

Enviro Express Kenworth LNG tractor. *Connecticut Clean Cities Future Fuels Project*

Case Study – Liquefied Natural Gas

As a part of the U.S. Department of Energy’s broad effort to develop cleaner transportation technologies that reduce U.S. dependence on imported oil, this study examines advanced 2011 natural gas fueled trucks using liquefied natural gas (LNG) replacing older diesel fueled trucks. The trucks are used 6 days per week in regional city-to-landfill long hauls of incinerator waste with two fills per day. This is a workable fit for the limited range LNG trucks. Reduction of fuel costs and harmful emissions relative to the replaced trucks are significant.

Introduction

The American Recovery and Reinvestment Act legislation (the Recovery Act) was passed in 2009 as a direct response to the economic downturn in 2008. The Recovery Act sought to create new jobs and save existing ones; spur economic activity and invest in long-term growth; and foster unprecedented levels of accountability and transparency in government spending. A total of \$840 billion was ultimately provided to achieve these goals.

The U.S. Department of Energy’s (DOE) Office of Energy Efficiency and Renewable Energy (EERE) received funding from the Recovery Act for energy-related projects. Clean Cities, an activity within the EERE Vehicle Technologies Office, received almost \$300 million in Recovery Act funding to speed the deployment of alternative fuel and advanced technology vehicles across the United States. A total of 25 projects were awarded through a competitive solicitation process. Thousands of vehicles using a variety of fuels and technologies and hundreds of alternative fuel stations have been deployed. Fleets are required to report operational data to DOE as part of these grants.

The Greater New Haven Clean Cities Coalition received \$13.2 million under this funding opportunity for its Connecticut Clean Cities Future Fuels Project: with cost share, the total project value was \$29 million. Project partner Enviro Express Inc. became the first company east of the Mississippi to open a fueling facility for liquefied natural gas and to operate an LNG fleet. Funding from this grant covered around 45% of the total cost of the LNG truck and fueling station project.

Vehicle fleets have become much more interested in natural gas over the past several years, as new technologies have markedly expanded the potential supply of natural gas. This has not only increased natural gas availability for use in transportation applications, but has also increased the potential for significant fuel cost savings. LNG is particularly interesting to trucking fleets, as it enables sufficient natural gas storage onboard for driving ranges suitable for over-the-road trucks.

This case study includes information on a total of 18 LNG Class 8 truck tractors deployed in fleet service in Connecticut over the course of approximately 15 months. Operational data from these vehicles were analyzed to explore how well they perform in real-world operation.



Figure 1.
Enviro Express LNG and CNG infrastructure. *Connecticut Clean Cities Future Fuels Project*



Figure 2.
Enviro Express LNG trucks. *Connecticut Clean Cities Future Fuels Project*



Fleet/Company Profile

Enviro Express Inc. provides collection services for ash, trash, and solid waste to municipal, residential, and commercial clients in Fairfield and New Haven, Connecticut. The company was founded by Bill Malone, who began with a two-truck refuse operation in the late 1970s, and expanded to provide ash hauling from waste-to-energy plants in the early 1990s. Enviro Express hauls municipal waste to the waste-to-energy plants seven days per week, 24 hours per day, and hauls away the ash from these plants to landfills. The Enviro Express fleet consists of 40 vehicles, 19 of which now use LNG (including the 18 trucks which were part of this project and an additional LNG truck added after the project completed).

Motivation for Project

Natural gas provides fleets with an opportunity for cost savings through low and stable fuel prices. This is particularly helpful for over-the-road trucking fleets, which typically operate with very small profit margins against stiff competition. In addition to the cost savings, natural gas can offer greenhouse gas and criteria air pollutant emissions benefits over conventional diesel trucks.

For Enviro Express, both considerations played a role in their selection of natural gas fuel for a portion of its vehicle fleet. In 2008, Mr. Malone visited the Port of Los Angeles and saw the success of their natural gas truck activities in reducing emissions and petroleum use at the ports. Mr. Malone subsequently “decided to pursue [natural gas] as an edge, an advantage, to cut our costs and try to clean up the air.”



