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What Set of Conditions Would Make the Business Case to Convert Heavy Trucks to Natural Gas? – a Case Study

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Abstract

Benefits to national security, the trade deficit, and the environment of a nation that uses natural gas trucks are attractive to society, but it is the trucking industry who would make the capital investment and take on the risk of this transition. We ask the question: "What set of conditions would make the business case to convert to natural gas trucks?" As a case study, we developed a financial model that takes into account the economic and operational factors of converting a heavy truck fleet to compressed (CNG) and liquefied (LNG) natural gas. Lynden Inc,. a Pacific Northwest - Alaska based trucking company, participated in this process and provided financial modeling and operational insight from a trucking industry perspective. This paper provides a detailed overview of what it means to run heavy trucks on natural gas and a summary of the economic and operational factors that a trucking company must consider. We modeled for three of Lynden's operations: pick-up and delivery (CNG), farm pick up (CNG and LNG), and line haul (LNG spark and HDPI engines) to look for the minimum number of annual miles per truck needed for an investment in natural gas trucks to be economically attractive. At today's fuel prices, conditions are right for many high mileage (>70,000 miles per truck per year) fleets to begin testing natural gas trucks where fuel is available. If those tests are successful, then fleets will begin to purchase new natural gas trucks as old diesel trucks are retired. Some significant barriers still remain to the mainstream adoption of natural gas trucks, but barriers related to fueling infrastructure and available engines are beginning to see major breakthroughs. Policy incentives that address remaining barriers can help accelerate this transition and make natural gas attractive to lower mileage fleets.

Summary

This is an exciting time for heavy-duty natural gas trucks. Refueling infrastructure is finally beginning to be developed, the price differential between natural gas and diesel has reached a tipping point where running natural gas is now profitable for high mileage fleets, and a higher powered spark-ignited engine that will fit a much larger number of heavy truck operations will soon be available.

Policy makers, the trucking community, and environmental groups share a common interest in running heavy trucks on natural gas for three compelling reasons:

1. Natural gas will remain less expensive and less volatile than diesel for the foreseeable future.
2. Natural gas is domestic and abundant. This benefits national security and reduces the trade deficit.
3. Natural gas is cleaner burning and emits fewer greenhouse gas emissions than diesel.

This is an attractive possibility for society, but it is the trucking industry that would make the capital investment and take on the risk of this transition. This paper asks the question, "What set of conditions would make the business case to convert heavy trucks to natural gas?" We address the risks and rewards of converting a heavy truck fleet from diesel to natural gas from the point of view of a trucking company.

As a case study, Lynden Inc., a Pacific Northwest-Alaska based trucking company, has participated in this process to provide financial modeling and operational insight from a trucking industry perspective.

This paper provides a detailed overview, as well as the pro's and con's, of what it means to run heavy trucks on compressed (CNG) and liquefied (LNG) natural gas, including the physical properties of natural gas as a fuel, fuel tanks, available and future engines, refueling options, maintenance, and safety requirements.

There are a number of economic and operational factors that a trucking company must consider when deciding whether or not to convert a fleet of diesel trucks to natural gas. We address the current and future price of fuels, additional cost of natural gas trucks, reduced fuel economy of engines, reduced operating range, additional weight of natural gas trucks, LNG venting and tank issues, limited engine options, maintenance costs, safety upgrades for maintenance shops, and limited refueling infrastructure.

We developed a financial model that takes into account fuel price, annual miles per truck, payload, fuel economy, operating range, maintenance costs, and the additional weight and cost of a natural gas trucks for three of Lynden's operations: in-city pick-up and delivery (CNG), milk tanker farm pick-up (CNG and LNG), and line-haul (LNG spark-ignited and HDPI engines). We did not include upgrades to maintenance shops because costs and options to outsource maintenance vary greatly.

Based on the model, we estimated the minimum number of miles required to generate a 20% Return On Investment for each scenario at varying diesel fuel prices ($3.50, $3.75, $4.00, and $5.00/ gallon) while keeping natural gas prices consistent ($2.50/ Diesel Gallon Equivalent).

Since 2010, the price of natural gas ($2 to $5 per mcf) has dropped to roughly one quarter the price of oil ($80 to $120 per barrel) on an energy equivalent basis. At these prices, where natural gas is approximately $1.50/ DGE less expensive than diesel at the pump, the line haul and farm pick-up LNG operations required a minimum of around 70,000 miles per truck per year using a spark-ignited engine and 140,000 miles for the HDPI engine to reach a 20% ROI. Pick-up and delivery operations that are not weight sensitive, required only 60,000 miles per year.

Not surprisingly, at lower priced diesel, the minimum number of miles required for an attractive ROI, increases. Once the price differential decreases to $0.75 per DGE, natural gas becomes impractical because the number of miles required to be profitable exceeds the number of miles that can be driven in a year.

At the other end of the spectrum, when diesel is $2.50/ DGE more expensive than natural gas, natural gas becomes an attractive option for fleets traveling 30,000-40,000 miles per year (70,000 miles for the HDPI engine). At these prices, the model was much less sensitive to differences in the additional weight and price of natural gas trucks.

