The per-mile Costs of Operating Compressed Natural Gas Trucks

Experience from 16 Million Miles with the Cummins ISX 12G

ampCNG

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Executive Summary

This report updates the findings of our earlier report "The Per-Mile Operating Costs of Operating Compressed Natural Gas Trucks and Diesel Trucks", as of January 31, 2013, by Larry D. Kristoff of Renewable Dairy Fuels, LLC. That report detailed Renewable Dairy Fuels' experience on prior fleet of 42 heavy duty Kenworth trucks powered by the Cummins 8.9 liter ISL G natural gas engine and compared it with three diesel fleets, one running similar miles per year, a fleet with similar sized engines and one hauling similar loads. We do not attempt to recreate the analysis of operating costs for diesel trucks, but rather document the experience of 16 million miles operating similar Kenworth chassis with the Cummins ISX 12G.

As a reminder, the key findings of the previous paper included total maintenance costs for the CNG fleet of $0.122/mile versus a pre-2010 diesel fleet cost of $0.072/mile while fuel economy for the CNG fleet averaged 5.28 miles per diesel gallon equivalent vs. an estimated industry average of 6.1 miles per gallon for diesel fleets.

In this report we demonstrate that maintenance costs per mile decreased by 33% in the new generation truck to $0.082/mile, and fuel economy improved 18% to 6.22 miles per gallon. While average diesel fuel economy continues to improve, the cost of DEF and issues with regen have increased diesel operating costs. We believe that our experience demonstrates that CNG is closing the gap in absolute terms, and when factoring in the lower cost of CNG fuel vs. diesel fuel, represents a positive ROI proposition for an increasing number of fleets.

Introduction

The following analysis serves to share our experience running CNG, and in particular, maintenance costs on the Cummins Westport ISX 12G engine on Kenworth T660 trucks. We hope that in sharing this information we help lay the foundation for others to find success running CNG in their own trucking applications.

We find that the initial consideration of CNG often involves modeling hard-to-find and hard-to-interpret data from multiple sources. Often, the case for CNG is hard to 'pencil out' because fleets

use overly conservative data for fuel efficiency and maintenance costs. We believe our experience should add to the collective industry knowledge and give confidence to fleets in developing their next CNG business case.

Along with the various benefits CNG offers, we draw attention to the higher capacity 12L engine and benchmark various parameters to that of 9L engine.

Summary of the benefits of CNG

Compressed Natural Gas is clean, low-cost, and American.

Clean

CNG burns cleaner than diesel. With the exception of Carbon Monoxide, CNG emits lower levels of pollutants than diesel in every category[1]. When CNG is created from waste material, its net emission are zero. In fact, renewable natural gas (RNG) offers a 72-97% well to wheels emissions reduction in greenhouse gases as compared to diesel.[2]

Emissions Reduction (%) of New NGVs compared to Diesel Vehicles (Heavy Duty Truck) [1]

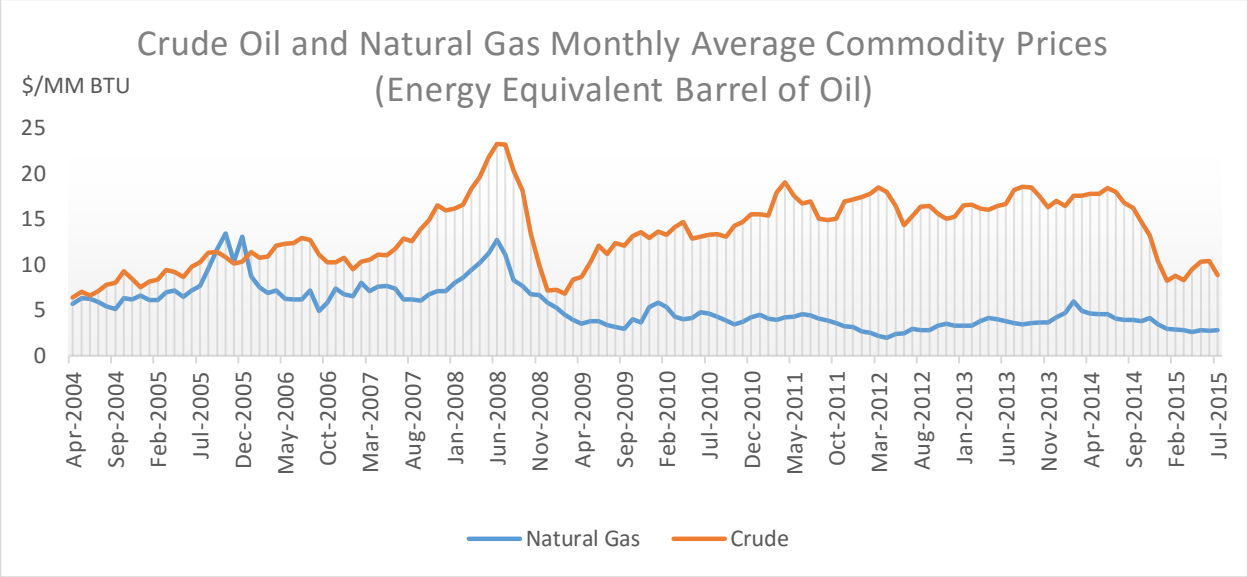
	2002	2007	2012
GHG	25	25	13
NOx	95	88	40
Carbon Intensity of fuel (gco2e/mj)	n/a	n/a	28

