

## Case Studies



## Running Refuse Haulers on Compressed Natural Gas

By Paul Norton and Ken Kelly, NREL



### The New York City Experience

Warren Greitz, NREL/PIX 03756

One of New York City's quiet low-emissions compressed natural gas refuse haulers

In the fall of 1992, six new refuse haulers appeared on the streets of New York City. These trucks were different from any the city had seen before. Compared to their conventional brothers, these trucks were much quieter and refrained from the occasional belch of black smoke. The difference? The new trucks ran on compressed natural gas (CNG).

Since 1992 the CNG trucks have accumulated more than 60,000 miles in regular service in the New York City fleet. Overall, their performance has been excellent. "We've really enjoyed running the trucks on natural gas," New York City Department of Sanitation Manager Tim Harte reports. "Our drivers are satisfied with the horsepower and speed. And the vehicles are quieter and cleaner, there's no diesel knock, and there are no fumes."

The drivers have appreciated the significantly lower engine noise levels of the CNG vehicles compared to their diesel counterparts. These are the only garbage packers in the city in which the driver and assistant can easily talk to each other in the cab.

## MASTER

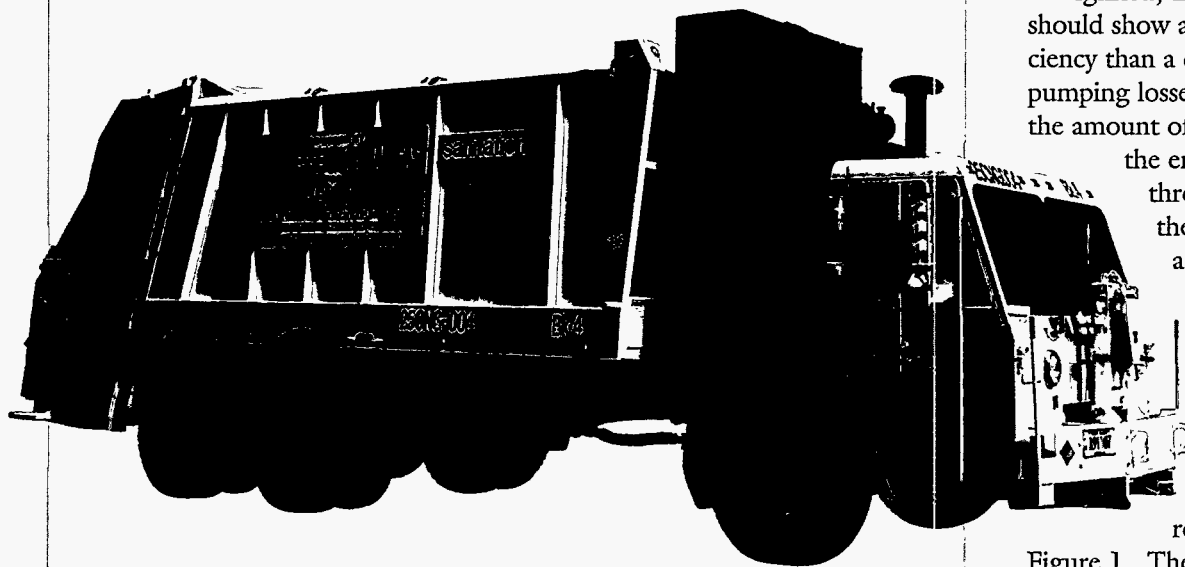


Produced for the U.S. Department of Energy (DOE) by the National Renewable Energy Laboratory (NREL), a U.S. DOE national laboratory

## To Be Specific.....

The specifications for the New York City Department of Sanitation refuse haulers are listed below:

Chassis:	Crane Carrier Corporation Model LT484M, 25-cubic-yard capacity, low-entry cab
Fuel:	compressed natural gas
Gross Vehicle Weight:	70,000 pounds
Engine:	1992 Cummins L10-240G
Displacement:	10 liters
Power:	240 horsepower
Torque:	750 foot-pounds
Gas Cylinders:	Pressed Steel Tank Company
Capacity:	36 diesel equivalent gallons



According to Harte, "These vehicles are so quiet, our workers can listen to the radio on routes. With the diesel engines, that's impossible."