Based on this model, conditions are right for many high mileage fleets to begin testing natural gas trucks where fuel is available in the next few years, even without government subsidies. If those tests are successful (i.e. trucks are profitable and reliable), then fleets will begin to purchase new natural gas trucks as old diesel trucks are retired. This is likely to be a gradual process as fleets learn to navigate the remaining barriers:

1. **Limited fueling infrastructure** means a loss of flexibility for "go anywhere" fleets to meet customer needs. Operating range is limited by the tanks that can fit on a truck at an economical price and reasonable weight. Until infrastructure is widely available, fleets will be limited to centrally-fueled operations and routes where fuel is available.
2. **Limited engine options**. Available engines are either too small (8.9L spark) or too expensive (15L HDPI) for most operations. However, larger spark-ignited engines that can meet the needs of many long-haul fleets will be available soon.
3. **Natural gas trucks are more expensive,** mainly because of the specialized high pressure or super-insulated fuel tanks. This is a significant barrier to fleets and owner-operators with limited access to capital.
4. **The high cost of upgrading a maintenance shop** can make an investment in natural gas trucks considerably less attractive. Full service leases and maintenance packages are available, but this is not always practical for fleets in rural areas and is generally less desirable than performing maintenance "in-house."
5. **LNG use is limited to operations where trucks are refueled every 1-2 days** so that venting of fuel is not an issue.
6. **Additional weight of fuel tanks** detracts from available payload and revenue. This is a concern for fleet managers who are constantly looking for ways to reduce weight.
7. **Fleets are apprehensive about new technology.** It takes time to learn about and carefully test a new kind of truck and fuel.

Interest from fleets is likely to increase in the first quarter of 2013 as two primary barriers, lack of refueling infrastructure and limited engine options, see major breakthroughs. Policy incentives that address remaining barriers can help accelerate this transition and make natural gas attractive to lower mileage fleets.

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What Set of Conditions Would Make the Business Case to Convert Heavy Trucks to Natural Gas? – a Case Study

1. Introduction

There is a great deal of interest in running heavy trucks on natural gas from the trucking industry, policy makers, and environmental groups. However, there are some significant barriers to its mainstream adoption.

Running heavy trucks on natural gas is appealing for three main reasons.

1.) **Natural gas will remain less expensive and less volatile than diesel for the foreseeable future.** Natural gas is approximately $1.50 to $2.00 per gallon less expensive than diesel on an energy equivalent basis. Futures commodity markets for crude oil and natural gas predict that natural gas will remain substantially less expensive than diesel in the future. Natural gas represents a savings of 20 to 25 cents per mile in fuel costs over diesel. Because it is produced domestically, natural gas is not impacted by foreign supply and prices are less volatile. This price savings and stability has caught the attention of the trucking industry where fuel is often the largest expense.

2.) **Natural gas is domestic and abundant. This benefits national security and reduces the trade deficit.** Recent discoveries of shale gas resources have fueled predictions that the U.S. will be a net exporter of natural gas by 2030. If all heavy trucks in the U.S. converted to natural gas, we would reduce oil use by approximately 2 million barrels of oil per day, 12% of total U.S. oil consumption. At $85 per barrel, this translates to reducing our trade deficit by over $150 million per day.

   The National Energy Policy Institute (NEPI) has identified that the transition of heavy trucks to run on natural gas is one of the most cost effective potential energy policies studied. This transition also reduces oil consumption more than any other policy measured.

3.) **Natural gas is cleaner burning and emits fewer greenhouse gas emissions than diesel.** Natural gas burns cleaner than diesel. This allows some natural gas powered trucks to meet EPA 2010 standards for criteria air pollutants (PM and NO_x emissions) without heavy after-treatment emissions systems (e.g. diesel particulate filters and SCR) found on EPA 2010 compliant diesel engines.

   From "well to wheels" natural gas vehicles reduce greenhouse gas emissions by 12-23% (LNG) and 28% (CNG) compared to ultra-low sulfur diesel. Vehicles that use natural gas sourced from landfill gas, wastewater treatment, and farm waste "biomethane" generate 85-90% fewer GHG emissions. The magnitude of this advantage depends on the fuel's source and processing method.

   Natural gas emits fewer greenhouse gases when used as a fuel, however its impact can become detrimental if leaked into the atmosphere where it can be 25 times more potent than CO_2 as a greenhouse gas.

Benefits to both national security and the environment make this an attractive possibility for society, but it is the trucking industry that would make the investment and take on the risk of this transition.

This paper addresses the risks and rewards of converting a heavy truck fleet from diesel to natural gas from the point of view of a trucking company. We ask the question: "*what set of conditions would make the business case to convert heavy trucks to natural gas?"*

As a case study, Lynden Inc., a Pacific Northwest-Alaska based trucking company, has participated in this process to provide financial modeling and operational insight from a trucking industry perspective.

