

Case Study – Compressed Natural Gas Refuse Fleets

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Case Study – Compressed Natural Gas Refuse Fleets

Background

This case study explores the use of heavy-duty refuse trucks fueled by compressed natural gas (CNG). CNG shows promise for this application because fleets can save money on fuel while taking advantage of other benefits, such as low criteria pollutant emissions, lower greenhouse gas emissions, and quieter operation. This case study highlights three fleets from very different types of organizations that used CNG refuse trucks successfully: *Republic Services*, a national waste and recycling services company; *Groot Industries, Inc.* a smaller residential pick up and disposal company operating regionally in northern Illinois; and the *City of Milwaukee's Department of Public Works* (DPW), a municipal agency. These fleets did have the advantage of receiving federal funding through the American Recovery and Reinvestment Act (Recovery Act) of 2009.

The U.S. Department of Energy's (DOE's) 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 reduce petroleum consumption and emissions through the deployment of alternative fuel and advanced technology vehicles across the United States. In total, 25 projects were awarded nationwide, through a competitive solicitation process. Partners in these projects contributed more than \$500 million in cost share. Thousands of vehicles using a variety of fuels and technologies and hundreds of alternative fuel stations have been deployed.

This case study synthesizes information from *Republic*, *Groot*, and the *City of Milwaukee* and broadly discusses their experiences, lessons learned, and considerations for deployment in other fleets.

This case study was sponsored by the Clean Cities program and developed by Argonne National Laboratory (Argonne) and Energetics, Incorporated. The fleets discussed in this case study provided critical assistance in information collection, as did the local Clean Cities coordinators who worked closely with these fleets to implement these projects.

Republic Services provides waste and recycling services for commercial, industrial, municipal, and residential customers in 40 states and Puerto Rico. The company has established a goal to have 3,100 trucks nationwide running on natural gas or other alternative fuels by the end of 2015. For the past 30 years, *Republic Services* has served the greater Boise, Idaho, area with solid waste and recycling services for more than 68,000 residential and commercial customers. *Republic* has been a Clean Cities coalition stakeholder since 2006.

MAJOR FINDINGS

- The fleets in this study chose CNG to save money on fuel (around 50% on average), and to satisfy corporate or municipal environmental initiatives.
- Fleets in this study saved approximately \$0.90 per mile in fuel costs by using CNG.
- The incremental cost of the CNG vehicles and fueling infrastructure can be recouped in 3–8 years.
- Driver feedback has been very positive: drivers appreciate the quieter operation of the trucks and noted the good acceleration performance.
- CNG trucks in this case study traveled around 14,500 miles per year on average and achieved fuel economy of 2.1 miles per diesel gallon equivalent.

Groot Industries, Inc. is the largest independent solid waste management services company in Illinois. It provides 250,000 homes and thousands of businesses with weekly service in northern Illinois. The company's experience with alternative fuels began in 2005 with a biodiesel program and expanded to CNG in 2008.

The *City of Milwaukee's Department of Public Works* (DPW) provides residential pickup and disposal of refuse for 190,000 households. DPW also supervises ice and snow control and provides leaf pickup.

Motivation for Adopting CNG

In general, these three fleets chose CNG to help meet corporate and municipal financial, environmental, and energy sustainability goals.

Financial Benefits

Republic Services decided to convert its fleet to CNG based on the lower cost of CNG relative to diesel fuel. These cost savings can be passed on to customers to keep rates under control. *Groot* projected it would save almost 40% on fuel costs with natural gas, and because natural gas pricing is less volatile, *Groot* would be much less exposed to fluctuating petroleum fuel prices. On average, the fleets in this study saved around 50% on fuel costs.

Environment and Energy Benefits

Groot committed to converting its fleet to CNG to reap the emissions and noise benefits compared to conventional diesel vehicles. The CNG project is part of the company's broader environmental initiative, which has also included fueling its diesel fleet with a biodiesel blend.

In the *City of Milwaukee*, a city-wide initiative has driven use of natural gas for fleet vehicles. In 2005, Mayor Tom Barrett appointed a "Green Team" to oversee the city's sustainability initiative. This Green Team helped guide the city's efforts to reduce emissions and dependence on foreign fuel sources. The *City of Milwaukee* responded to this challenge on several fronts, including use of CNG for vehicles.

Other Benefits

Republic's drivers prefer the CNG trucks because they are quieter and they can save time for drivers because truck fueling is done overnight with an automated time-fill system.

Groot has won awards for its commitment to establishing a CNG fleet. In 2010, it was named a Clean Fuels Champion by the Chicago Area Clean Cities Coalition, while in 2011, it received the Partnership Award for Innovative Energy Solutions from the Energy Solutions Center. In 2012, *Groot* received the Illinois Green Fleet Award.