Source: NGVAmerica[1]

[1] https://www.ngvamerica.org/natural-gas/environmental-benefits/

[2] National Petroleum Council. "An Overview of the Feedstock Capacity, Economics, and GHG Emission Reduction Benefits of RNG as a Low Carbon Fuel." 2012. http://www.npc.org/FTF_Topic_papers/22-RNG.pdf

Low-cost



On an energy equivalent basis, natural gas is less expensive than oil[3]. Despite the recent fall in crude prices, natural gas maintains its cost advantage. In 2013, the US set a new record for proven natural gas reserves at 354 trillion cubic ft[4].

American

US Natural Gas Supply by Source, 2014		
Country of Origin	MMcf consumed	Percentage of total
US supply (Implied)	25,637,482	95.6%
Canada & Mexico (Net Imports)	1,121,993	4.2%
Non North America Imports	59,143	0.2%
Total	26,818,618	

Nearly 95% of natural gas consumed in the United States, comes from the United States. Of the remaining 5% consumed, 9.8% comes from our neighbors in Canada and Mexico. That means

[3] http://tonto.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=RWTC&f=M
http://tonto.eia.gov/dnav/ng/hist/rngwhhdm.htm
http://www.irs.gov/pub/irs-drop/n-99-18.pdf
[4] http://www.eia.gov/naturalgas/crudeoilreserves/

99.8% of natural gas consumed in the United States comes from North America. CNG is an overwhelmingly American sourced fuel. [5]

Backstory

In September 2011, ampCNG embarked on an ambitious venture to close the supply chain loop at Fair Oaks Dairy. Our innovative project set out to fuel a fleet of 42 Class 8 milk delivery trucks using methane collected from raw cow manure. First, ampCNG used an anaerobic digester to create 1.5 million DGEs of transportation grade renewable natural gas (RNG) per year from dairy cow manure. We then built 2 CNG stations, in Fair Oaks, IN and Sellersburg, IN, to enable routes for trucks carrying 53 loads of milk a day from Fair Oaks Farms to dairy plants in Indiana, Kentucky and Tennessee. As a final step in the project we also leased our own fleet of 42 CNG trucks to make the 53 daily deliveries of raw milk to plants. This project with CNG fueled, heavy duty trucks, was one of the first of its' kind in the country and ultimately helped pave the way for the success of CNG fuel in Class 8 trucking industry.

9L CNG Fleet

In 2011, the only available option for heavy duty CNG engines was the Cummins Westport ISL G (9 liter). The Fair Oaks milk delivery fleet was not running a duty-cycle typical of most 9L applications. The fleet hauled an average of 80,000 GVWR loads up to 220 miles on a single leg trip- which is considered excessive for the 9L engine and drivetrain. To prove the CNG concept and enable the project, ampCNG (through its subsidiary Renewable Dairy Fuels, "RDF") leased 42, 9L CNG Kenworth T660s from Palmer Leasing. RDF also negotiated special allowances from Cummins Westport to run the trucks on this excessive duty cycle. The parties held daily calls to document issues, resolve problems, and keep the trucks running as best as possible. As expected,

[5] http://tonto.eia.gov/dnav/ng/hist/n9140us2a.htm, http://tonto.eia.gov/dnav/ng/hist/n9100us2a.htm, http://tonto.eia.gov/dnav/ng/hist/n9102us2a.htm

the 9Ls had a tough time with the duty cycle, but by the time the trucks were returned to Paclease for resale in the used truck market, the fleet had run more than 15 million miles.