2. What Does it Mean to Run Heavy Trucks on Natural Gas?

Converting a heavy truck (class 8, greater than 33,000 gross vehicle weight) fleet to run on natural gas means adjusting to a new fuel. This section explains the differences between diesel and natural gas fuels and a gives an overview of natural gas heavy-duty tractor trailers, engines, fuel systems, maintenance, and safety requirements.

Natural Gas Fuel Characteristics

Natural gas is composed primarily of methane with smaller amounts of propane, ethane, helium, and water. It is "lighter than air" at temperatures above 160° F. Natural gas is either compressed (CNG) or super cooled (LNG) so that it can be stored in tanks on a truck.

CNG is stored as a gas under high pressure (3,600 psi), which reduces its volume to less than 1/100th of the space it would otherwise occupy. Liquefied natural gas (LNG) is cryogenically cooled to approximately -260˚ F where it condenses to a liquid that occupies 1/600th the space it would occupy at standard temperature and pressure.

Natural gas contains less energy than diesel on a per gallon basis. When comparing LNG and CNG to diesel, it is often described in terms of diesel gallon equivalent (DGE's) to account for the lower energy content. Figure 1 compares the physical properties of diesel to LNG and CNG.

Property	Diesel	LNG	CNG
Energy Content (Btu/ gal)	128,700	74,700	20,300
Diesel Gallon Equivalent "DGE" (gal)	1 gal	1.72 gal	3.7 gal
Diesel Gallon Equivalent "DGE" (gal)	1 gal	0.23 cu ft	0.49 cu ft
Density (lbs./ gal)	6.8	3	1
Energy Density (Btu/lb)	18,250	28,266	28,266

Figure 1. Natural Gas & Diesel Physical Properties

One gallon of diesel contains 128,700 Btu's, the amount of energy in 135 cubic feet of natural gas.

At atmospheric pressure natural gas would fill a container nearly 1000 times larger than a gallon of diesel to get the same amount of energy. Compressed to 3,600 psi (CNG), the container would be 4 times larger, and cooled to -260 degrees F (LNG) the container would be 1.7 times as large. In other words, to carry the same amount of energy as diesel, CNG tanks take up 4 times and LNG tanks take up 1.7 times as much space.

Natural gas has less energy per gallon than diesel, but it is lighter. The energy density (energy per pound) of natural gas is higher than diesel, however the heavy tanks required to store CNG and LNG offset this energy to weight advantage. Figure 2 summarizes the benefits and disadvantages of natural gas fuels.

Natural Gas Pro's	Natural Gas Con's
Less expensive than diesel on an energy equivalent basis. National Average (October '11): - Diesel: \$3.81/ DGE - CNG: \$2.33/ DGE - LNG: \$2.17/ DGE	New distribution and refueling infrastructure is required.
Prices are less volatile than oil because natural gas is produced domestically and is not impacted by foreign supply.	
Prices are listed in DGE to account for the difference in energy content. - 1 DGE = .23 cu ft LNG - 1 DGE = 6.3 gallons CNG	Contains less energy (Btu's) on a per gallon basis so it requires more space on a truck to get the same range.
Compression-ignited natural gas engines are as efficient as diesel engines.	Spark ignited natural gas engines are less efficient (10%) than a diesel engine.
Cleaner burning fuel allows spark-ignited natural gas to use less expensive, lighter weight after-treatment devices to meet EPA standards.	Natural gas engines are currently limited to few available options (7.6L, 8.9L, and 15L).
Lighter than diesel on a per gallon basis. - energy density (Btu/ pound) is 50% higher	Tanks are heavier.

Figure 2. Pro's and Con's of Natural Gas Fuel Properties.

Fuel Tanks

Fuel storage for natural gas is considerably different from that of diesel and accounts for the bulk of the additional weight and higher cost of natural gas trucks.

CNG is typically stored at 3,600 psi and 70 degrees F. These high pressures require very robust cylinders. The cylinders typically used in heavy trucks are made of a plastic gas-tight container and a full composite wrap in order to optimize weight, however, these tanks are very expensive.

An LNG fuel tank is essentially a giant thermos constructed as a ¼" thick stainless steel "tank within a tank" with a vacuum and super-insulation between the two walls. This vacuum thermos design is intended to prevent ambient heat from entering the tank and causing evaporation of fuel and achieves the highest known thermal efficiency (R value exceeds 5000). LNG is typically stored at near atmospheric pressure, but the tank design must compensate for heat gain and higher pressure when not in use. The inner tank is usually made of nine percent nickel steel and the outer tank is usually made of carbon steel.

Tanks are generally described by their diesel gallon equivalent (DGE) volume. This accounts for the lower energy content of natural gas. "Usable fuel" is less than actual volume because of the need to maintain vapor space in the tank (LNG) and the fact that fuel does not flow below pressures of about 150 psi (CNG). In other words, you cannot use every molecule of fuel in a tank. Figure 3 compares key variables in CNG and LNG fuel systems. Figure 4 summarizes the advantages and disadvantages of CNG and LNG systems.