Project-Specific Activities

Vehicles Deployed

The three fleets in this case study purchased a total of 70 natural gas refuse haulers with support from Recovery Act funds. All used the Cummins ISL-G natural gas engine and were fueled by CNG; other specifications, such as refuse body size and fuel capacity, were tailored to the individual needs of each fleet.

As part of the Idaho Petroleum Reduction Leadership Project, *Republic* received \$5.5 million in Recovery Act funds for CNG implementation in its Boise fleet.

Republic used approximately \$900,000 of this funding for the incremental cost of 29 new CNG refuse haulers. *Republic* purchased 24 trucks in 2010 and an additional 5 trucks in 2011.^{i (1)} Figure 1 shows several of *Republic's* CNG trucks fueling at a private CNG fueling facility constructed as part of the project.



Figure 1. CNG refuse haulers fueling in Idaho. *Republic Services*

Groot received \$2.6 million in Recovery Act funding to implement CNG in its fleet as part of the Chicago Area Alternative Fuels Deployment Project. *Groot* used approximately \$1 million of this funding to help cover the incremental cost of 20 new CNG refuse trucks (Figure 2).ⁱⁱ The state of Illinois provided additional financial support from the Illinois Alternate Fuels Rebate Program amounting to approximately \$4,000 per CNG truck.



Figure 2. CNG refuse hauler in service with *Groot*. *Chicago Area Clean Cities Coalition*

As part of the Wisconsin Clean Transportation Program, the *City of Milwaukee* received \$4.4 million to purchase CNG vehicles and construct CNG fueling stations. *Milwaukee* placed a total of 21 CNG refuse haulers in service as part of this project, using approximately \$750,000 of this funding for the incremental cost of these trucks. One of *Milwaukee's* trucks is shown in Figure 3.ⁱⁱⁱ



Figure 3. Crane Carrier CNG recycling truck for the *City of Milwaukee*. *Wisconsin Clean Cities*

Infrastructure Deployed

The fleets constructed three new public CNG stations and three new private CNG stations. They also upgraded the equipment for one additional private CNG station as part of these projects.

Republic Services enlisted Clean Energy Fuels Corporation^{iv} to construct two public fast-fill and two private time-fill natural gas fueling stations in the Boise area. *Republic* chose Clean Energy because the infrastructure provider was also able to provide services for the operation and maintenance of the facilities. The first private facility was completed in 2009 in Boise; the second facility was completed in 2011 in Nampa (Figure 4). The

¹ These endnotes indicate the availability of supplemental information at the end of the document to provide additional perspective or more technical explanations.

public fast-fill stations were opened in 2011. At the opening of the Nampa public station, Nampa Mayor Tom Dale gave kudos to the company for being willing to “...think outside the box and embrace new technologies and embrace new ideas...” for the community’s benefit.



Figure 4. CNG fueling dispenser at public station in Nampa, Idaho (Republic). U.S. Department of Energy

Groot upgraded an existing CNG station in the Chicago suburb of Elk Grove Village, Illinois, and constructed a new CNG station northwest of Chicago in the Village of Round Lake Park, Illinois. Both stations are available for use by other fleets if advance arrangements are made. These stations were developed by Dual Fuel Systems, Inc.^v

The *City of Milwaukee* included two CNG fueling stations as part of the CNG project. ANGI Energy Systems^{vi} built the primary CNG fueling station, which was configured for both fast-fill and time-fill operation. A sequential fueling system governs the time-fill connections to enable the system to fuel up to 16 trucks in sequence and record each individual fueling event. This enables the fleet manager to track fuel use for each individual truck connected to the time-fill system; otherwise, an additional \$500 meter would be required at each of the 16 ports. This station was also equipped with a public-access, fast-fill dispenser and four fleet-only, fast-fill dispensers.

The sequential system was designed to accommodate both present and future fleet needs for CNG fueling. As there are plans to expand *Milwaukee’s* entire truck fleet to natural gas, the fueling facility will eventually reach full utilization.

Training for Drivers and Technicians

Fleets in this case study conducted training for technicians and drivers to improve the level of success for the vehicle deployments.

Republic started mechanics training and cylinder inspection certification training one month prior to the arrival of the first trucks. The company had difficulty in finding shop-ready technicians because only a limited number of junior colleges and vocational technology programs nationwide offer CNG training. *Republic* used natural gas maintenance classes from the Natural Gas Vehicle Institute^{vii} and Cummins Inc.^{viii} to certify a number of maintenance technicians. Two technicians have been certified to perform tank inspections.

Republic also trained its drivers using both hands-on and video resources about vehicle operation and safe fueling practices. In addition, CNG trucks are only assigned to drivers with good safety records and longevity with the company.