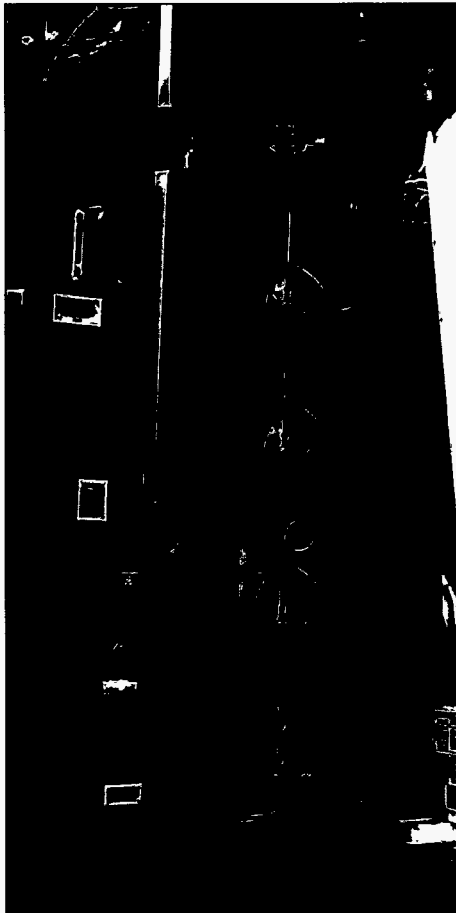
The U.S. Department of Energy (DOE) sponsors this project. The Alternative Fuels Data Center (AFDC) at DOE's National Renewable Energy Laboratory (NREL) has been accumulating refueling and maintenance data on these trucks since October 1992. As of September 1995, more than 2000 refueling records and hundreds of repair records have been collected and studied.

## Fuel Economy and Range

Because the CNG engines are spark-ignited, throttled engines, they should show a slightly lower fuel efficiency than a diesel engine because of pumping losses. Pumping losses are the amount of energy required for the engine to draw in air through the throttle during the intake cycle. Because a diesel engine has no throttle, the pumping losses are much smaller.

The average fuel economy of the CNG refuse haulers and that of an equivalent diesel refuse hauler are shown in Figure 1. The fuel economies are presented in miles per diesel equivalent gallon, which allows for a direct comparison between the CNG and diesel trucks. A diesel equivalent gallon is the amount of CNG that has the same energy content as a gallon of diesel fuel. The fuel efficiency of the CNG trucks has been between 5% and 20% lower than that of the diesel truck. This is within the

Five gas cylinders give the refuse haulers a range of about 61 miles.



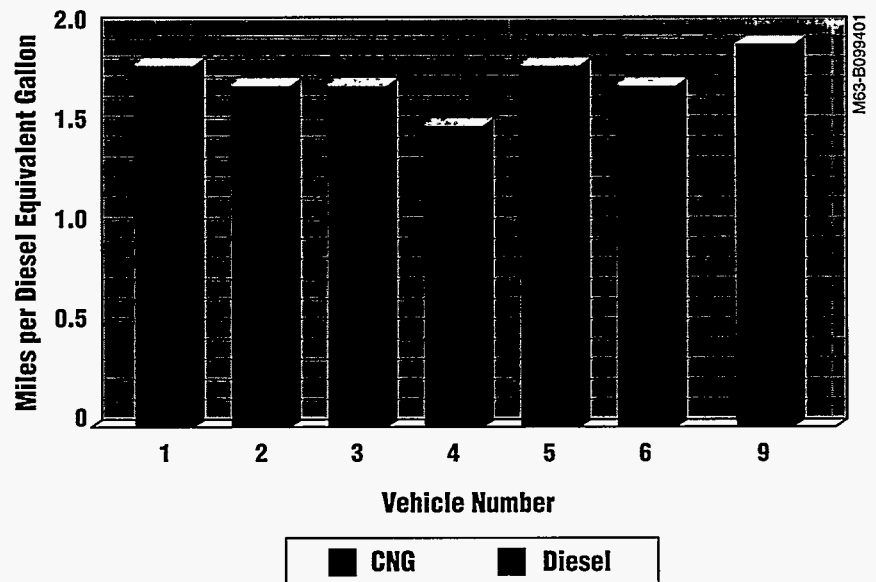
Warren Gretz, NREL/PIX 03753

*"We refuel the collection trucks every other day just like the diesels,"*  
 Manager Tim Harte explained to New York's Clean Rider magazine.  
*"Refueling is quick and easy and takes only a few minutes."*

Figure 1. Average in-use fuel economy of the NYC refuse haulers from October 1992 to September 1995

expected range for the difference in efficiency between a spark-ignited, throttled engine and a diesel engine.