Fuel	Tank Configuration and Nominal Size	Effective Size[1] "Usable Fuel"	Range[2]	Fuel System Weight (full fuel)	Additional Cost of Fuel System Installed[4]
Diesel	75 gallon	75 DGE	450 miles	1,200 lbs[3]	--
CNG	(5) 15 DGE tanks behind cab	68 DGE	367 miles	2,050 lbs	$27,000
CNG	(2) 41 DGE side mounted	74 DGE	400 miles	1,650 lbs	$35,000
LNG	(1) 119 gallon side mounted	60 DGE	324 miles	1,200 lbs	$22,000
LNG	(1) 150 gallon side mounted	75 DGE	405 miles	1,400 lbs	$26,000
LNG	(2) 150 gallon side mounted	150 DGE	810 miles	2,800 lbs	$45,000
LNG Westport HD 15L	(1) 119 gallon side mounted	58 DGE	365 miles	1,600 lbs[5]	$70,000[6]

Figure 3. Typical CNG and LNG Fuel Systems.

1. Effective size is "usable" fuel in diesel gallon equivalents. This accounts for the vapor space (LNG tanks) and the "heat of compression" and residual fuel at low pressure (CNG tanks) which reduces the amount of fuel that is "usable". Westport GX LNG storage tanks volume is reduced due to pump displacement for 5% diesel mixture.
2. Range assumes 6 mpg for diesel and 10% fuel economy penalty for "spark" natural gas engines. Compression-ignited natural gas engines have approximately the same fuel economy as diesel and account for 5% diesel mixture.
3. Diesel weight includes diesel tank, fuel and after-treatment system (DPF + SCR + Urea Storage with solution = 546 lbs).
4. Does not include Federal Excise Tax (FET).
5. Westport HD weight assumes that 45 gallon diesel tank, hydraulic pump and diesel weigh 400 lbs.
6. Westport HD fuel system includes HDPI engine, hydraulic pump, and fuel tank.

Compressed Natural Gas (CNG) Pro's	Compressed Natural Gas (CNG) Con's
- Infrastructure is more readily available. - Trucks can sit idle for weeks without losing pressure or "venting."	- Space and heavy tanks required to store CNG make this impractical for long distances. - Tanks are heavier compared to LNG.
Liquid Natural Gas (LNG) Pro's	**Liquid Natural Gas (LNG) Con's**
- LNG is more dense than CNG, so is more practical for long distances. - Tanks are lighter compared to CNG.	- Infrastructure is very limited outside of California, but is expanding. - LNG should only be used in applications where the truck is working (and being refueled) daily to avoid warming fuel and "venting."

Figure 4. Pro's and Con's of Compressed Natural Gas (CNG) and Liquefied Natural Gas (LNG).

Another important factor to consider when comparing CNG to LNG is the duty cycle. LNG works well in applications where trucks have very little down-time so that new cold LNG is continually added to the system. If a tank sits idle, the gas inside will warm and expand; after about five days it will begin to vent into the atmosphere.

Tank valves are designed to release this pressure, so it is not a safety issue. But this equates to lost fuel and represents an added cost. In addition, the environmental benefits of using natural gas are negated (methane is 25 times more potent as a greenhouse gas than carbon dioxide). CNG tanks do not vent over time because the tanks are designed to contain gas under high pressure.

LNG tank life should exceed the life of the vehicle, however the vacuum will slowly decay over time as gasses diffuse into the tank materials causing the tank to lose some of its super-insulation properties. Once the vacuum within the tank decays to a point where the pressure increases by more than 40 psi over the course of a day, then the tank is no longer considered adequate and needs to be re-evacuated by a competent maintenance facility. This is typically required after the first 4-5 years and every 2-3 years thereafter. The cost is approximately $1,000 per unit and would include other minor parts replacement or refurbishment.

Fuel tanks require visual inspections only. No other maintenance is required over the life of the tank.

Fuel System:

Natural gas is stored as CNG or LNG, but all engines burn natural gas as a vapor.

In a spark-ignited natural gas engine, which can operate on CNG or LNG, the CNG flows from the storage tanks into a fuel line, then into a regulator to reduce the pressure to engine specifications. Delivery of LNG to a spark-ignited engine is provided by the fuel pressure. There are no pumps in the system. When the engine demands fuel the pressurized LNG flows out of the tank toward the engine. The cold pressurized fuel then passes through a heat exchanger, using engine coolant to warm and vaporize the liquid into a gas. From this point on, the process is the same for CNG and LNG. Gas is mixed with air and the exhaust gas recirculation (EGR) system before it is introduced to the intake manifold system and delivers power via a four-stroke internal combustion engine.

In contrast, Westport's compression ignited HPDI (High Pressure Direct Injection) engine uses an engine driven hydraulic pump, located in the fuel tank to move fuel. The pump pressurizes the LNG to about 4,500 psi. The pressurized liquid travels through a heat exchanger, using engine coolant to vaporize the pressurized liquid into a pressurized gas which is then supplied to the engine.

Engines:

The "spark" in a diesel engine comes from the compression of the diesel fuel. Natural gas engines can be either spark-ignited or compression-ignited with pilot injection of diesel fuel. This can be a source of confusion for those learning about natural gas trucks. Figure 5 summarizes advantages and disadvantages of spark-ignited versus compression-ignited engines.

