesel trucks and Hartford and Waterbury trucks.

The order changed slightly between the study groups. The Waterbury CNG trucks had the brakes as the fifth-highest cost system and the inspection hours as the sixth-highest.

Total Engine- and Fuel-Related Systems

The CNG trucks at Hartford had engine- and fuel-related system costs 52% higher than the diesel trucks. The Waterbury CNG truck costs were only 17% higher. This cost includes the following:

- **Exhaust System** – The maintenance costs for the CNG trucks were significantly higher because there were almost no costs for the diesel trucks.
- **Fuel System** – The Hartford CNG truck maintenance costs were about the same as for the diesel trucks and 36% lower than the CNG trucks at Waterbury. The diesel trucks had problems with the fuel pumps. The CNG trucks had issues with the fuel regulators, which had to be rebuilt. However, Cummins continued to cover the rebuilds under warranty even at the end of the data collection

period. Hartford had higher costs for the fuel system than the Waterbury CNG trucks because the fuel filters were changed at every PMI in Hartford to counteract the oil carryover problem. The Hartford CNG trucks had seven road calls for the fuel system; the Waterbury CNG trucks had one.

- **Engine System** – The CNG truck maintenance costs at Hartford were three times higher and, at Waterbury, they were 1.7 times higher than the diesel trucks, caused by the higher engine oil costs. The Hartford CNG trucks had higher costs than the Waterbury CNG trucks because Waterbury had a longer PMI cycle (7,000 to 8,000 miles versus 5,000 miles at Hartford) and for many minor repairs performed on the Hartford CNG trucks. The diesel trucks had very little scheduled maintenance for the engine system.

- **Non-Lighting Electrical Systems** – Each group had repairs to replace alternators ($110 each), starters ($92 each), batteries ($58 each), starter solenoids ($11 each), and ignition switches ($23 each). The CNG trucks required replacement spark plugs and wires ($113.52 for the set) that the diesel trucks did not. The CNG trucks at Hartford had 76% higher costs and the Waterbury CNG trucks had 55% higher costs than the diesel trucks. The Hartford CNG trucks had five road calls reported for "won't start"; the Waterbury CNG trucks had four such road calls.

- **Air Intake System** – The maintenance costs for the CNG and diesel trucks were low and about the same for the three groups. The Hartford CNG trucks had higher costs.

- **Cooling System** – The maintenance costs for the diesel trucks were slightly higher because of radiator replacements and problems with the coolant reservoir.

Brake System

The CNG trucks at both sites incurred significantly higher costs than the diesel trucks (41% higher at Hartford and 33% higher at Waterbury). This was caused by differences in the timing of brake relines; it does not imply that the CNG systems caused higher brake costs.

Table 4. Breakdown of Vehicle System Maintenance Costs

System	Windsor Diesel		Hartford CNG		Waterbury CNG	
	Cost/Mi	%	Cost/Mi	%	Cost/Mi	%
Total Engine- and Fuel-Related Systems	0.045	26	0.068	32	0.053	34
Cab, Body, and Accessories Systems	0.036	22	0.034	16	0.027	17
Tires	0.020	12	0.027	13	0.023	15
Inspection Hours	0.019	11	0.020	9	0.013	8
Clutch and Transmission	0.016	10	0.037	17	0.017	11
Brakes	0.010	17	0.016	7	0.015	10
Frame, Steering, and Suspension	0.011	7	0.007	3	0.003	2
Lighting	0.005	3	0.003	1	0.002	1
Axle, Wheel, and Drive Shaft	0.002	1	0.002	1	0.002	1
HVAC	0.002	1	0.001	1	0.002	1
Total	**0.167**	**100**	**0.215**	**100**	**0.157**	**100**