Figure 3.
Westport GX 15 liter engine. *Westport Innovations*

Implementation

The Enviro Express LNG project consisted of two parts: the construction of an onsite LNG/CNG fueling station and the purchase of 18 LNG powered tractors for refuse hauling service. The Connecticut Clean Cities Future Fuels Project administered the funding for the project with assistance from Innovation Drive, a company focused on commercialization of advanced technologies.

LNG Fueling Station

The Connecticut Clean Cities Future Fuels Project helped fund the construction of a \$6.2 million fueling station adjacent to I-95 in Bridgeport, Connecticut. The fueling station (shown in Figure 1) provides fuel to the Enviro Express LNG fleet and provides CNG to fleets and the public. The station stores approximately 14,000 gallons of LNG onsite. The station’s design allows LNG boil-off vapors to be recaptured, compressed, and stored as CNG, minimizing the amount of natural gas vented to the atmosphere. Enviro Express also purchased a 12,000 gallon cryogenic tanker to collect LNG from wholesalers (chiefly Distrigas of Massachusetts, from their Everett Marine Terminal). The station was developed by Air & Gas Technologies, Inc. in partnership with NorthStar LNG, Inc.

LNG Tractors

Enviro Express purchased 18 Kenworth T800 Class 8 LNG powered trucks from MTC Kenworth in Ridgefield Park, New Jersey to replace 18 diesel refuse haulers (see Figure 2). Kenworth offers the T800 with an OEM option for the Westport GX dual fuel natural gas engine. The 15 liter engine is offered in horsepower ratings of 400 to 475 horsepower, and torque ratings of 1,450 to 1,750 ft-lb. The GX engine is EPA and CARB 2010 certified. Kenworth offers the truck with single and dual LNG tank configurations, in purchaser-specified combinations of 70 gallon, 100 gallon, or 120 gallon tanks (nominal capacity).

The Westport GX engine (Figure 3) is built on the Cummins ISX 15 diesel engine platform, with modifications for the engine to use natural gas. The principal modification is the use of high-pressure direct injection (HPDI) technology, which uses small amounts of diesel for pilot ignition of the main natural gas injection (in a split of 5% diesel and 95% natural gas on an energy basis). The engine maintains the compression-ignition combustion cycle to retain the horsepower, torque, and efficiency of the base diesel engine.

The Enviro Express trucks were configured with the 450 hp/1,650 lb-ft version of the Westport GX engine. The trucks were ordered with a single 120 gallon LNG tank. In this configuration, each truck’s total cost was \$204,802. The reported LNG incremental cost was approximately \$90,000 per vehicle.

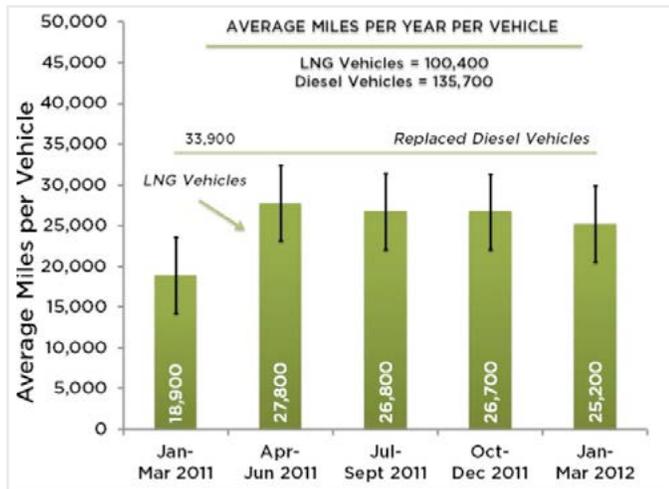
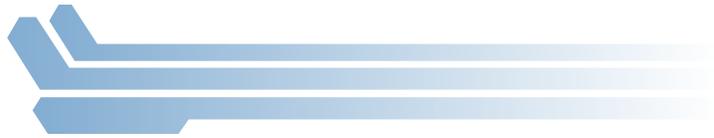


Figure 4. Average Mileage Accumulation by Quarter

The trucks transport ash from an incinerator in Bridgeport to a regional landfill 110 miles away in Putnam, with each truck making this trip twice daily. The duty cycle reported by the fleets involves about 10% local streets, 10% arterial roads, and 80% interstate highway travel. The trucks are usually loaded to a gross vehicle weight of 80,000 pounds.