Spark ignited engines use spark plugs similar to a gasoline engine and meet EPA 2010 emission standards using only a 3-way passive catalyst that is lightweight and maintenance free. These engines use “stoichiometric” combustion where the chemically ideal ratio of fuel and air is burned by the engine without any excess of fuel or air left over. Like their diesel counterparts, they are able to use cooled Exhaust Gas Recirculation (EGR) NO_x control where the EGR system takes a measured quantity of exhaust gas, passes it through a cooler before mixing it with the incoming air charge to the cylinder to lower the in-cylinder temperature and reduce oxygen concentration in the combustion chamber by diluting the incoming ambient air with cool exhaust gases. The Cummins-Westport spark ignited engines use EGR, but this is not necessarily true for all spark-ignited engines. They are approximately 10% less fuel-efficient than a comparable new diesel engine due to the lower compression ratio.

Compression ignited engines are virtually the same as a diesel engine, except that they are able to run on natural gas. Westport's HD system injects both diesel (~5%) and the natural gas (~95%) into the combustion chamber of the engine where the diesel ignites under pressure, which in turn ignites the natural gas. These engines operate with LNG only, due to the common rail pressure (constant 4500 psi) required by the engine. Even though these engines operate with 95% cleaner burning natural gas, EPA emissions requirements call for diesel particulate filters (DPF) and liquid urea Selective Catalytic Reduction (SCR) after-treatment to meet 2010 emission standards. This requirement and the additional diesel tank, make this engine system heavier and more expensive than the spark-ignited system. However, these engines maintain the same fuel efficiency as their diesel counterparts.

“Dual-Fuel” is a term that is sometimes inaccurately applied to compression-ignited engines that require both diesel and natural gas. The term was originally used to describe Clean Air Power’s “dual-fuel” engine that can run on 70% natural gas and 30% diesel and has the ability to run on 100% diesel. It is currently in use in Europe and is under development for the U.S.

There are currently only two natural gas engines on the market for use in heavy-duty trucks. 1.) the spark ignited Cummins-Westport ISL-G 8.9 L and 2.) the compression-ignited Westport Innovations HD 15L engine. Figure 6 shows engine specifications for these engines compared to their diesel counterparts. ESI- Navistar has a 7.6L spark-ignited engine available today for lighter-duty applications.

There are also a handful of new engines currently under development and being field tested that are expected to be “game changers” by filling the niche for higher-powered, lighter weight spark-ignited engine systems. Among these are spark ignited Cummins-Westport 11.9 L and ESI Navistar 13L engines. Also under development are an ESI Navistar 9.3 L spark-ignited engine and the Clean Air Power (CAP) 13L compression-ignited “dual-fuel” engine, which will be able to run on 100% diesel if natural gas is not available. Cummins has also announced that it will be developing a 15L spark-ignited engine. (Figure 7)

Retrofit kits are also available that convert existing diesel engines to run on natural gas (CNG or LNG). Eco-Dual's conversion kit is approved for the 2004-2009 Cummins ISX 15L engine platform. Converted engines use 60-80% natural gas with diesel pilot injection and can default to run on 100% diesel at any time if natural gas is not available.

Spark Ignited Engine Pro's No DPF or SCR after-treatment necessary to meet 2010 emission standards - Maintenance Free - Lighter Weight - No diesel tank required - Less expensive - Engine braking capability and manual transmission available with the 11.9 L - Available with CNG or LNG	**Spark Ignited Engine Con's** Lower Compression Ratio means: - Less fuel efficient (7-10%) - Limited options available in the near term (7.6L, 8.9L, 11.9L, and 15L) - Engine braking is currently not available with the 8.9L. - Automatic transmission (8.9L) is expensive. - More frequent maintenance intervals
Compression Ignited Engine Pro's Maintains partial attributes of a diesel engine: - Same compression ratio as diesel - Same fuel efficiency as diesel - 475 hp max - Engine braking - Manual transmission options - Same maintenance intervals SCR after-treatment provides 5% better fuel economy over engines without it. Greenhouse gas emissions per mile are lower: - Well-to-wheels reduction compared to ULSD is 25% (HD) vs. 16% (ISL-G LNG).	**Compression Ignited Engine Con's** Heavier system: - Requires diesel after-treatment systems and a diesel fuel tank - After-treatment system ~ 500 lbs - Diesel tank and fuel weighs ~400 lbs Space is required for diesel and diesel exhaust fluid (DEF) tanks, so dual 58 DGE (116 DGE) is the maximum fuel capacity. After-treatment maintenance is required. More expensive than spark-ignited systems ($20,000-$40,000) and $70,000 more than diesel. LNG only. Currently not available with CNG.

Figure 5. Pro's and Con's of Existing Spark-Ignited and Compression-Ignited Natural Gas Engines.