Groot stated that orientation of its drivers was critical to the successful deployment of CNG trucks. *Groot* provided safety training to ensure that the drivers were aware of the safety features of the vehicles and how to operate them, to address concerns that drivers had expressed about CNG vehicle safety. *Groot* also provided operational training to demonstrate proper vehicle operation, including such items as the requirement to connect a block heater to the engine when outside temperatures were below 20°F to ensure reliable starting at those temperatures.

The *City of Milwaukee* is improving understanding and acceptance of the vehicles through training designed under the broader Wisconsin Clean Transportation Program that funded the city’s vehicles. This grant

included an extensive outreach component and training for vehicle operators, technicians, fueling site supervisors, and users.

Fleet Acceptance and Feedback

Drivers have received the trucks favorably and drivers from all three fleets singled out their quieter operation for particular praise.

“Drivers obviously love the trucks. They love the fact that they no longer have to wear earplugs at work. They love the fact that the trucks are efficient. They don’t break down as often as some of the older diesels,” said *Republic’s* Business Development Manager, Rachele Klein.

“Quiet, lots of power — plenty of power. There’s just no comparing one of these — a CNG truck to a diesel truck. I feel great about working for a company that’s gone CNG,” affirmed Rick Larson, one of *Republic’s* drivers.

The CNG vehicles have produced significant labor cost savings for *Republic*. The overnight time-fill fueling system allows drivers to spend less time fueling the vehicles. They only need to return their vehicles, do a post-trip inspection, and clock out for the day. They no longer need to wait in a 15-minute line for fueling as they did with diesel trucks.

Community and environmental groups have been supportive of *Republic’s* CNG initiatives. The move to CNG has led to a greater number of municipal contract renewals, among other business benefits.

Groot’s drivers are generally happy with the performance of the CNG trucks. In particular, they cited good acceleration and quieter operation as positive aspects of the trucks.

Most *City of Milwaukee* drivers are much happier with the CNG trucks because of their quieter operation and absence of diesel fumes. The drivers say they feel better and have more energy after their shifts.

Deployment Challenges

Garage Modifications

To accommodate the new CNG vehicles, *Republic* used a two-stage plan to implement maintenance facility modifications necessary for operating and maintaining the CNG vehicles. Two maintenance bays were upgraded prior to the arrival of the first CNG trucks and the other two bays were upgraded in subsequent years as the CNG truck fleet expanded. *Republic’s* shop upgrades included additional ventilation systems to exhaust potential methane releases and visual/audible methane alarms. Audible methane alarms were added to supplement the visual alarms that could be overlooked by technicians who were working on vehicles.

Because CNG was new to the Boise area, it was difficult to find the right contractors to perform the work — contractors who were not only familiar with the scope of garage modifications in general, but also with specifically installing the right systems. The cost of these upgrades was an issue, as the upgrades described above (methane alarms, ventilation systems) had a cost of \$90,000 to \$95,000.

Fuel Resale for Public Stations

Existing Idaho Public Utilities Commission (PUC) rules on the resale of natural gas slowed *Republic's* progress in deploying natural gas stations. Since Idaho has not deregulated retail electricity and natural gas service, competitors are prohibited from entering the state and reselling these services in the regulated utility territories. The local utility, Intermountain Gas, asked for assurance from the PUC that it would not be in violation of any laws if it resold natural gas to third parties for use in CNG fueling stations. The project partners assisted in obtaining a declaratory order by the PUC to expressly allow the resale of natural gas for use in vehicles. The order states that the PUC does not have jurisdiction over the resale of natural gas by non-utility third parties.

Republic needed to educate the Idaho Department of Weights and Measures on calibration of the CNG dispensers. This was because the Department of Weights and Measures was unsure about how to confirm the volume calibrations, and this department has jurisdiction over approving calibrations to enable CNG sales to the public. Proven calibration equipment was flown in from outside the state to perform the calibration tests to secure the necessary approvals for public CNG sales.

Groot encountered permitting difficulties for its Elk Grove Village station. The station property was not zoned for retail fuel sales, so *Groot* worked with permitting officials on rezoning the property.

Construction and opening of the two CNG fueling stations with the *City of Milwaukee* were delayed due to difficulty establishing a payment mechanism for customers other than city fleets and determining how to price and tax the retail CNG for sale to the public. The city did not initially intend to take any profit from the retail sale of natural gas, but the local Public Works Committee asked for profit to be included in the price. The city developed a formula to add station maintenance costs and the credit card fee to the base natural gas cost. The resulting price was then rounded to the nearest nine-tenths of a cent to be displayed properly by the station.

The *City of Milwaukee* addressed taxation issues by having the natural gas vendor collect the state road tax. The vendor then passes along the tax collected to the state. The State Department of Revenue is working on the logistics of providing refunds for natural gas used in off-road vehicles. For federal taxes, the city tracks the CNG sold to city vehicles separately, and the city is then billed for the federal taxes for customers other than the city fleet.