The replaced refuse tractors were all Mack tractors using 12 liter diesel engines of varying vintages. Four of the trucks were Mack RD tractors from the early 1990s using the Mack E7 diesel engine; the remaining 14 tractors were Mack CXN613 tractors of 2005-2006 vintage, using the Mack AC diesel engine. The fleet reported that these diesel trucks traveled approximately 435 miles per day, 6 days per week, and achieved fuel economy of 5.5 to 5.8 miles per diesel gallon. The fleet has a replacement cycle of 6 years or 600,000 miles – older trucks are placed on local routes, and the oldest trucks are sold.

Technical

The major technical issue identified to date is with vehicle range. The fleet stated that it can achieve a driving range of approximately 300 miles between refueling. The vehicle is fueled approximately 12 times per week, with a fueling time of around 3 minutes. With only one LNG station in Connecticut, the fleet is limited in how far the natural gas trucks can travel from their home base, preventing their use on some routes. As noted above, Kenworth offers the trucks with multiple tank configurations, so future trucks could be purchased with more onboard fuel storage to address this issue.

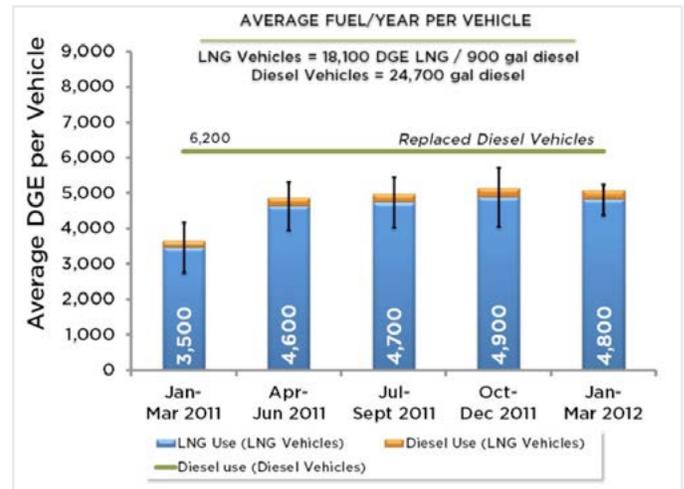


Figure 5. Average Fuel Use per Quarter

Outcomes to Date

Project Data Summary

Funding recipients under the Recovery Act were asked to conduct a detailed data collection effort to document quarterly usage of the project vehicles (fuel use and miles traveled). Information on the vehicles being replaced was also provided, allowing for comparisons of the project vehicles to conventional vehicles.

Approximately 15 months of operational data have been included in this study on the 18 LNG trucks (January 2011 through March 2012). The diesel trucks were not operational at the same time as the LNG trucks, as the LNG vehicles replaced them. The diesel vehicle information presented here is thus from averages provided by the fleet (e.g., average miles per week, average fuel economy, etc.) for the historical operation of these vehicles prior to replacement.

The graph in Figure 4 shows the quarterly average number of miles accumulated per vehicle for the 18 LNG tractors. After an initial period of ramp-up, the quarterly mileage accumulation stabilized at a level of 25,000-27,000 miles per vehicle. (The black bars represent the standard deviation for the quarterly mileage per truck.) Total mileage accumulation was 2.3 million miles for the LNG trucks over the 15 month period. The driving range limitation for the LNG trucks can be seen in Figure 4, as the LNG trucks traveled just over 100,000 miles per year per truck, while the replaced diesel trucks covered around 135,000 miles per year per truck.