Table 5. Maintenance Costs by Vehicle System

Maintenance System Costs	Similar Vehicle Lifetimes (28 Months)		
	Windsor Diesel	Hartford CNG	Waterbury CNG
Milage	142,058	395,155	285,703
Total Engine- and Fuel-Related Systems (VMRS Codes 30, 31, 32, 33, 41, 42, 43, 44, 45)			
Parts ($)	3,751.72	11,311.23	5,504.26
Labor Hours	52.90	314.00	191.00
Total Cost ($)	6,394.22	27,012.23	15,052.26
Total Cost ($) per Mile	**0.0450**	**0.0684**	**0.0527**
Exhaust System Repairs (VMRS Code 43)			
Parts ($)	0.00	111.18	32.39
Labor Hours	0.90	12.10	5.30
Total Cost ($)	46.00	715.68	294.89
Total Cost ($) per Mile	**0.0003**	**0.0018**	**0.0010**
Fuel System Repairs (VMRS Code 44)			
Parts ($)	1,198.21	2,004.12	584.95
Labor Hours	17.80	77.00	42.00
Total Cost ($)	2,085.71	5,856.12	2,686.45
Total Cost ($) per Mile	**0.0147**	**0.0148**	**0.0094**
Engine System Repairs (VMRS Code 45)			
Parts ($)	502.77	1,801.99	943.33
Labor Hours	4.40	81.40	30.80
Total Cost ($)	720.27	5,869.49	2,482.33
Total Cost ($) per Mile	**0.0051**	**0.0149**	**0.0087**
Electrical System Repairs (VMRS Codes 30-General Electrical, 31-Charging, 32-Cranking, 33-Ignition)			
Parts ($)	1,546.20	6,818.73	3,380.07
Labor Hours	22.50	125.10	99.10
Total Cost ($)	2,670.20	13,074.23	8,335.07
Total Cost ($) per Mile	**0.0188**	**0.0331**	**0.0292**
Air Intake System Repairs (VMRS Code 41)			
Parts ($)	187.88	560.21	350.55
Labor Hours	1.10	8.10	0.80
Total Cost ($)	242.88	966.71	388.05
Total Cost ($) per Mile	**0.0017**	**0.0024**	**0.0014**
Cooling System Repairs (VMRS Code 42)			
Parts ($)	316.86	15.00	212.97
Labor Hours	6.30	10.30	13.10
Total Cost ($)	629.36	530.00	865.47
Total Cost ($) per Mile	**0.0044**	**0.0013**	**0.0030**
Brake System Repairs (VMRS Code 13)			
Parts ($)	647.55	2,550.80	1,606.39
Labor Hours	18.60	73.30	52.40
Total Cost ($)	1,578.55	6,215.80	4,223.89
Total Cost ($) per Mile	**0.0111**	**0.0157**	**0.0148**

VMRS – vehicle maintenance reporting system codes from American Trucking Associations.

Continued

HVAC System

The maintenance costs for all three groups were low and about the same. The CNG trucks at Waterbury had the highest cost.

Preventive Maintenance Inspections

These included labor hours only. The CNG trucks at Hartford had 7% higher PMI labor than the diesel trucks. The CNG trucks at Waterbury had lower costs because the PMI cycle was longer than for the diesel or the CNG trucks at Hartford (7,000 to 8,000 miles between PMIs at Waterbury versus 5,000 miles at Hartford and Windsor).

Cab, Body, and Accessories Systems

The maintenance costs for these systems were nearly the same for the diesel and the CNG trucks. The repairs included doors, mirrors, seats, windshield wipers, windshield glass, and window glass. Accessory equipment included UPS's communications equipment and tracking (two-way communication with the truck) supplies and inspections.

Frame, Steering, and Suspension Systems

The maintenance costs for the Waterbury CNG trucks were lower than for the CNG trucks at Hartford and the diesel trucks. The Hartford and Windsor diesel trucks had higher costs because of problems with the steering and some extra suspension work. The steering problems were part of a national recall for spindle problems. Some costs for troubleshooting these problems were not covered under warranty.

Clutch and Transmission Systems

All the study trucks have manual transmissions. All the Hartford CNG trucks had clutches replaced or repaired, at significant cost.

Axle, Wheel, and Drive Shaft Systems

The maintenance costs for these systems were low for all three sets of trucks. The CNG trucks at Waterbury had slightly higher costs.

Tire Systems

The tire system maintenance costs were nearly the same.

Lighting System

The maintenance costs were nearly the same. The diesel trucks had the highest costs.

Overall Operating Costs

The Hartford CNG trucks had a 4% higher fuel cost than the Windsor diesel trucks; the maintenance costs were 29% higher. This gives a total cost 19% higher. For the Waterbury CNG trucks, the fuel cost was 5% higher than the Windsor diesel trucks and the maintenance costs were 6% lower. This gives a total cost 2% lower. The mileage accumulation at Waterbury implies a significant duty cycle difference compared to the Windsor or Hartford trucks; this affected the total cost-per-mile comparison.