Other Fueling Infrastructure Challenges

Republic encountered other difficulties with constructing its stations. Since this was the first time public CNG fueling sites were constructed in the area, permitting authorities with the City of Boise were not familiar with the specifics of installing such equipment, and they wanted to impose requirements for new gasoline stations or convenience stores. The project team needed to explain, for example, that bathroom facilities were not necessary at basic public CNG stations.

Completion of the necessary permits required negotiations with multiple agencies. *Republic* was required to make changes to local roadways to improve traffic flow around its station. This increased permitting complexity because the City of Boise was responsible for building permits while the Ada County Highway Department was responsible for road permits. The highway department required a number of changes to the

site of the public station and assessed impact fees based on long term expectations of traffic through the public station.^{ix} All of this extended the time necessary to secure the permits required to construct the station.

Groot encountered delays on construction of the CNG stations because of the six-month lead time required for the compression equipment. As a resolution, the station designers identified the specifications for the compression equipment early in the process so the equipment could be ordered. Upgrades to natural gas and electricity supplies for the stations were also a source of delays and these were resolved by working closely with the utility to work through the necessary processes.

Vehicle Configurations and Operations

For *Groot*, the tank configuration it specified for the initial truck orders provided inadequate capacity for the longer routes in Round Lake Village. For this reason, *Groot* specified an additional saddle-mounted tank for added range on vehicles for Round Lake.^x

The *City of Milwaukee* found that the fuel tanks installed in the first two CNG refuse trucks were too small, limiting the trucks' driving range. To address this, the city specified that the next 13 trucks were to be fitted with 26-inch frame extensions to support larger CNG tanks behind the cab. The frame extensions have increased the trucks' turning radius, so the city modified the truck routes to adjust for this reduced maneuverability.

The *City of Milwaukee* encountered significant delays while ordering the trucks that almost jeopardized its funding eligibility. Members of the city's Common Council could neither agree on where the trucks would be deployed, nor could they decide whether to adopt single- or dual-stream recycling, which determines recycling truck specifications.

Data Analysis Results

The three fleets operating the 70 refuse haulers described in this case study provided data sets on vehicle operation during 2011 and 2012. This information was analyzed to provide some insight into the performance of these vehicles (fuel economy, fuel cost per mile, and environmental performance).^{xi} In general, the CNG trucks were used in much the same way that conventional diesel trucks were used, achieved similar fuel economy performance, and provided notable petroleum displacement and greenhouse gas emission reductions. Most importantly, the fuel cost savings available to these fleets produced quick payback of the upfront capital costs for CNG vehicles (incremental vehicle costs, fueling station costs, and vehicle maintenance facility upgrades).

Summary of Vehicle Operational Data

Figure 5 presents a summary of the basic operational data for the 70 refuse trucks considered in this case study. Figure 5 shows that the fleets used the CNG refuse haulers consistently throughout the year and the fuel economy did not vary significantly from season to season. On average, the CNG refuse trucks and the comparable diesel trucks both traveled about 14,500 miles per year^{xii}, and used around 6,800 diesel gallon equivalents (DGE) per year.^{xiii} This results in the fuel economies shown in Figure 5, which are around 2.1 miles per DGE for both the CNG and diesel trucks.^{xiv, xv}

The fleets provided information on other aspects of fleet vehicle operations as well, as summarized in the averages below.

- Average number of stops per day: 460 (range of 150–600 stops)
- Average amount of idling per day: 60 minutes (range of 3–150 minutes)^{xvi}
- Average use per day: 9 hours (range of 7–10 hours)
- Average use per week: 5 days
- Average fuelings per week: 5 (range of 5–6)
- Vehicle replacement schedule: replace vehicles at 10–15 years^{xvii}