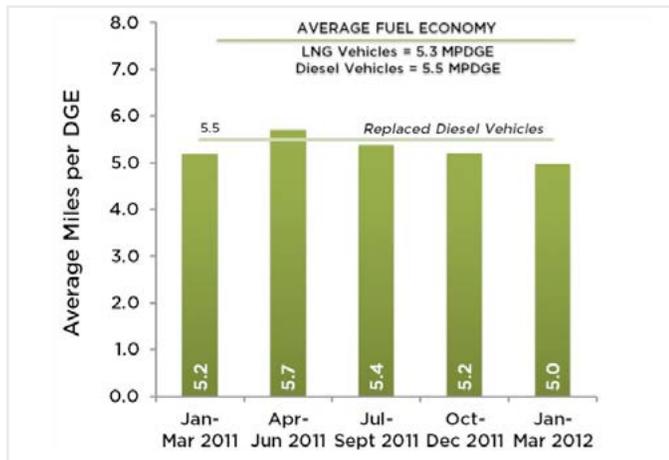


Figure 6. Average Fuel Economy by Quarter

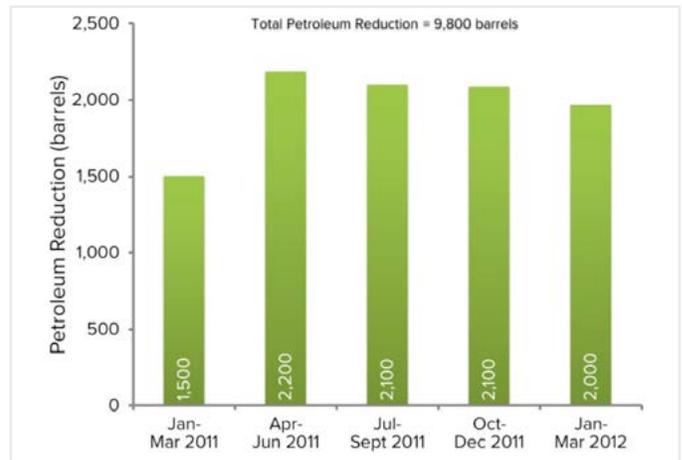


Figure 8. Petroleum Reduction by Quarter

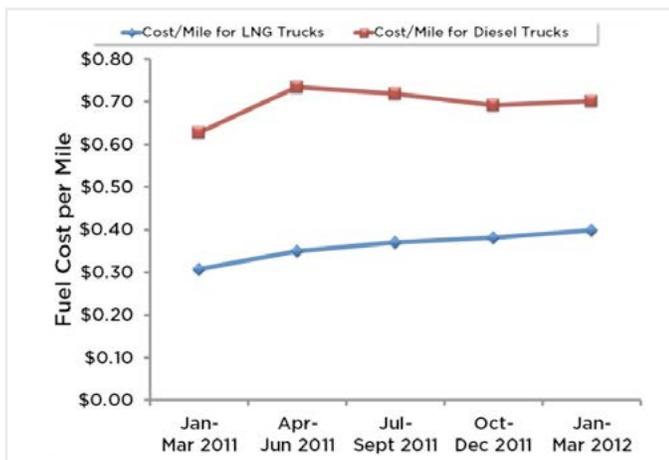


Figure 7. Average Fuel Cost per Mile

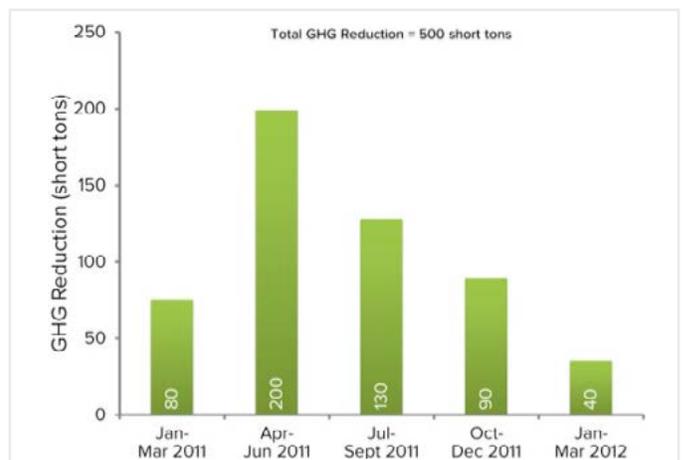


Figure 9. Greenhouse Gas Reduction by Quarter

As seen in Figure 5, the average quarterly amount of LNG used per vehicle remains relatively constant. Quarterly LNG use varied between 4,700 and 5,300 gallons per vehicle. As noted previously, the Westport GX engine uses a ratio of 95% natural gas to 5% diesel fuel on an energy basis: the 5% diesel fuel is represented by the orange bar atop the LNG bar. Total fuel use was approximately 407,000 diesel equivalent gallons (DGE) of LNG and 20,000 gallons of diesel for the LNG trucks over the 15 month data collection period. The fleet reported only LNG fuel use, so the 5% diesel fuel was added to the total fuel use as a calculation. On an annual basis, each LNG truck used about 19,000 diesel equivalent gallons of fuel per year, while the diesel trucks had been using approximately 24,700 gallons of diesel per year (as they had been driven more miles per year).