	6.7-7.6 L		ISL-G 8.9 L		ISX 11.9 L		HD 15 L	
	Diesel	Natural Gas	Diesel	Natural Gas	Diesel	Natural Gas*	Diesel	Natural Gas
Manufacturer	Navistar DT466	ESI Navistar Phoenix	Cummins	Cummins-Westport	Cummins	Cummins-Westport	Cummins	Westport Innovations
Displacement	6.7 L	7.6L	8.9 L	8.9 L	11.9 L	11.9 L	15 L	15 L
Ignition	Compression	Spark	Compression	Spark	Compression	Spark	Compression	Compression HPDI
Cylinder Head	4 valve	4 valve	4 valve	2 valve	4 valve	4 valve	4 valve	4 valve
Fuel System	Common rail system	Throttle Body Intake Manifold	Common rail system	Intake manifold	Common rail system	Intake manifold	Common rail system	Common rail system
2010 Emissions Strategy	Particulate Filter and advanced EGR after-treatment	Passive 3-Way Catalyst	Particulate Filter and SCR after-treatment	Passive 3-Way Catalyst	Particulate Filter and SCR after-treatment	Passive 3-Way Catalyst	Particulate Filter and SCR after-treatment	Particulate Filter and SCR after-treatment
Weight (dry)	1,425 lbs.	1,290 lbs	1,850 lbs	1,625 lbs	2,888 lbs	~2,700 lbs	3,286 lbs	3,243 lbs
Horsepower	210-300 hp	300 hp	330-380 hp	260-320 hp	310-425 hp	320-400 hp	400-600 hp	400-475 hp
Peak Torque	520-869 lb-ft	250-860 lb-ft	1,150-1,300 lb-ft	660-1,000 lb-ft	1,150-1,650 lb-ft	1,450 lb-ft	1,450-2,050 lb-ft	1,450- 1,750 lb-ft
Peak Torque RPM	1,300 RPM	1,300 RPM	1,400 RPM	1,300 RPM	1,200 RPM	1,200 RPM	1,200 RPM	1,200 RPM
Clutch Engagement Torque	400 lb-ft	400 lb-ft	550 lb-ft	550 lb-ft	800 lb-ft	800 lb-ft	1000- lb-ft	1000- lb-ft
Engine Braking	Exhaust brake -yes	No	Yes	No	Yes	Yes	Yes	Yes

Figure 6. Specifications for available heavy-duty natural gas engines and comparable diesel engines.

* The 11.9 L Cummins-Westport will not be available until January 2013, however a limited number are available for testing in 2011 and 2012.

Make	Cummins-Westport ISX	ESI Navistar	ESI Navistar	Clean Air Power
Displacement	11.9	9.3	13	13
Ignition	Spark	Spark	Spark	Compression
Fuel	CNG, LNG Biogas	CNG, LNG, Biogas	CNG, LNG, Biogas	CNG, LNG, Biogas, or 100% diesel
HP	320-425 hp	350 hp	TBA	430 hp
Torque	1,450 lb ft	850-1,200 lb ft	TBA	1,150 lb ft
EGR	Yes	No	Yes	Yes
Test Engine	Complete	Underway 2011	2012	Complete
Field Test	Underway 2011	2012	TBA	2012
Available	Q1 2012	TBA	TBA	TBA
OEM Partner	Kenworth, Peterbilt, Freightliner, Volvo, Autocar	International	International	International

Figure 7. Natural Gas Engines for Heavy Trucks Currently Under Development.

* Cummins Inc. has also announced the development of a 15L spark-ignited engine.

Transmissions and Braking:

Truck OEM's offer automatic transmissions with torque converter technology for use with spark-ignited natural gas engines. This transmission multiplies engine torque at start to deliver adequate power to the drive wheels and makes the most efficient use of fuel. Current (8.9L) spark-ignited natural gas engines are designed for use with automatic transmissions to enable performance over a wide range of applications, including heavy duty applications, that would not otherwise be possible.

Spark-ignited engines must reduce the compression ratio in order for gas to burn and provide a richer mixture. Currently, engine braking is not available in the 8.9L engine, but this is partially compensated by the auxiliary braking provided by an automatic transmission. Spark-ignited engines are capable of engine braking and this will be available with the 11.9 liter engine.

Compression ignited natural gas engines maintain the attributes of a diesel engine such as a high compression ratio and engine braking. Box 1 has additional discussion of power and efficiency of natural gas engines.

POWER AND EFFICIENCY:

Spark-ignited natural gas engines are not able to achieve the high compression ratio (and associated efficiency) or horsepower of a diesel engine because of the need to prevent pre-ignition and engine damage. Most spark-ignited natural gas engines on the market today suffer a fuel penalty of about 10%, but this is improving. Horsepower is limited by the amount of gas that can be supplied to the cylinder without creating "engine knock". This is referred to as a "knock limit" (38 hp/ L for natural gas). Westport's compression-ignited engine can achieve the same compression ratio, fuel economy, and horsepower rating as a diesel engine because it uses direct injection of both diesel and natural gas. Current 8.9L natural gas spark-ignited engines can achieve a max 320 hp and 15L compression ignited engines achieve a max 475 hp. However, these ratings were chosen based on market demand and the technology is capable of developing engines with higher power.