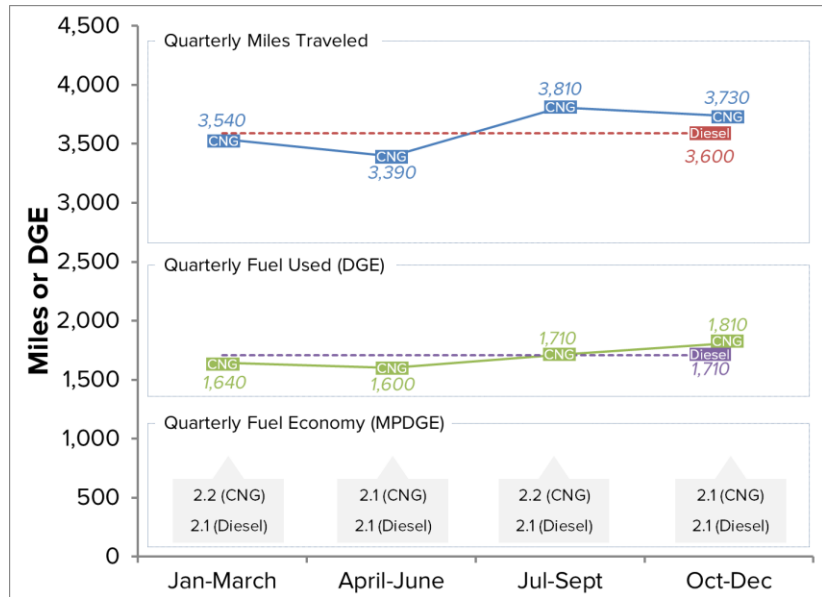


Figure 5. Summary of quarterly operational data (miles, fuel, MPG)

Environment and Energy Impact Data

Petroleum displacement and greenhouse gas reductions are important benefits of CNG vehicles. The operational data were used in the Alternative Fuel Life-Cycle Environmental and Economic Transportation (AFLEET) Tool, developed by Argonne National Laboratory for the Clean Cities program, to estimate the reductions in petroleum use and greenhouse gas emissions for these CNG vehicles. Figure 6 summarizes the total petroleum displacement and greenhouse gas reductions of the 70 CNG vehicles.^{xviii} The total petroleum displacement was 520,000 DGE per year for these vehicles, while GHG reductions were approximately 1,800 tons per year.^{xix}

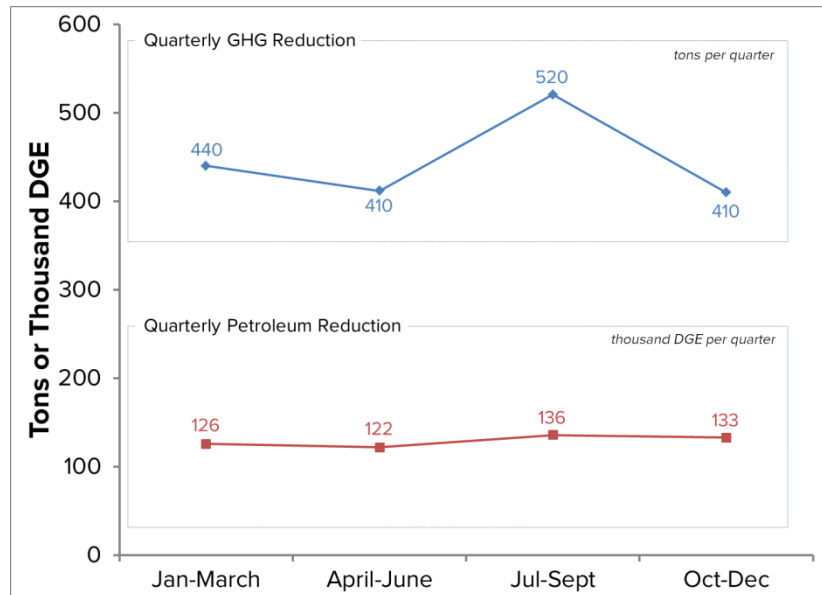


Figure 6. Summary of petroleum displacement and GHG reductions

Business Case Data

Unlike light-duty vehicles which are often purchased for personal reasons, heavy-duty trucks are purchased by businesses to do a job. This means that investments in new technologies such as CNG must pay for

themselves over time to be a viable choice. Lower and more stable fuel prices for CNG relative to diesel provide this payback opportunity and save the fleets considerable amounts of money after the capital costs for the vehicles, fueling stations, and garage modifications are recouped. The fleets in this case study provided information that allows for some assessment of the cost savings potential for these refuse vehicles.

Figure 7 shows the average fuel cost per mile for these refuse fleet trucks, which demonstrates the magnitude of the fuel cost savings possible with lower CNG prices. As this figure illustrates, the average price differential between CNG and diesel is just under \$1 per mile for these refuse fleets.^{xx} Average CNG prices in this calculation were around \$2.00 per DGE, while diesel prices were around \$3.80 per gallon.^{xxi}