Average fuel economy (in miles per diesel equivalent gallon) is illustrated in Figure 6. The Westport HPDI engine is more efficient than spark-ignition natural gas engines because of their use of the diesel cycle, so their efficiency on a DGE basis is close to a conventional diesel engine. As shown in the figure, the overall average fuel economy of 5.3 miles per DGE for the LNG trucks (including both the LNG use and diesel pilot use) is very close to the reported fuel economy of 5.5 miles per DGE for the replaced diesel vehicles. This represents a decrease of around 4% for the LNG vehicles relative to their predecessors.



If the total fuel use is combined with alternative fuel and conventional fuel prices by quarter, the fuel cost per mile for the LNG trucks and their equivalent diesel counterparts may be calculated, as shown in Figure 7. LNG pricing at Enviro Express was very favorable on an energy basis during the study period, and the trucks achieve similar fuel economy on an energy equivalent basis. This produces a cost per mile for the LNG trucks significantly lower than for the diesel baseline trucks. On average, the LNG fuel costs over the study period were around \$0.36 per mile, while conventional trucks would have cost approximately \$0.69 per mile. The costs per mile listed above and the LNG average travel of 100,000 miles per year yields a simple payback period of the incremental vehicle cost that is also favorable, just less than three years in the absence of incentives such as the Recovery Act grants.

Using the total fuel use by fuel type, estimates can be made of the total fuel cycle greenhouse gas reductions and petroleum reductions for these LNG trucks. Argonne National Laboratory has developed a tool for analyzing the greenhouse gas emissions and petroleum use for fleet vehicles. The tool is known as the GREET Fleet Footprint Calculator, and is available for public download at greet.es.anl.gov/carbon_footprint_calculator.

Applying the calculator analysis to the reported fuel use figures by quarter for the LNG trucks and comparable diesel trucks driving the same annual mileage as the LNG trucks yields the information presented in Figures 8 and 9. Figure 8 presents the total petroleum reduction represented by the use of the LNG trucks relative to the replaced diesel trucks, taking both the LNG use and diesel pilot fuel use into account. In general, quarterly petroleum reduction averaged around 2,000 barrels. Total petroleum reduction for the 15 month data collection period was 9,800 barrels.

Figure 9 presents the total greenhouse gas reduction from the LNG trucks. On average, the LNG trucks represent a quarterly greenhouse gas reduction of approximately 100 tons. Total greenhouse gas reductions for the 15 month data collection period were 500 tons.

Training/Behavioral Changes

The dealer for these trucks, MTC Kenworth, invested in training for its own maintenance personnel and equipping its

¹ It is important to note that the diesel vehicles were not in service at the same time as the LNG vehicles – the graph illustrates what the cost per mile would be if a diesel vehicle with the annual mileage and MPG characteristics of the replaced diesel vehicles were in service simultaneously.



Figure 10. First responders trained under this project. *Connecticut Clean Cities Future Fuels Project*

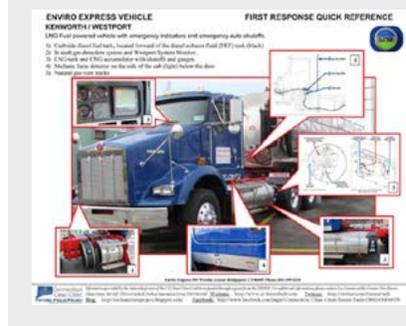


Figure 11. Quick Reference Guide for Kenworth T800 LNG tractor. *Connecticut Clean Cities Future Fuels Project*

maintenance shop to service natural gas trucks. The dealer characterized these as long term investments that will pay off for the dealer. MTC Kenworth provided a three-day training session for Enviro Express' service technicians and drivers to help them get accustomed to the new trucks. Drivers are happy with the trucks' performance, stating that they accelerate well and make less noise.

In addition to the training for service technicians and drivers, the Connecticut Clean Cities Future Fuels Project emphasized the importance of training sessions for first responders (Figure 10). The Future Fuels Project included training for over 800 first responders about the wide variety of vehicle and fuel technologies they could potentially encounter on Connecticut's roads. These training events included both classroom instruction and hands-on training opportunities. The project team developed maps of the state that highlighted key routes that the LNG trucks and other project vehicles would be traversing regularly, as well as the location of the LNG and CNG stations developed as part of the project.