Table 6 summarizes overall operating costs (without driver labor) based on vehicle mileage.

Table 5. Maintenance Costs by Vehicle System (continued)

Maintenance System Costs	Similar Vehicle Lifetimes (28 Months)		
	Windsor Diesel	Hartford CNG	Waterbury CNG
HVAC System Repairs (VMRS Code 01)			
Parts ($)	67.47	32.00	118.12
Labor Hours	2.80	8.50	9.30
Total Cost ($)	206.47	459.00	585.12
Total Cost ($) per Mile	**0.0015**	**0.0012**	**0.0020**
PMIs—no parts replacements (101)			
Parts ($)	0.00	0.00	0.00
Labor Hours	54.00	161.60	73.60
Total Cost ($)	2,700.50	8,077.50	3,680.00
Total Cost ($) per Mile	**0.0190**	**0.0204**	**0.0129**
Cab, Body, and Accessory System Repairs (VMRS Codes 02-Cab and Sheet Metal, 50-Accessories, 71-Body)			
Parts ($)	1,383.98	2,744.44	1,965.98
Labor Hours	75.60	212.70	114.70
Total Cost ($)	5,162.98	13,380.94	7,698.98
Total Cost ($) per Mile	**0.0363**	**0.0339**	**0.0269**
Frame, Steering, and Suspension System Repairs (VMRS Codes 14-Frame, 15-Steering, 16-Suspension)			
Parts ($)	598.09	970.63	312.59
Labor Hours	18.80	39.90	12.70
Total Cost ($)	1,539.09	2,967.13	947.09
Total Cost ($) per Mile	**0.0108**	**0.0075**	**0.0033**
Clutch and Transmission System Repairs (VMRS Codes 23-Clutch, 26-Transmission)			
Parts ($)	918.18	7,462.83	2,190.42
Labor Hours	28.30	140.40	52.20
Total Cost ($)	2,334.18	14,482.83	4,799.92
Total Cost ($) per Mile	**0.0164**	**0.0367**	**0.0168**
Axle, Wheel, and Drive Shaft System Repairs (VMRS Codes 11-Front Axle, 18-Wheel, 22-Rear Axle, 24-Drive Shaft)			
Parts ($)	63.00	103.51	50.69
Labor Hours	2.70	11.40	14.00
Total Cost ($)	200.00	674.01	750.19
Total Cost ($) per Mile	**0.0014**	**0.0017**	**0.0026**
Tire System Repairs (VMRS Code 17)			
Parts ($)	2,406.92	8,559.52	5,356.89
Labor Hours	9.50	38.90	23.70
Total Cost ($)	2,879.92	10,502.52	6,539.39
Total Cost ($) per Mile	**0.0209**	**0.0266**	**0.0229**
Lighting System Repairs (VMRS Code 34)			
Parts ($)	117.94	256.19	90.52
Labor Hours	12.10	17.90	11.50
Total Cost ($)	720.44	1,152.19	663.02
Total Cost ($) per Mile	**0.0051**	**0.0029**	**0.0023**

VMRS – vehicle maintenance reporting system codes from American Trucking Associations.

Table 6. Summary of Operating Costs Based on Vehicle Mileage

Truck	Fuel Cost/Mi ($)	Maintenance Cost/Mi ($)	Total Cost/Mi ($)
651757	0.110	0.176	0.286
651763	0.105	0.193	0.298
651764	0.104	0.140	0.244
Windsor Diesel	**0.107**	**0.167**	**0.274**
684065	0.104	0.229	0.333
684066	0.110	0.219	0.329
684071	0.117	0.266	0.383
684075	0.104	0.199	0.303
684082	0.121	0.218	0.339
684087	0.113	0.204	0.317
684069	0.119	0.187	0.306
684084	0.101	0.204	0.305
Hartford CNG	**0.111**	**0.215**	**0.326**
684068	0.112	0.154	0.266
684074	0.111	0.155	0.266
684078	0.120	0.162	0.282
684083	0.115	0.166	0.218
684089	0.102	0.150	0.252
Waterbury CNG	**0.112**	**0.157**	**0.269**