The diesel trucks carry 50 gallons of diesel fuel, which gives the trucks a range of about 95 miles between refuelings. The gas cylinders in the CNG trucks can carry the energy equivalent of about 36 diesel gallons in natural gas. Therefore the average range of the New York City CNG trucks is about 61 miles, which has been acceptable for the New York City refuse haulers because their routes are within the city and tend to be short. The Department of Sanitation has been refueling the trucks only once every other day on the average.



## Cost

On an equivalent energy basis, the retail price of natural gas is lower than that of diesel fuel. In the week of January 8, 1996, the national average station price for diesel fuel was about \$1.15 per gallon. The average station price for CNG was about \$0.96 per diesel equivalent gallon. On an equal energy basis, CNG cost about 17% less than diesel. Some of this advantage is lost because the natural gas trucks have lower fuel efficiency than the diesel trucks. Using the average fuel efficiency of the natural gas and diesel refuse haulers in New York City, and the national average retail fuel prices in January 1996, the fuel cost would be about \$0.57 per mile for the natural gas

trucks and \$0.62 per mile for the diesel trucks. Actual fuel cost at any given site will depend on the local diesel and CNG prices, which can vary significantly from the national average.

The fuel cost savings must be balanced against the additional cost of a CNG truck. The New York City CNG refuse haulers were the first of their kind, and the costs of these prototypes were considerably higher than those of a comparable diesel truck. Experience with these trucks and subsequent demonstration vehicles has convinced major truck manufacturers that there is a place for alternative fuel heavy-duty trucks. In 1996 several manufacturers, including Peterbilt, Kenworth, Mack, Volvo/GM, and Crane Carrier will offer natural gas versions of some of their popular refuse

## Where Can I Get One of Those!

Because of the experience gleaned from this project and others like it, there are now several truck manufacturers offering natural gas refuse haulers. Here are some of the refuse haulers that are available now with natural gas options, or that will be in the near future:

Manufacturer: Crane Carrier Corporation  
Chassis Model: Model LT484M  
Engine: Cummins L10  
Fuel: compressed natural gas  
Contact: Rueben Brown, (918) 836-1651

Manufacturer: Volvo GM Heavy Truck Corporation  
Chassis Model: Xpedito  
Engine: Cummins L10  
Fuel: liquefied natural gas  
Contact your local Volvo GM heavy truck dealer

Manufacturer: Kenworth  
Chassis Model: T800  
Engine: Cummins L10  
Fuel: liquefied natural gas  
Contact: Evan Campbell (206) 828-5758

Manufacturer: Peterbilt  
Chassis Model: 320  
Engine: Cummins L10  
Fuel: compressed or liquefied natural gas  
Contact your local Peterbilt dealer, 1-800-447-4700

Manufacturer: Mack  
Chassis Model: MR Cab-over refuse hauler  
Engine: Mack E7  
Fuel: liquefied natural gas  
Contact: Kevin Flaherty (610) 709-3816

haulers (see the sidebar entitled “Where Can I Get One of Those!”).

When these new trucks are first released, production volumes are expected to be low, so the cost of the natural gas option may be substantial. As production volumes increase, however, manufacturers expect the cost of the natural gas trucks to drop. Natural gas engines are not inherently more expensive to make than advanced diesel engines, but the natural gas fuel systems will always be more complex and expensive than a diesel fuel system. However, because the fuel system is a small percentage of the total cost of the truck, the cost of a natural gas option will not greatly boost the overall cost of the truck at high production volumes.

## Maintenance and Repair Issues

Because these trucks were the first of their kind, we expected a steady stream of unforeseen problems. But, although problems did occur, the trucks have consistently performed above expectations. The Department of Sanitation has been delighted with them.

The prototypes had a few problems when they first went into service. Early in the project a piston melted down in one of the engines. The problem was traced to the air/fuel ratio control and corrected for the rest of the trucks in the project. The knowledge gained from this type of experience has helped the engine manufacturers greatly improve their fuel control systems on newer natural gas engines.