Quick reference guides/cards were prepared in conjunction with Westport HD for the Kenworth LNG trucks (as illustrated in Figure 11). These guides assisted first responders and drivers in identifying the key safety features of the truck in a short two-page overview. More than 2,000 of these guides were distributed.

This training proved to be very useful early in the project. In 2011, one of the trucks developed an LNG leak while out on the road. First responders were alerted, and the first person on the scene was a police officer who had received the project's training. Additional first responders arriving at the scene had also received training on LNG (onsite at Enviro Express in one of 8 such sessions for first responders), and were able to ascertain the leak was not a serious issue. The truck was secured and returned to Enviro Express, where the source of the leak was identified and repaired. The defective component was replaced on the other trucks in the fleet as well. As a result of the training, the first responders were able to react properly to the scene and identify the problem as a routine maintenance issue, and not a high-profile emergency incident.

Public Relations Benefits

Enviro Express has received compliments for using a "green vehicle" and has participated in numerous public events as a result of the company's LNG project. The LNG station initially opened in December 2010 with a high-level press event. The event attracted representatives from DOE, the City of Bridgeport, and other local dignitaries. One of the tractors was provided for an event in April 2011 in which the President of the United States announced the Clean Cities National Clean Fleet Partnership. The truck was used as part of a vehicle display at the event, held at a Maryland UPS facility.

In addition, Mr. Malone was honored as one of the 2012 Truck Fleet Innovators by Heavy Duty Trucking Magazine for this project. Each year, the magazine honors several of the industry's most innovative truck fleets. Winners are profiled in the March issue of the magazine, honored during a special event in conjunction with the Mid-America Trucking Show, and serve as a resource for the magazine's editors throughout the year.

Lessons Learned

Mr. Malone emphasized the importance of establishing a good relationship with local government, without which a natural gas project is unlikely to succeed. "It all starts with the local government. If your mayor and your fire department are open to new ideas, then it's a winner. If they're resistant, move to another town."

For more information contact:

Andrew Burnham 630.252.6606 or aburnham@anl.gov



The Class 8 LNG trucks have been significant to the success of the Connecticut Clean Cities Future Fuels Project. The project has deployed 266 alternative fuel vehicles, including the 18 LNG trucks. The fuel use of the 18 LNG trucks represented 38% of the total fuel use for the project for the fourth quarter of 2012. Because of their high fuel use, heavy-duty trucks can be a very important contributor to a project's total petroleum displacement.

Future Plans

Since completion of the initial project acquisition of trucks and infrastructure, Enviro Express has purchased one additional Peterbilt LNG vehicle and is now building a natural gas fueling station in Newark, NJ to expand the routes on which the LNG trucks can be used. Mr. Malone would also like to build a station in Pennsylvania, in order to establish a natural gas corridor from Boston to Washington, DC.

The project has facilitated additional fleet deployments of natural gas trucks. Gulf/Cumberland Farms, a regional chain of convenience stores and gasoline retailers, has added 35 LNG tractors to their fleet operations in New England, partly as a result of the Connecticut alternative fuel projects. These trucks are Peterbilt 386 tractors, also using the Westport GX engine. Trucks were deployed in New Haven (Connecticut), Providence (Rhode Island), and Chelsea (Massachusetts). Like Enviro Express, Gulf/Cumberland has specified the 120 gallon LNG tank configuration for its trucks. Gulf has noted that it sees supplying and distributing LNG to Class 7-8 fleet users as a business growth and diversification strategy, and is actively pursuing this strategy.

Conclusion

LNG tractors were successfully deployed into an over-the-road Class 8 trucking application. Overall fuel efficiency is similar to diesel on an energy equivalent basis, but onboard fuel storage limits vehicle range. The vehicle incremental cost payback is just under three years. Training was an important component of this project, and helped resolve a potential safety concern without incident. No major problems were observed with the vehicles during the data collection period. The project has spurred additional investment in natural gas in the region.



U.S. DEPARTMENT OF

ENERGY

Argonne National Laboratory is a U.S. Department of Energy laboratory managed by UChicago Argonne, LLC