Figure 13. CSHVR cycle trace from one of the UPS trucks

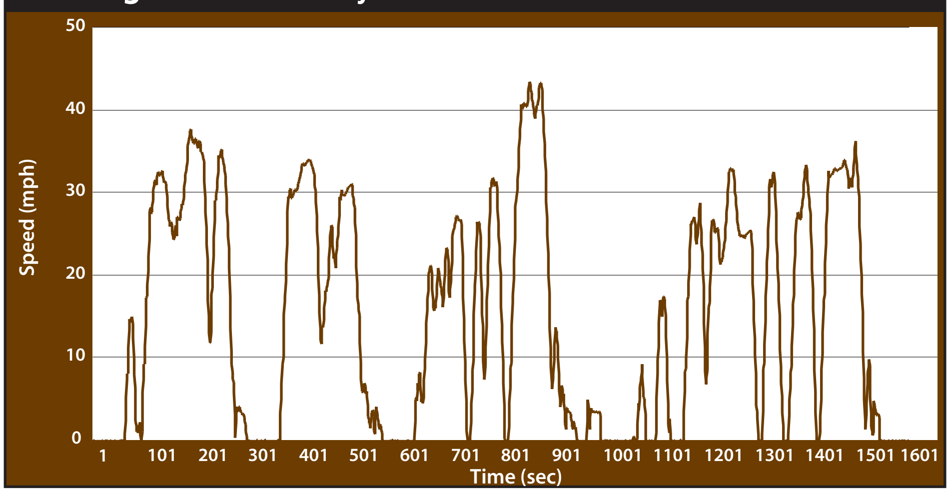
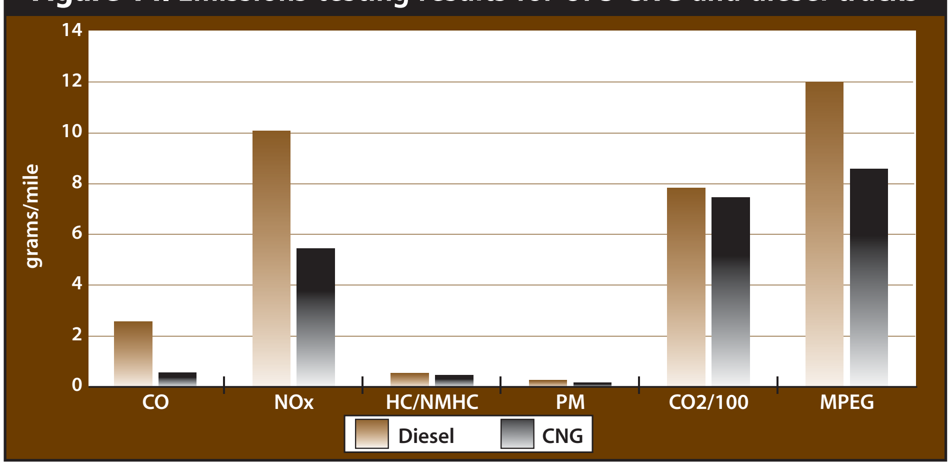


Figure 14. Emissions testing results for UPS CNG and diesel trucks



Emission Testing Results

DOE funded WVU's Department of Mechanical and Aerospace Engineering project to design and construct a portable chassis dynamometer to test for emission levels from heavy-duty vehicles. The dynamometer allows a large number of "real world" emission tests to be performed on heavy-duty vehicles around the country (see Figure 13). The first transportable unit was built in 1991; WVU has traveled to transit agencies and heavy-duty vehicle sites to test vehicles since early 1992. A second unit was built in 1994 and began testing vehicles in 1995. In 1999 and 2000, WVU developed a medium-duty vehicle chassis dynamometer for use with smaller vehicles. It was validated at WVU before being sent to Hartford for testing, and uses an instrumentation trailer similar to the heavy-duty dynamometer. The UPS vehicle testing was the first field experience with this dynamometer.

Figure 14 shows the results of the emission testing by truck and summaries for each group. Only the CNG trucks from the Hartford facility and diesel trucks from the Windsor facility were tested. The Waterbury CNG trucks were not emission tested because moving the CNG trucks from Waterbury to Hartford was not convenient.