The maintenance and repair database accumulated on the CNG trucks shows that they have been somewhat more

*New York City put 10 new CNG refuse haulers (for a total of 16) into service in 1995.*



Warren Greiz, NREL/PIX 00087

expensive to maintain than the diesel trucks. A significant part of this differential cost has been the spark plugs and wires for the CNG trucks. Tim Harte explains, “In terms of regular maintenance...[the CNG trucks] have been right alongside the rest. The spark plugs and wires were the parts that really caught us by surprise.” At the beginning of the project, the spark plug wires had to be replaced every 6 to 8 months at a cost of about \$125.00 per wire. With the help of the manufacturer, the wire life is now doubled. In their newer natural gas engines, manufacturers have integrated the design of the spark plug wires and coils. This design change should further increase the wire life and reduce maintenance costs. As Tim Harte put it, “..if you didn’t start somewhere, you wouldn’t find that the weak link is your ignition wire and that’s part of why we did this.”

## Lessons Learned

When asked to outline some of the lessons learned during the Department of Sanitation's experience with the CNG trucks, Harte explained some of the problems the department encountered and their solutions. Through the New York City project and similar demonstration projects sponsored by DOE, such issues are being uncovered and addressed. This makes each generation of alternative fuel trucks more trouble-free and reliable than the last.

### Fuel supply

"Don't put all your eggs in one basket. We have had some areas where the compressor has gone down, and, through no fault of their own, just an availability of products, they haven't been able to get the compressor back up for a day or so. So some redundancy or some backup means of getting fuel close by is important."

### Fuel contamination

"We found contaminants in the fuel supply that we didn't expect to find. We installed filters on all the vehicles. They now have coalescent filters in between the fuel filter and the cylinders because of compressor oil and some debris that we found in the fuel, bits and pieces of Teflon tape, thread shavings, things like that. Nothing tremendous, but the compressor oil did cause some problems with the vehicles, regulators, etc."

### On-board fuel reserve

"We put a thousand-pound check valve on the last cylinder. So as the others continue down to, say, 200 psi, where [the truck] will no longer run, the last cylinder has retained 1000 psi of fuel. Then by throwing a switch, a solenoid opens and now introduces that 1000 psi of fuel back into the other cylinders, and that gives them the equivalent of 2.5 or 3 gallons or so that they can run to the fuel station with. It's not a lot, but the guys are real grateful for it. It's come in handy, you know. This way they don't have to answer to the boss because they forgot to fuel it up. They just throw the switch, run over, get the fuel, and get back to the route."

### Leaky fuel supply lines

"Between the fuel cylinders on the six trucks, when we first got them, they had stainless-steel lines. The stainless-steel line has proved to be too hard and inflexible for mounting between the cylinders, and it wasn't till after about a year or so that we started to develop leaks between the cylinders. We went through and we replaced them all with flex lines. When we first built the trucks, flex lines were not available."

"Also, the use of welded tubing versus seamless tubing, while it does meet the pressure requirements, etc., some of the finish on the welded tubing doesn't work well with the compression fittings. Just minor leaks. And none of the leaks we had were to the extent that they were anywhere near causing any other problem. What would happen is you'd walk past the vehicle, you'd go, 'Do I smell gas?'"