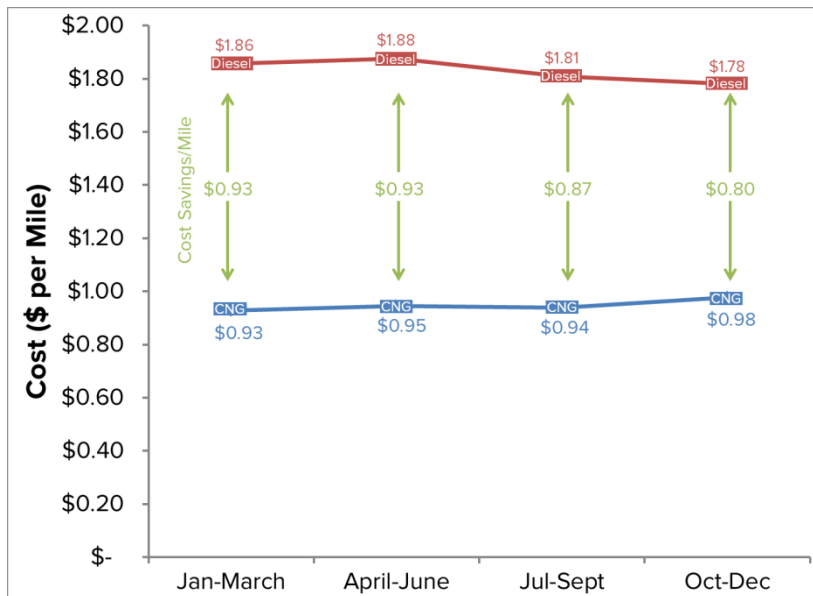


Figure 7. Fuel cost savings per mile for CNG refuse haulers

The major capital costs for implementing these vehicles in refuse fleets include vehicle incremental costs and fueling station costs. The average incremental cost per CNG vehicle in this study was \$38,200 and the average cost of construction for the CNG infrastructure in these projects was \$1.1 million per station.

At a minimum, a favorable business case for a CNG refuse truck project would require yearly fuel cost savings that are sufficient to repay the initial capital costs of the vehicles, stations, and other costs in a relatively short time frame.^{xxii} Table 1 explores the simple payback results of several business case scenarios using the parameters for capital cost and fuel cost savings from fleet averages in this case study.^{xxiii}

Table 1. Example Business Case Analysis – Four Scenarios

	Case 1	Case 2	Case 3	Case 4
CNG fleet size	20	20	30	30
Number of fleet-owned fueling stations	0	1	1	2
CNG price (\$/DGE)	2.22	1.78	1.78	1.78
Diesel price (\$/gal)	4.01	3.90	3.90	3.90
Total vehicle incremental cost (\$ thousands)	760	760	1,100	1,100
Total fueling station cost (\$ thousands)	0	1,100	1,100	2,200
Total capital cost (\$ thousands)	760	1,860	2,200	3,300
Yearly fuel savings with CNG versus diesel (\$ thousands)	251	296	444	444
Simple payback (years)	3.0	6.2	5.0	7.5

In the simplest business case scenario (Case 1 in Table 1), a fleet would purchase CNG vehicles and use public or shared fueling infrastructure and maintenance facilities. In this case, only vehicle incremental costs would need to be recouped from fuel cost savings. This case has a simple payback period of about three years. This payback is well within the vehicle's full useful life of 10 to 15 years. (Note that Table 1 includes a fleet of 20 vehicles, but this payback holds for any number of vehicles because there are no station costs.)

Case 2 adds one CNG station at a capital cost of \$1.1 million to the fleet of Case 1. This additional cost lengthens the simple payback to just over six years.

Case 3 still includes a single CNG station, but increases the number of vehicles to 30 (this assumes that the single station can meet the fueling needs of the 30 vehicles). The additional vehicles represent more capital cost, and also additional fuel cost savings. Thus, the simple payback period decreases to about five years because the station costs are being recouped with higher annual fuel use than in Case 2.

Finally, in Case 4, the fleet purchases 30 CNG trucks, but decides that two CNG stations are necessary to meet its fueling needs. In this case, the additional capital cost for the second station lengthens the simple payback to just over seven years.

It should be noted that the impact of the fueling station costs associated with Cases 2–4 will diminish as additional CNG vehicles are added to the fleets. Once the initial investment of the station(s) is recovered, the payback for additional vehicles would presumably be closer to Case 1 (up to the point that the full station capacity is utilized).

Garage maintenance costs of \$95,000 for an average two-bay maintenance shop can be added to the capital costs in Table 1. With this additional capital cost, the simple payback periods for Cases 2, 3, and 4 increase to 6.6, 5.2, and 7.7 years, respectively.^{xxiv}

Because use of CNG in these fleet vehicles can save a considerable sum of money each year, the capital investments can be recouped fairly quickly, resulting in an overall cost savings over the life of the vehicle compared to their diesel counterparts. There are other benefits to the fleet that are not quantified here, such as improved competitiveness (some refuse haulers are more competitive in using CNG because municipalities are asking companies to consider CNG as part of their bids). These benefits, if quantified, can improve the overall payback of a CNG project.

These general conclusions are confirmed by feedback from fleets in the project. Speaking at a Boise-area CNG workshop, General Manager of Allied Waste Idaho, Dave Fisher, said, “You do the right thing for your customers and those customers will support you. And financially it has all worked out for us. I honestly don’t know what the downside is. We haven’t found one.”