Box 1. Power and Efficiency of Natural Gas Engines.

Maintenance:

Maintenance requirements differ between spark ignited natural gas engines and their diesel counterparts, but the overall cost is roughly the same. Spark-ignited engines require more frequent valve adjustments, spark plug replacement, and specialized oil. This means up to approximately 3 cents per mile in additional maintenance costs. However, spark-ignited engines do not require diesel after-treatment systems or maintenance (DPF and urea) which is estimated to cost 4-5 cents per mile, so overall maintenance costs are expected to be similar to or slightly lower than diesel.

Compression-ignited engines follow the same maintenance intervals as their diesel counterparts, however the engine and fuel system require additional fuel filters and inspections. This adds approximately 1.4 cents per mile using outside labor and 0.9 cents per mile using internal labor. They require the same after-treatment system maintenance as a diesel truck, but use less DEF. Figure 8 compares the maintenance intervals of diesel and natural gas engines.

Some fleets use an accelerated oil change interval for the 8.9L engine because it is being used in a more severe duty-cycle than it was designed for. But this is a product of using a smaller engine, not natural gas. The 11.9L engine will better suit these types of operations.

The maintenance costs for a natural gas truck are comparable to a new diesel truck, but the upgrades required for shops servicing natural gas vehicles can be substantial.

LNG units will start to vent if the tanks are warm for more than a few days (CNG tanks do not vent). To deal with this potential fire hazard, natural gas compliant shops may be required to have sloped roofs, methane detection systems, automated ventilation systems, and explosion proof lighting. These improvements can be very expensive. Price estimates range between $200,000 and $1 million dollars depending on local code requirements and size of the shop.

	Diesel Cummins ISL 8.9L	CNG/ LNG Cummins ISL-G 8.9L	Diesel Cummins ISX 15L	LNG Westport HD 15L
Oil & Filter	15,000	15,000	25,000	25,000
Fuel Filter	15,000 (primary) 30,000 (secondary)	30,000	25,000	High Pressure Diesel 125,000 Low Pressure Diesel 31,250 High Pressure LNG 125,000
Spark Plugs	N/A	45,000	N/A	N/A
Coolant Filter	15,000	15,000	50,000	50,000
Coolant Change	80,000	60,000	250,000	250,000
Valve Adjustment	150,000	60,000	500,000	500,000
DPF (PM Trap)	200,000	N/A	300,000	300,000
DEF Dosing Filter	200,000	N/A	200,000	200,000

Figure 8. Maintenance Intervals of Heavy Duty Diesel vs. Natural Gas Engines.

Many maintenance procedures (tires, oil changes, etc.) can be done without modifications to the shop. Bringing trucks into the shop with low or empty LNG tanks minimizes the risk of venting and associated fire danger. Performing maintenance outdoors may be practical alternative in some cases.

Many fleets choose to operate under full service lease agreements or outsource the maintenance of natural gas trucks in order to remove the uncertainty of maintenance costs and shop upgrades.

Heavy Trucks:

Heavy-duty natural gas trucks are available in the U.S. from Daimler-Freightliner (M2), Paccar's Kenworth (T800, T440), Peterbilt (384, 386, 388, 367), Navistar, and Volvo (VNM).

A natural gas (CNG or LNG) heavy truck with the ISL-G 8.9L spark ignited engine is $30,000-$45,000 more expensive than a comparable diesel. LNG tanks are slightly less expensive than CNG tanks assuming equal range requirements. An LNG truck with the Westport HD 15L engine is about $70,000 more expensive than a comparable diesel. This is primarily due to the cost of the fuel system.

The best way to determine an accurate price and weight differential for a specific application is to obtain a quote. This will also ensure that the fuel tanks will work with specific chassis length, positioning of the 5th wheel, required turning radius, and other necessary equipment.

Conversion kits are also beginning to become available. These kits retrofit existing diesel engines so that they are able to run on compressed or liquefied natural gas and include natural gas fuel tanks and fuel system. Kits cost between $25,000 and $40,000 depending on the size and type of the natural gas fuel tank.

Refueling Process:

Filling up the "gas tank" may be the most obvious difference between a natural gas and diesel truck.

A CNG filling station typically takes natural gas from the local pipeline at low pressure and compresses it to be stored in above ground storage tanks at high pressure. In rural communities, the pipeline may not have adequate capacity for a CNG filling station.

CNG refueling equipment can either be "fast fill" or "time fill". A "fast fill" system uses a large compressor and a high-pressure storage tank to fill the truck tank in about the same amount of time as a typical diesel truck, however filling beyond 75% requires a slower trickle. These systems require a significant amount of electricity to run the compressor. A "slow-fill" system is typically used where fleets are able to fill over a few hours. In both systems, natural gas nozzles lock onto the receptacles and form a leak-free seal, similar to the coupling on an air compressor nozzle. The receptacles are designed so that when the nozzle is removed the gas is prevented from escaping. Basic driver training is required, but personalized protective equipment is not necessary.