Summary and Conclusions

- CNG delivery trucks at the Hartford and Waterbury sites are used as much as or more than the diesel vehicles in the area. If better CNG compression equipment were available at Hartford, the CNG trucks would be used more. UPS also expressed an interest in public refueling (especially for Hartford, but also for Waterbury) that would allow the range of the CNG vehicles to be extended en route; however, there is no conveniently located public refueling for the UPS operation (see Figure 15).
- The CNG truck engine was upgraded before delivery to a slightly higher horsepower and torque rating than smaller diesel vehicles used in the area (including the diesel control vehicles in this study). This has alleviated early driver complaints regarding the performance of the Freightliner CNG trucks delivered to UPS and compared to the diesel trucks. The CNG engine has a slightly different torque curve than the diesel engine, so the higher horsepower and torque rating on the CNG engine helped overcome that difference.
- The CNG engine and fuel system used at UPS are early production models. Some problems with spark plug wires and fuel regulators were caused by excess compressor oil. Cummins and Freightliner continue to support these products at UPS. Newer engine and fuel system technologies would likely have a significant, positive impact in this environment.
- The energy equivalent fuel economy of the CNG trucks was 27% to 29% lower than that of the diesel trucks.

Battelle/PIX 07055

Figure 15. Refueling at a CNG station is similar to using gasoline pumps.

- The maintenance costs were 29% higher for the Hartford CNG trucks than for the diesel trucks because of engine problem troubleshooting, replacement of spark plugs and wires, and clutch and transmission repairs. The Waterbury CNG trucks had maintenance costs 6% lower than the diesel trucks because of higher vehicle use and longer PMI cycles.
- Total operating costs (without driver labor costs) include fuel and maintenance costs for operating the trucks in service. The CNG trucks at Hartford had 19% higher total operating costs than the diesel trucks; at Waterbury they were 2% lower. The Waterbury CNG operating costs were consistent with the diesel operating costs, but had a higher mileage duty cycle. The Hartford CNG trucks and the diesel trucks had similar duty cycles and provided a better comparison. Improved fuel economy (with new technology, the fuel economy may be 15% lower than the diesel trucks rather than 29% lower), lower CNG fuel cost (or incentives) to offset the fuel economy penalty, better spark plug wire life, and lower costs for repair parts would change the cost comparison positively for the CNG trucks at Hartford.
- For most implementations of natural gas vehicles, the goal is to reduce mobile emissions with the least impact on operating costs. The CNG trucks had 75% lower emissions for carbon monoxide, 49% lower oxides of nitrogen, and 95% lower particulate matter than the diesel trucks of similar age. The hydrocarbon emissions were about 4% higher for the diesel trucks than were the non-methane hydrocarbons for the CNG trucks. The carbon dioxide emissions were 7% lower for the CNG trucks, which were equipped with an exhaust catalyst.

Future CNG Operations at UPS

UPS's use of CNG vehicles is a core part of the company's strategy to use cleaner and more efficient alternative fuels in its fleet. This commitment is critical to the company's long-term viability and its ability to serve customers, employees, and shareholders in a socially responsible manner.

Across its operations, UPS has 140 OEM Freightliner CNG and 1,000 converted CNG package delivery vehicles in service. LNG has been used in a UPS tractor in California since 2001. In addition, UPS uses propane in 735 package delivery vehicles in Canada and 80 in Mexico. In late 2001, UPS began testing a hybrid electric vehicle in its fleet in Huntsville, Alabama. Initial testing has been positive, and the company will continue testing this technology.

UPS currently has no purchase requests for CNG vehicles, but continues to use CNG package delivery vehicles. The company demonstrates, evaluates, and watches the economics of new technology vehicles.

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Appendix A

Fleet Summary Statistics

Fleet Summary Statistics

UPS (Hartford and Waterbury, CT) Fleet Summary Statistics

Fleet Operations and Economics

	Windsor Diesel	Hartford CNG	Waterbury CNG
Number of Vehicles	3	8	5
Period Used for Fuel and Oil Op Analysis	12/98 - 6/99, 5/00 - 10/00	9/98 - 6/99, 5/00 - 10/00	9/98 - 6/99, 5/00 - 10/00
Total Number of Months in Period	13	15	15
Fuel and Oil Analysis Base Fleet Mileage	50,889	159,267	147,816
Average Maintenance Evaluation Period	1/97 - 5/99	12/97 - 5/00	12/97 - 4/00
Average Number of Months in Period	28	29	28
Maintenance Analysis Base Fleet Mileage	142,058	395,155	285,703
Average Evaluation Period Mileage per Vehicle	47,353	49,394	57,141
Total Number of Months in Period	84	230	140
Average Monthly Mileage per Vehicle	1,684	1,720	2,027
Fleet Fuel Usage in Diesel #2 Equiv. Gal.	4,535	19,574	18,279
Representative Fleet MPG (energy equiv.)	11.22	8.14	8.09
Ratio of MPG (CNG/DSL)		0.73	0.72
Average Fuel Cost per Gal (with tax)	1.20	0.90	0.90
Average Fuel Cost per Energy Equivalent	1.20	0.90	0.90
Fuel Cost per Mile	0.107	0.111	0.112
Total Scheduled Repair Cost per Mile	0.028	0.042	0.027
Total Unscheduled Repair Cost per Mile	0.139	0.173	0.130
Total Maintenance Cost per Mile	0.167	0.215	0.157
Total Operating Cost per Mile	0.274	0.326	0.269