Lessons Learned and Future Plans

All of the fleets included in this case study have made plans to continue deployment of CNG for refuse fleets, either expanding the use of existing CNG infrastructure or making plans to add additional stations.

Republic aims to operate its Boise fleet solely on CNG within the next five years. *Republic* purchased about 800 natural gas vehicles nationwide in 2012 and is on track to purchase a similar number in 2013. It forecasts purchases of about 450–500 vehicles per year in 2014 and beyond. The company installed 13 CNG stations in its western region in 2011, and built an additional 7 stations in this region in 2012 and 2013. *Republic* expects

to complete three more stations in the region by the end of 2014. Nationwide, *Republic* has future plans to build 6–8 new stations per year, with about half of those to be in the western region. The company’s western region also plans to construct 1 landfill gas processing plant per year for the next several years. The landfill-gas-to-energy plants will help offset the energy use of its 17,000 collection vehicles.

DOE’s investment in the refuse truck projects in the Chicago area (including the *Groot* project) has led to greater private investment in natural gas for this application. As a result of the Recovery Act, several additional CNG refuse trucks have been deployed. An additional CNG station has been constructed near Chicago’s Midway Airport (with Waste Management). More than \$5 million in private funds has been invested in CNG for refuse applications in Chicago as a result of the Recovery Act project.

The two new CNG fueling facilities are providing additional fueling capability for the *City of Milwaukee’s* growing municipal fleet of CNG vehicles, as well as for the public. City officials note that the use of the Lincoln Avenue public CNG station is increasing greatly over time. The fleet operations manager stated that the DPW is excited to be on the forefront of CNG development in Milwaukee and it plans to add more CNG vehicles to its fleet each year.

Conclusion

With the aid of the Recovery Act, CNG refuse haulers were successfully deployed in numerous fleets across the country in different daily duty cycles. This study considered three of those fleets. The trucks were well received by drivers and fleet management. As Rachele Klein from *Republic* stated, “Our experience with natural gas over the last year-and-a-half has been amazing.”

Overall fuel economy for the CNG vehicles is close to that of the comparable diesel vehicles. In total, these fleet vehicles are annually displacing around 520,000 DGE of petroleum and around 1,800 tons of greenhouse gas emissions. Fleets can save around 50% on fuel costs with CNG. A simple business case analysis shows that the considerable fuel cost savings these high-fuel-use fleets are achieving, compared to diesel, can yield relatively rapid payback of vehicle, fueling, and maintenance facility capital expenditures.

Fleets encountered some initial implementation issues (including garage maintenance facility upgrades and public fuel resale complexities), but these issues now have been largely resolved. Each fleet in this case study plans to make additional purchases of CNG vehicles and expand fueling infrastructure in the future as a result of their successful initial deployments.

Supplemental Information

- i. Republic's trucks were Autocar ACX64 models with the Cummins ISL-G 8.9 liter natural gas engine (320 horsepower and 1,000 lb-ft torque rating). Trucks were configured with four natural gas cylinders atop the refuse body holding a total of 60 diesel gallon equivalents (DGE). The trucks were equipped with McNeilus refuse bodies in automated side loader, residential rear loader, commercial rear loader, and commercial front loader designs. Information on the specific models and configuration of the replaced diesel trucks was not available for this case study.
- ii. Groot's truck acquisition included 2010 Mack TerraPro Low Entry models with McNeilus front loader refuse bodies. These also used the Cummins ISL-G with the 320 horsepower and 1,000 lb-ft torque rating. Trucks were equipped with roof-mounted CNG tanks of 54 DGE capacity. Information on the specific models and configurations of the replaced diesel trucks was not available for this case study.
- iii. City of Milwaukee purchases included Crane Carrier LET/LDT and Mack chassis with rear loader refuse bodies by Heil and automated side loader refuse bodies by Labrie. The Crane Carrier LET is a low-entry standard chassis, while the LDT is a low-entry drop-frame chassis to accommodate the recycling body. These trucks used the Cummins ISL-G engine. The CNG trucks replaced Crane Carrier diesel trucks that were 10–22 years old. The replaced trucks used several diesel engines: Cummins C8.3 (8.3 liters), Cummins L-10 (10 liters), Cummins ISL (8.9 liters), and Caterpillar 3306B (10.4 liters).
- iv. Clean Energy Fuels Corporation, of Newport Beach, California, is the largest provider of natural gas fuel for transportation in North America.
- v. Dual Fuel Systems, Inc., of Batavia, Illinois, (Chicago area) specializes in turn-key CNG fueling stations and CNG vehicle conversions.
- vi. ANGI Energy Systems, of Janesville, Wisconsin, is a supplier of natural gas fueling equipment and systems.
- vii. The Natural Gas Vehicle Institute is a Las Vegas, Nevada-based provider of training and consulting on natural gas as a transportation fuel.
- viii. Cummins Inc., of Columbus, Indiana, is a major manufacturer of diesel and natural gas engines for medium-duty and heavy-duty trucks.
- ix. Changes to the site included adjusting curbs and adding medians to the street for optimal traffic flow, as well as revisions to mature landscaping. The initial impact fees were quite high, as they were based on traffic estimates for stations in the Salt Lake City area, so *Republic* needed to negotiate lower impact fees.
- x. The saddle-mounted tank on the frame rails provided an additional 18 DGE of fuel capacity.
- xi. This case study analysis aggregates information collected from the fleets to prevent disclosure of proprietary company data. The performance data were reported quarterly to DOE throughout 2011 and 2012. The fleets provided data for six months to one year of operation over slightly different time frames. The information was also aggregated by calendar quarter data to capture seasonal trends wherever possible. For fleets with less than one year of data, existing performance trends were extrapolated to fill out one calendar year of service.