ISL G Specifications

Maximum Horsepower	320 HP	239 kW
Peak Torque	1000 LB-FT	1356 N•m
Governed Speed	2200 RPM	
Clutch Engagement Torque	550 LB-FT	746 N•m
Type	4-cycle, spark-ignited, in-line 6-cylinder, turbocharged, CAC	
Engine Displacement	540 CU IN	8.9 LITERS
Bore and Stroke	4.49 IN x 5.69 IN	114 MM x 144.5 MM
Operating Cycles	4	
Oil System Capacity	7.3 U.S. GALLONS	27.6 LITERS
Coolant Capacity	13.1 U.S. QUARTS	12.4 LITERS
System Voltage	12 V	
Net Weight (Dry)	1,625 LB	737 KG
Fuel Type	CNG/LNG/RNG	Methane number 75 or greater
Aftertreatment	Three-Way Catalyst (TWC)	

Source: Cummins[6]

[6] Cummins ISL G, retrieved Aug. 2015 *http://www.cumminswestport.com/models/isl-g*

12L CNG Fleet

In September 2013, Cummins Westport brought to market its' new CNG engine -- the ISX 12G. The new engine design was re-engineered based in large part on lessons learned from the 9L RDF fleet. With the introduction of the ISX 12G, which is built to haul 80,000 GVWR loads, most of the trucking industry is within the realm of CNG possibility. In September 2013, RDF started replacing its 9L fleet with a new fleet of 42 Kenworth T660s equipped with the much better suited-to-load 12L CNG engine. As of July 1, 2015, the RDF 12L fleet had run a cumulative 16,426,041 miles with the highest truck mileage around 440,000 miles. The average maintenance cost per mile across the fleet was $0.0823 with an average fuel economy of 6.22 miles per DGE.

ISX12 G Specifications

Maximum Horsepower	400 HP	298 kW
Peak Torque	1450 LB-FT	1966 N•m
Governed Speed	2100 RPM	
Clutch Engagement Torque	700 LB-FT	949 N•m
Type	4-cycle, spark-ignited, in-line 6-cylinder, turbocharged, CAC	
Engine Displacement	726.2 CU IN	11.9 LITERS
Bore and Stroke	5.11 IN x 5.91 IN	130 MM x 150 MM
Operating Cycles	4	
Oil System Capacity	12 U.S. GALLONS	45.4 LITERS
Coolant Capacity	26.5 U.S. QUARTS	25.1 LITERS
System Voltage	12 V	
Net Weight (Dry)	2,650 LB	1,202 KG
Fuel Type	CNG/LNG/RNG	
Aftertreatment	Three-Way Catalyst (TWC)	

Source: Cummins[7]

[7] Cummins ISX 12G, retrieved Aug. 2015 *http://www.cumminswestport.com/models/isx12-g*

Methodology

We have recorded every maintenance item for each of our 12L CNG trucks since we put the trucks in service beginning in June 2013. For this analysis, we present maintenance costs as "CNG – Specific" and "Non CNG – Specific" in order to facilitate a comparison with similar diesel fleets, and to isolate differences between CNG and diesel. Costs common between diesel & CNG include: preventative maintenance, tire, oil, and tow costs. "CNG – Specific costs (unique to CNG) include Tank, Spark Plugs, and Filters & Bad Fuel.

ampCNG performed an analysis of every maintenance cost RDF incurred from June, 2013 through June 30, 2015. Below is a line item table summarizing our maintenance costs:

Maintenance Items	$/mile	Cost ($)
CNG Specific Costs		
Tank	$0.0024	$38,975.23
Spark Plugs	$0.0063	$103,690.74
Filters	$0.0038	$63,066.23
Bad Fuel	$0.0032	$52,854.80
CNG Other	$0.0003	$4,928.29
Sub-Total	**$0.0160**	**$263,515.29**
Non CNG Specific Costs		
PM	$0.0066	$108,074.83
Tire	$0.0149	$245,021.79
Oil	$0.0099	$163,416.97
Tow	$0.0008	$13,226.31
Miscellaneous	$0.0341	$560,142.88
Sub-Total	**$0.0663**	**$1,089,882.82**
Total Maintenance Cost	**$0.0823**	**$1,353,398.07**

Based on 16,426,041 miles

Category Definitions

Tanks- Parts and labor costs for scheduled tank inspections, tank inspections after accidents, and loose bolts on tank shields, loose fuel lines/fuel leaks, tank OEM updates.