Maintenance Costs

	Windsor Diesel	Hartford CNG	Waterbury CNG
Fleet Mileage	142,058	395,155	285,703
Total Parts Cost	9,954.85	33,988.15	17,195.86
Total Labor Hours	275.2	1018.7	554.9
Average Labor Cost (@ $50.00 per hour)	13,761.50	50,936.00	27,744.00
Total Maintenance Cost	23,716.35	84,924.15	44,939.86
Monthly Maintenance Cost per Truck	282.34	369.24	321.00
Total Maintenance Cost per Mile	0.167	0.215	0.157

Breakdown of Maintenance Costs by Vehicle System

	Windsor Diesel	Hartford CNG	Waterbury CNG
Fleet Mileage	142,058	395,155	285,703
Total Engine/Fuel-Related Systems (ATA VMRS 30, 31, 32, 33, 41, 42, 43, 44, 45)			
Parts Cost	3,751.72	11,311.23	5,504.26
Labor Hours	52.9	314.0	191.0
Average Labor Cost	2,642.50	15,701.00	9,548.00
Total Cost (for system)	6,394.22	27,012.23	15,052.26
Monthly Cost (for system) per Truck	76.12	117.44	107.52
Total Cost (for system) per Mile	**0.0450**	**0.0684**	**0.0527**
Exhaust System Repairs (ATA VMRS 43)			
Parts Cost	0.00	111.18	32.39
Labor Hours	0.9	12.1	5.3
Average Labor Cost	46.00	604.50	262.50
Total Cost (for system)	46.00	715.68	294.89
Monthly Cost (for system) per Truck	0.55	3.11	2.11
Total Cost (for system) per Mile	**0.0003**	**0.0018**	**0.0010**
Fuel System Repairs (ATA VMRS 44)			
Parts Cost	1,198.21	2,004.12	584.95
Labor Hours	17.8	77.0	42.0
Average Labor Cost	887.50	3,852.00	2,101.50
Total Cost (for system)	2,085.71	5,856.12	2,686.45
Monthly Cost (for system) per Truck	24.83	25.46	19.19
Total Cost (for system) per Mile	**0.0147**	**0.0148**	**0.0094**
Power Plant (Engine) Repairs (ATA VMRS 45)			
Parts Cost	502.77	1,801.99	943.33
Labor Hours	4.4	81.4	30.8
Average Labor Cost	217.50	4,067.50	1,539.00
Total Cost (for system)	720.27	5,869.49	2,482.33
Monthly Cost (for system) per Truck	8.57	25.52	17.73
Total Cost (for system) per Mile	**0.0051**	**0.0149**	**0.0087**
Electrical System Repairs (ATA VMRS 30-Electrical General, 31-Charging, 32-Cranking, 33-Ignition)			
Parts Cost	1,546.20	6,818.73	3,380.07
Labor Hours	22.5	125.1	99.1
Average Labor Cost	1,124.00	6,255.50	4,955.00
Total Cost (for system)	2,670.20	13,074.23	8,335.07
Monthly Cost (for system) per Truck	31.79	56.84	59.54
Total Cost (for system) per Mile	0.0188	0.0331	0.0292

Breakdown of Maintenance Costs by Vehicle System (continued)