## Emissions

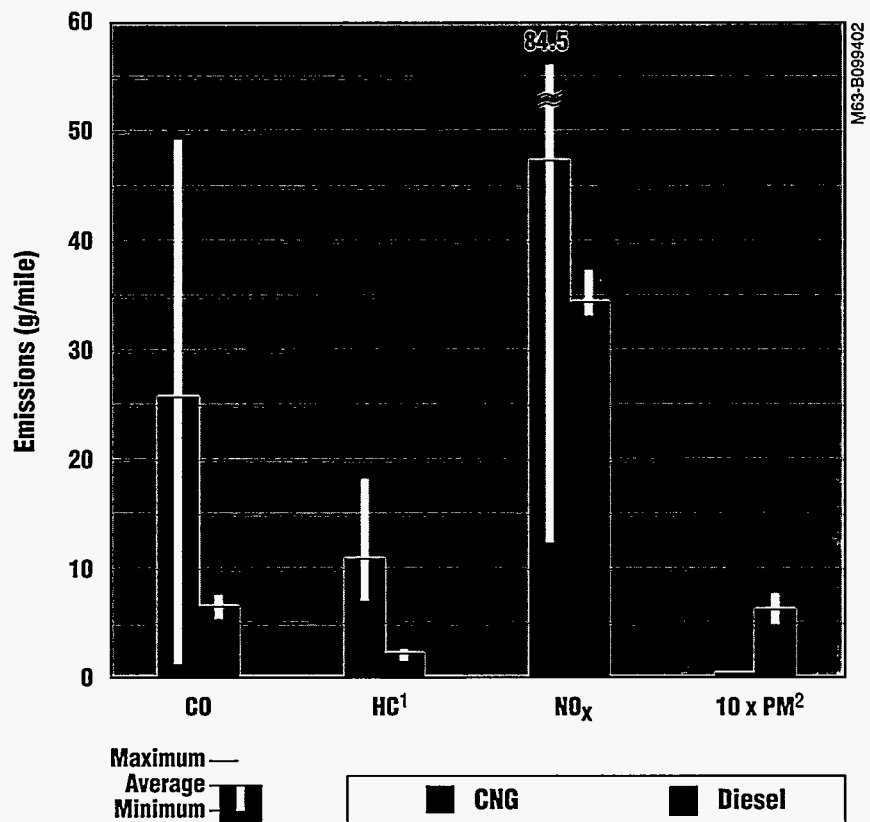
The in-use emissions levels of the truck can be approximated using a chassis dynamometer. The truck is placed on the chassis dynamometer and a driver follows a specific driving cycle while the emissions from the tailpipe are measured. Heavy duty engines are certified for emissions independent of any truck chassis using an engine dynamometer (rather than a chassis

dynamometer) and a standardized cycle defined by the Environmental Protection Agency (EPA). Unfortunately, there is currently no accepted standard driving cycle for chassis dynamometer testing of heavy-duty trucks. West Virginia University has tested the New York City trucks on the university's transportable heavy-duty chassis dynamometer using a driving cycle called the Central Business District (CBD) cycle. The CBD cycle is designed to simulate urban stop-and-go driving.

Because the NYC trucks were placed into service as prototype demonstration and development vehicles, the engines were not optimized for emissions reductions. The emissions results from these prototype trucks have been highly variable. Figure 2 shows the average, minimum, and maximum emissions from the CNG and diesel refuse haulers. Emissions of oxides of nitrogen and carbon monoxide were sometimes less from the CNG trucks and other times less from the diesel trucks. On the average, the diesel trucks emitted less of these types of pollutant.

The total hydrocarbon emissions from the CNG trucks were consistently greater than those from the diesel trucks. However, hydrocarbon emissions from natural gas vehicles are typically 90% to 95% methane. EPA and the California Air Resources Board (CARB) regulations are written in terms of non-methane hydrocarbons because methane does not contribute to urban ozone (smog). The nonmethane hydrocarbon emissions from the CNG trucks were not measured directly, but the values are projected to be similar to, or lower than, those of the diesel trucks.

In particulate emissions, the CNG trucks consistently demonstrated a clear advantage. In 6 of 11 tests performed to date, particulate emissions were essentially zero (too low to measure); the particulate emissions from the diesel trucks averaged about 0.7 grams per mile. This is an attractive feature for a refuse hauler because it operates in populated urban areas where particulate emissions from vehicle exhaust are a serious health concern. The truck drivers have noticed this too. In New York City, the senior drivers get the first choice of trucks and they consistently choose the CNG trucks.



EPA and CARB require that new engines be emissions-certified using standard procedures on engine (rather than chassis) dynamometer tests. During an engine dynamometer test, the engine is put on a test stand and run through specific loads and speeds while the exhaust emissions are measured. In 1993 and 1994, these tests were performed on emissions-optimized natural gas and diesel versions of the type of engines used in the New York City trucks (Cummins L10). The results of these tests are shown in Figure 3.

It is clear that the natural gas engine emitted significantly less carbon monoxide, oxides of nitrogen, and particulate matter emissions than did the equivalent diesel engine.