Spark Plugs- Parts and labor costs for scheduled spark plug replacements, valve adjustments, and fixing fouled/broken spark plugs.

Filters- Parts and labor costs for scheduled filter replacements and filter failures.

Bad Fuel- Damages from wet fuel.

CNG Other- Costs related to remove water inside EGR caused by Joule-Thompson effect and intake manifold.

PM- All costs associated with preventative maintenance.

Tires-Costs of parts and labor for replacing tires from regular wear and tear, punctures, and mismatching.

Oil- Costs of parts and labor for regular oil changes

Tow- Costs for all tows made during this time period.

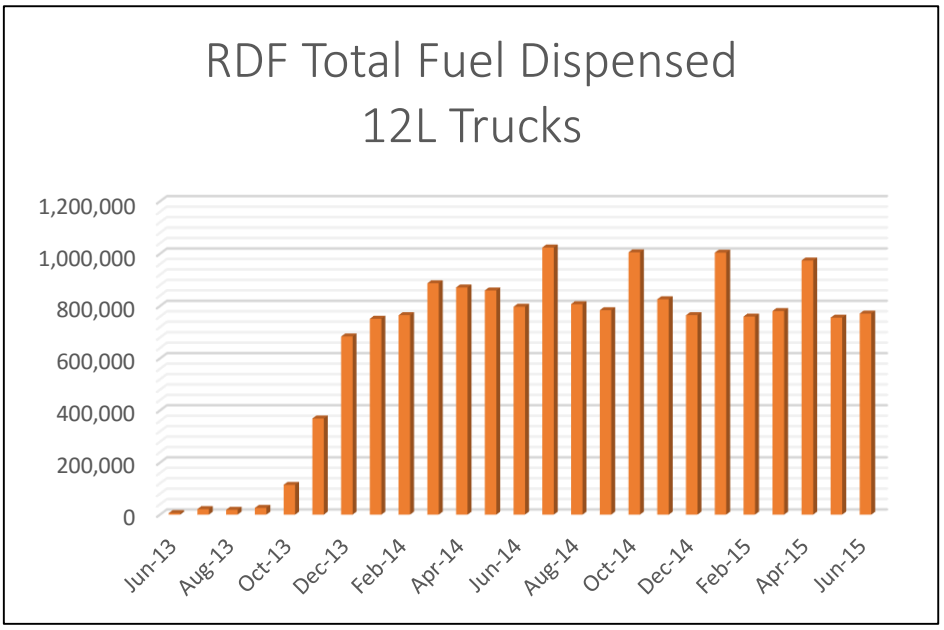
Misc.-Costs for everything else it takes to maintain a truck. Including, winterization, EGR failures (not related to water caused by CNG), windshield wiper blades, back of cab air-line fixes, and sensor adjustments among others.

Fuel economy

Our 12L fleet has achieved 6.22 miles per DGE over its life from June 1, 2013 – June 28, 2015 running 16,426,041 miles. The table below compares the fuel economy of our 12L fleet vs our 9L fleet. The timeframe for our data comparison is June 2, 2014 – May 31, 2015 for the 12L trucks and November 1, 2011 – October 31, 2012 for the 9L trucks.

	ISX 12G	ISL G
# of Trucks	42	42
Annual Miles	10,281,974	6,675,391
Average Miles per DGE	6.31	5.28

First- notice that during this period, we have 3.6 million miles more on the 12L fleet. This is a result of higher uptime and more trucks available for deployment. During this comparison period, we achieve 6.31 miles per DGE vs 5.28 miles per DGE which is a significant increase from 9L fleets.



Analysis

There are various factors that played a role in our findings. The following section attempts to explain the reasons behind our improved fuel economy and lower maintenance cost. Factors that are unique to our CNG experience will also be explored. These factors may not play a role in other fleets running CNG and as such should be accounted for when considering CNG for a fleet.

Engine Technology

Cummins Westport (CWI) developed the ISX 12 G to meet customers' expectations for performance and efficiency at higher loads. As stated earlier in this report, the ISL G was not designed for the RDF fleet application. According to CWI, the ISL G is an excellent choice for applications running less than 60,000 miles per year and up to 66,000 lb GVW. The ISX 12G is better designed to handle loads up to 80,000 lb GVW. The larger cylinder displacement resulted in a larger torque of 1,450 lb-ft, a 45% increase and higher HP rating of 400 hp, which is a 25% increase over the 9L engine.