	Windsor Diesel	Hartford CNG	Waterbury CNG
Air Intake System Repairs (ATA VMRS 41)			
Parts Cost	187.88	560.21	350.55
Labor Hours	1.1	8.1	0.8
Average Labor Cost	55.00	406.50	37.50
Total Cost (for system)	242.88	966.71	388.05
Monthly Cost (for system) per Truck	2.89	4.20	2.77
Total Cost (for system) per Mile	**0.0017**	**0.0024**	**0.0014**
Cooling System Repairs (ATA VMRS 42)			
Parts Cost	316.86	15.00	212.97
Labor Hours	6.3	10.3	13.1
Average Labor Cost	312.50	515.00	652.50
Total Cost (for system)	629.36	530.00	865.47
Monthly Cost (for system) per Truck	7.49	2.30	6.18
Total Cost (for system) per Mile	**0.0044**	**0.0013**	**0.0030**
Brake System Repairs (ATA VMRS 13)			
Parts Cost	647.55	2,550.80	1,606.39
Labor Hours	18.6	73.3	52.4
Average Labor Cost	931.00	3,665.00	2,617.50
Total Cost (for system)	1,578.55	6,215.80	4,223.89
Monthly Cost (for system) per Truck	18.79	27.03	30.17
Total Cost (for system) per Mile	**0.0111**	**0.0157**	**0.0148**
Transmission Repairs (ATA VMRS 26)			
Parts Cost	17.29	49.06	16.24
Labor Hours	3.4	14.7	5.0
Average Labor Cost	170.50	737.00	251.00
Total Cost (for system)	187.79	786.06	267.24
Monthly Cost (for system) per Truck	2.24	3.42	1.91
Total Cost (for system) per Mile	**0.0013**	**0.0020**	**0.0009**
Clutch Repairs (ATA VMRS 23)			
Parts Cost	900.89	7,413.77	2,174.18
Labor Hours	24.9	125.7	47.2
Average Labor Cost	1,245.50	6,283.00	2,358.50
Total Cost (for system)	2,146.39	13,696.77	4,532.68
Monthly Cost (for system) per Truck	25.55	59.55	32.38
Total Cost (for system) per Mile	**0.0151**	**0.0347**	**0.0159**

Breakdown of Maintenance Costs by Vehicle System (continued)

	Windsor Diesel	Hartford CNG	Waterbury CNG
Cab, Body, and Accessories Systems Repairs (ATA VMRS 02-Cab and Sheet Metal, 50-Accessories, 71-Body)			
Parts Cost	1,383.98	2,744.44	1,965.98
Labor Hours	75.6	212.7	114.7
Average Labor Cost	3,779.00	10,636.50	5,733.00
Total Cost (for system)	5,162.98	13,380.94	7,698.98
Monthly Cost (for system) per Truck	61.46	58.18	54.99
Total Cost (for system) per Mile	0.0363	0.0339	0.0269
Inspections Only - no parts replacements (101)			
Parts Cost	0.00	0.00	0.00
Labor Hours	54.0	161.6	73.6
Average Labor Cost	2,700.50	8,077.50	3,680.00
Total Cost (for system)	2,700.50	8,077.50	3,680.00
Monthly Cost (for system) per Truck	32.15	35.12	26.29
Total Cost (for system) per Mile	**0.0190**	**0.0204**	**0.0129**
HVAC System Repairs (ATA VMRS 01)			
Parts Cost	67.47	32.00	118.12
Labor Hours	2.8	8.5	9.3
Average Labor Cost	139.00	427.00	467.00
Total Cost (for system)	206.47	459.00	585.12
Monthly Cost (for system) per Truck	2.46	2.00	4.18
Total Cost (for system) per Mile	**0.0015**	**0.0012**	**0.0020**
Air System Repairs (ATA VMRS 10)			
Parts Cost	0.00	0.00	0.00
Labor Hours	0.0	0.0	0.0
Average Labor Cost	0.00	0.00	0.00
Total Cost (for system)	0.00	0.00	0.00
Monthly Cost (for system) per Truck	0.00	0.00	0.00
Total Cost (for system) per Mile	**0.0000**	**0.0000**	**0.0000**
Lighting System Repairs (ATA VMRS 34)			
Parts Cost	117.94	256.19	90.52
Labor Hours	12.1	17.9	11.5
Average Labor Cost	602.50	896.00	572.50
Total Cost (for system)	720.44	1,152.19	663.02
Monthly Cost (for system) per Truck	8.58	5.01	4.74
Total Cost (for system) per Mile	**0.0051**	**0.0029**	**0.0023**

Breakdown of Maintenance Costs by Vehicle System (continued)