xii. Each CNG truck in this study traveled an average of 3,600 miles quarterly, or around 14,500 miles per year. Each comparable diesel vehicle traveled approximately 14,500 miles per year (quarterly data were not provided, so the average of 3,600 miles per quarter is shown in the graph). This comparable yearly mileage illustrates that the CNG vehicles are generally meeting the same mission as their diesel counterparts. In total, the 70 CNG trucks traveled about 1.01 million miles annually, and the 70 comparable diesel vehicles traveled about 1.01 million miles annually.

xiii. Quarterly fuel use for the CNG vehicles averaged 1,700 DGE per vehicle, or about 6,800 DGE per year. The comparable diesel vehicles also used approximately 1,700 diesel gallons per vehicle per quarter or 6,800 gallons per vehicle per year. In total, the 70 CNG vehicles used 470,000 DGE per year and the 70 comparable diesel vehicles used about 480,000 gallons of diesel per year.

xiv. The close agreement in fuel economy between the spark-ignited CNG engines and the compression-ignition diesel engines might be due to a number of factors. Many of the diesel engines being replaced were relatively old and engine efficiency technology has improved in recent years. Additionally, some research has indicated that comparative spark-ignition natural gas versus compression-ignition diesel fuel economy results should be better for highly-loaded natural gas vehicles. At low loads, spark-ignition engines have relatively high throttling losses because the throttle is mostly closed. When these engines operate at high load, the throttle is mostly open, so throttling losses are minimized and the efficiency gap with the compression-ignition diesel engine is reduced significantly.

xv. Duty cycles for all three fleets involve travel on mostly local streets or arterial roads. Two of the three fleets reported very little or no highway travel, while the third had a more significant percentage of highway travel. Highway travel can represent travel from the vehicle home base to the collection sites or from the collection sites to the landfill or transfer station. The mix of local and highway travel can have an effect on the overall fuel economy of the vehicle.

xvi. All three fleets provided driver training for both idling reduction and efficient driving practices. Only one of the fleets equipped trucks with idle limiting devices, which shut down the vehicle after three minutes of idling. The other fleets typically had extended idle times when waiting at a transfer station or other locations to unload the trucks. These differences significantly affected the average idle time for the vehicles in this study.

xvii. One fleet typically scrapped its vehicles at the end of their lives, while the other two sold the vehicles at a fixed age or mileage accumulation.

xviii. Both petroleum displacement and greenhouse gas reductions for the CNG vehicles were calculated on a quarterly basis relative to comparable diesel vehicles driving the same annual mileage (annual vehicle miles traveled (VMT) was normalized to the CNG vehicles).

xix. In this calculation, “tons” refers to the short ton (2,000 pounds).

xx. The average fuel cost per mile was derived using regional fuel prices for CNG and diesel published in the *Alternative Fuel Price Report* and the fuel use/VMT reported by the fleets.

xxi. These prices are from the *Clean Cities Alternative Fuel Price Report*, using private station prices for both CNG and diesel as these fleets are all using private stations for their fueling needs.

xxii. This is commonly known as simple payback, which excludes the time value of money.

xxiii. Several key assumptions underlie this analysis. The smallest fleet of CNG vehicles in this case study was 20 and the largest was 29. The cases use vehicle fleets of 20 and 30 vehicles, so the sample business case results would be representative of the fleets in this study. The average prices paid by the fleets in the case study for CNG and diesel are used here as the prices at private stations. To reflect the potential for reduced fuel costs to fleets from private stations, average fuel price differentials between public and private CNG and diesel stations from the *2013 Alternative Fuel Price Reports* are added to the private station fuel prices to calculate the public station fuel prices for Table 1.

xxiv. Note that no maintenance facility costs were associated with Case 1, as this case assumes that the fleet would be using outside fueling and maintenance facilities.



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