Transmission

Another major difference between the original fleet and current fleet, apart from the engine and cab, was ISX 12G's compatibility with manual *and* automatic transmissions. Our 9L fleet used all 6-speed automatic speed transmission. As we upgraded the fleet's engines to ISX 12 G, we also replaced the automatic with a 10-speed manual transmission.

Truck Configuration

The 12L engine weighs about 2,650 lbs, a 63% increase from the 9 L engines. To compensate for the added weight of the larger engine, the current fleet embarked upon some weight saving measures. One such measure is the use of wide based tires ("super singles") which were not used in the 9L ISL G fleet and could have played a role in fuel economy and maintenance cost. Theoretically, these tires improve fuel economy because of the lower rolling resistance as well as the weight reduction. Drivers also report improved handling vs dual tire setups. Another weight saving measure, on the 12L fleet, was the use of disc brakes vs drum brakes used in the 9L fleet. The added advantage was the reduced downtime during service.

Fuel Quality

The only CNG related maintenance cost not directly tied to the Cummins Westport ISX 12G was a result of bad fuel, which is a direct effect of the quality of CNG fuel pumped into the trucks. Bad fuel is categorized by the presence of water in CNG. Unfortunately, our station at Fair Oaks was the root cause of this cost item due to insufficient drying of the gas. With the extreme cold experienced earlier this year, the station's dryer did not have sufficient time to regenerate the desiccant and as such allowed some moisture in to the dispensers. We learned from our experience, and have since upgraded all of our cold weather stations to include more robust heating for the gas path to prevent this situation from recurring.

Large Breadth of CNG Experience

Our significant CNG experience on the 9L fleet likely contributed to better operations for the 12L fleet drivers and mechanics. Our drivers are quite accustomed to driving CNG rigs with a combined total of 32.3 million miles across both the 9L and 12L fleets since 2011. Our maintenance teams at Palmer and Ruan have some of the most extensive experience working on CNG engines in the industry. They also have the advantage of having been in close contact with the team at Cummins Westport during our early adoption period of the 9L engines.

Conclusion

This study does not account for the differences in maintenance costs per mile between diesel and CNG. Rather, it offers a point of comparison for our reader's interpretation. Fleets across the country run differently and so each experience is expected to be somewhat unique. The goal of this report is to show running CNG trucks is within a very realistic realm of maintenance costs. Our data points to the fact that CNG is just not for pioneers anymore but is fast becoming a mature technology with maintenance costs in line with diesel. When viewed in aggregate with lower and more stable fuel costs for CNG vs diesel, we believe these data demonstrate that CNG is an attractive option for an increasing number of trucks in the US. This technology is proven and reliable.

We invite questions and peer review of our findings. Please direct inquiries to:

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Appendix A

Mileage Data for the ISX 12G Fleet

Time period	CNG Miles	CNG used (DGE)
June 3, 2013 – Dec 29, 2103	1,238,953	187,939
Dec 30, 2013 - Jan 26, 2014	751,451	120,233
Jan 27 - Mar 2, 2014	765,065	169,647
Mar 3 - Mar 30, 2014	887,074	133,234
Mar 31 - Apr 27, 2014	870,948	131,683
Apr 28 - June 1, 2014	859,355	153,227
June 2 - June 29, 2014	797,253	121,838
June 30 -Aug 3, 2014	1,023,455	156,144
Aug 4 - Aug 31, 2014	807,028	121,812
Sept 1 - Sept 28, 2014	783,982	118,818
Sept 29 - Nov 2, 2014	1,005,135	158,228
Nov 3 - Nov 30, 2014	825,877	137,311
Dec 1 - Dec 28, 2014	765,162	128,149
Dec 29, 2014 - Feb 1, 2015	1,003,871	176,419
Feb 2, 2015 - Mar 1, 2015	759,780	123,205
Mar 2, 2015 - Mar 29, 2015	781,012	121,081
Mar 30 - May 3, 2015	973,868	152,740
May 4 - May 31, 2015	755,551	113,669
June 1, 2015 - June 28, 2015	771,221	114,384
Total	**16,426,041**	**2,639,761**

Study Comparison Period for last 12 months

6.31 miles per DGE

Lifetime data gives

6.22 miles per DGE