	Windsor Diesel	Hartford CNG	Waterbury CNG
Frame, Steering, and Suspension System Repairs (ATA VMRS 14-Frame, 15-Steering, 16-Suspension)			
Parts Cost	598.09	970.63	312.59
Labor Hours	18.8	39.9	12.7
Average Labor Cost	941.00	1,996.50	634.50
Total Cost (for system)	1,539.09	2,967.13	947.09
Monthly Cost (for system) per Truck	18.32	12.90	6.76
Total Cost (for system) per Mile	0.0108	0.0075	0.0033
Axle, Wheel, and Drive Shaft Repairs (ATA VMRS 11-Front Axle, 18-Wheels, 22-Rear Axle, 24-Drive Shaft)			
Parts Cost	63.00	103.51	50.69
Labor Hours	2.7	11.4	14.0
Average Labor Cost	137.00	570.50	699.50
Total Cost (for system)	200.00	674.01	750.19
Monthly Cost (for system) per Truck	2.38	2.93	5.36
Total Cost (for system) per Mile	**0.0014**	**0.0017**	**0.0026**
Tire Repairs (ATA VMRS 17)			
Parts Cost	2,406.92	8,556.52	5,356.89
Labor Hours	9.5	38.9	23.7
Average Labor Cost	473.00	1,946.00	1,182.50
Total Cost (for system)	2,879.92	10,502.52	6,539.39
Monthly Cost (for system) per Truck	34.28	45.66	46.71
Total Cost (for system) per Mile	0.0203	0.0266	0.0229

Notes

1. The engine and fuel-related systems were chosen to include only systems that could be directly affected by the fuel and aftertreatment technology.

2. ATA VMRS coding is based on parts that were replaced. If no part was replaced in a given repair, the code was chosen by the system being worked on.

3. In general, inspections (with no part replacements) were included in the overall totals only (not by system). 101 was created to track labor costs for PMIs.

4. ATA VMRS 02-Cab and Sheet Metal represents seats, doors, etc.; ATA VMRS 50-Accessories represents fire extinguishers, test kits, etc.; ATA VMRS 71-Body represents mostly windows and windshields.

5. Average labor cost is assumed to be $50 per hour.

6. Warranty costs are not included.

7. Fuel prices shown include federal and state taxes.

Appendix B

Emissions Test Results

Emissions Test Results

Test ID	Test Date	Truck No.	Fuel	Model Yr	Odometer	Cycle	CO	NOx	FIDHC	PM	CO2	MPG	BTU	CH4	NMHC
6089	11/3/00	684066	CNG	1997	90340	CSHVR	1.12	6.69	7.98	0.018	738	8.79	14340	6.8	0.52
6087	11/2/00	684071	CNG	1997	54026	CSHVR	1.06	5.58	7.38	0.004	610		11902	N/A	N/A
6080	10/27/00	684075	CNG	1997	70216	CSHVR	0.17	5.23	8.56	0.014	726	8.94	14110	7.4	0.53
6090	11/3/00	684082	CNG	1997	73138	CSHVR	0.39	6.58	8.12	0.012	754	8.62	14634	7.0	0.50
6083	10/30/00	684087	CNG	1997	90019	CSHVR	1.43	5.12	11.5	0.013	795	8.07	15619	10.1	0.60
6093	11/6/00	684091	CNG	1997	33674	CSHVR	0.13	3.65	6.48	0.016	818	8.02	15734	5.6	0.31
6084	10/31/00	684095	CNG	1997	49657	CSHVR	0.17	5.15	7.50	0.005	741	8.79	14348	6.5	0.41
				Average	**65867**		**0.64**	**5.43**	**8.22**	**0.012**	**740**	**8.54**	**14384**	**7.2**	**0.48**

N/A - not available

Test ID	Test Date	Truck No.	Fuel	Model Yr	Odometer	Cycle	CO	NOx	FIDHC	PM	CO2	MPG	BTU	CH4	NMHC
6104	11/13/00	651757	D1	1996	90310	CSHVR	2.41	10.9	0.46	0.22	785	12.2	10333		
6096	11/7/00	651763	D1	1996	94808	CSHVR	2.42	10.6	0.47	0.19	775	12.4	10199		
6107	11/14/00	651764	D1	1996	90310	CSHVR	2.95	10.5	0.57	0.30	831	11.5	10940		
				Average	**91809**		**2.59**	**10.7**	**0.50**	**0.24**	**797**	**12.0**	**10491**		
		Comparison CNG/Diesel (%)			**-28**		**-75**	**-49**	**1543**	**-95**	**-7**	**-29**	**37**		**-4**

NMHC/HC

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