Figure 2. Chassis dynamometer emissions results for New York City garbage packers

- <sup>1</sup> Total hydrocarbons
- <sup>2</sup> Particulate matter values were magnified 10 times to show results on the same scale



Alternative Fuel Trucks  
Case Studies

Cummins L10G  
natural gas engine

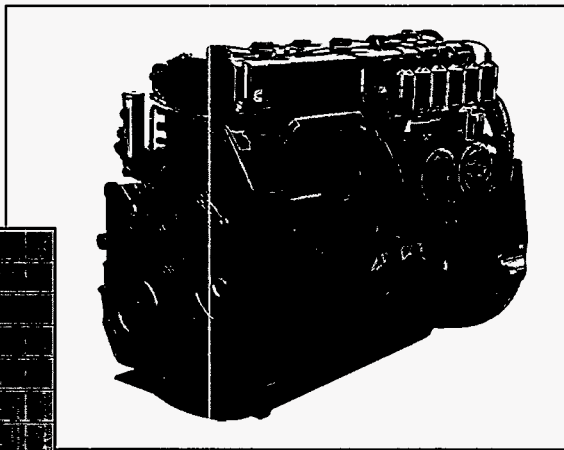
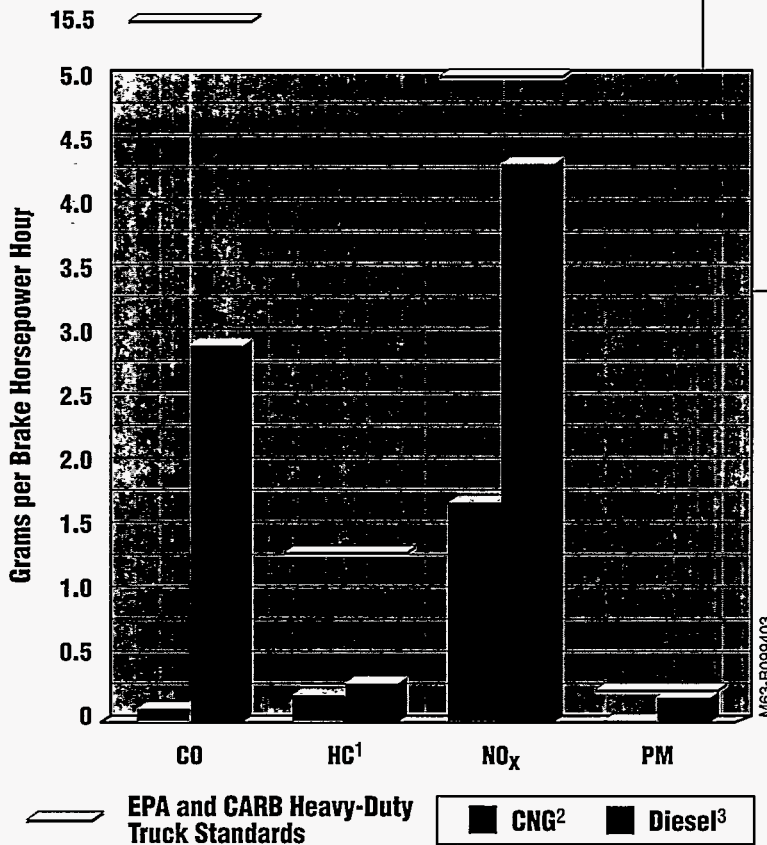


Photo Courtesy of Cummins Engine/PIX 03318

As this case study goes to press, the mixed emissions picture is becoming more clear. A recent study done by NREL in cooperation with West Virginia University and the engine manufacturer has identified some potential sources of the highly variable emissions. Also, emissions tests conducted on transit buses using the newer, emissions-certified versions of the Cummins L10 engines show substantial reductions in oxides of nitrogen and carbon monoxide emissions. Cummins released an even more advanced version of the engine incorporating a fuel system with full feedback control in March 1996. This new engine promises to be the cleanest L10 engine yet.

Figure 3. Cummins L10 Diesel and CNG engines emissions certification data from 1993

- <sup>1</sup> Total hydrocarbons for diesel, nonmethane hydrocarbons for natural gas
- <sup>2</sup> EPA Certification
- <sup>3</sup> CARB Certification

For more information visit our World Wide Web site at <http://www.afdc.doe.gov/0/demoproj/hdv/hdvsect.html>  
Call the National Alternative Fuels Hotline at 1-800-423-1DOE, or contact:

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(303) 275-4424

More Trucks on the Road . . .

As a result of the excellent performance and driver acceptance of the DOE-sponsored CNG trucks, New York City Department of Sanitation ordered ten additional CNG garbage packers. Five of the new trucks, equipped with Detroit Diesel Corporation Series 50 production engines, went into service in February 1995. The other five, equipped with Caterpillar 3306 field test engines, began service in April 1995.



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