LNG is typically delivered to the station via tanker truck and stored in cryogenic storage tanks. An LNG filling station consists of a liquid nitrogen (refrigerant) storage tank and a large (~16,000 gallon) LNG storage tank. LNG is pumped into the vehicle like any other liquid fuel, but with more sophisticated cryogenic fueling equipment. Employee training and protective equipment (gloves, mask, and apron) are necessary.

According to one LNG user, "refueling the truck is different, but simple". The tank looks like a regular diesel tank on the side of a truck. The nozzle looks like a "race car" nozzle. Drivers put on safety equipment (gloves, face shield, and apron) to protect their skin from the super-cooled fuel. They swipe their cards, hook up the nozzle, and hit a button. The computer knows how much fuel the truck needs and tells the driver when the tank is full. It takes about five minutes to refuel.

Compression-ignited engines require diesel in addition to LNG; although the diesel only needs to be refilled about 1 out of every 20 times it is refueled.

Fueling Infrastructure:

Natural gas refueling infrastructure has been a classic "chicken and egg" scenario, where fueling stations will not risk the $1.5M investment without a strong customer base and fleets are not willing to purchase natural gas vehicles without refueling infrastructure in place.

There are currently 47 LNG stations in the U.S. (Figure 9), however only about 1/3rd of those are open to the public (i.e. you do not need prior access or approval) and until recently, there were essentially no LNG filling stations outside of California. CNG is more widely available (936 public and private stations nationwide) with the majority in the Mid-West (Figure 10), but is still limited compared to diesel.

State	# of LNG Fueling Stations
California	36
Texas	5
Utah	1
Nevada	1
Alabama	1
Louisiana	1
Arizona	1
Connecticut	1

Figure 9. Number of LNG Fueling Stations by State. Includes private and public stations.
Alternative Fuels and Advanced Vehicles Database

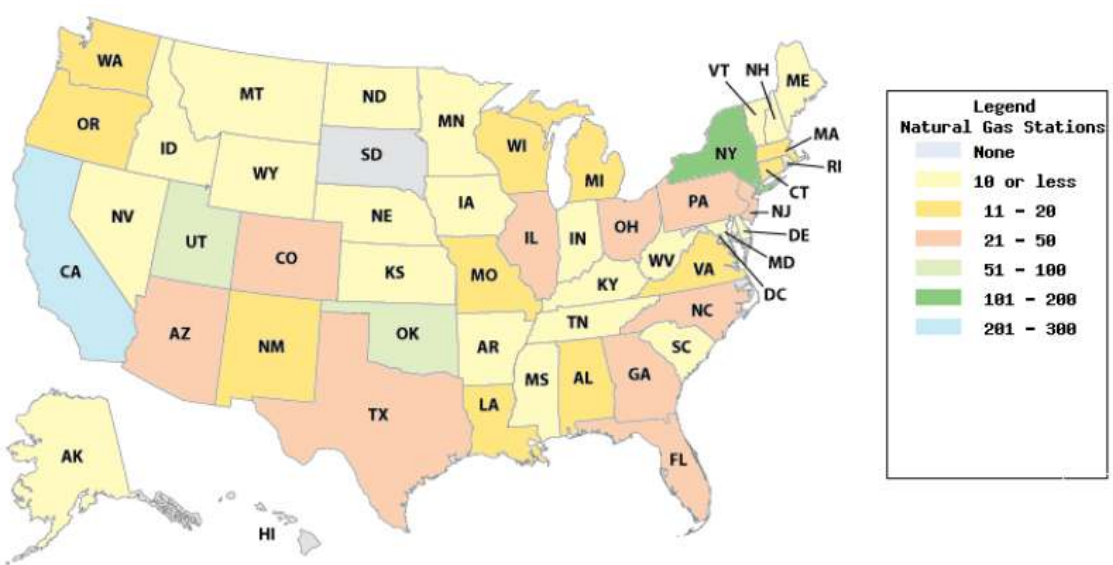


Figure 10. Natural Gas Fueling Station Locations. Includes CNG and LNG stations.
Alternative Fuels and Advanced Vehicles Database

Clean Energy (an LNG producer who builds natural gas refueling stations) has partnered with Pilot-Flying J truck stops to build 150 LNG fueling stations along major interstate corridors. They anticipate having an LNG fueling station every 200 to 300 miles by July 2013 and double that to 300 or 400 stations by 2015 to serve all regional routes. Chesapeake Energy and Temasek Holdings have each invested $150 million in this effort to construct a foundational grid of LNG stations for heavy-duty trucks. Figure 11 shows the proposed locations of LNG stations to be built in 2012 and 2013.

Infrastructure will first expand from California into a Southwest LNG truck re-fueling corridor with stations now present in Northern California, Arizona, Nevada and Utah. Efforts are also underway to create a natural gas vehicle corridor in Texas, the "Texas Triangle", connecting Austin, Dallas/ Fort Worth, Houston, and San Antonio. Also planned for early opening include stations linking Houston with Chicago, Chicago to Atlanta, and highways in the mid-west with high truck traffic.

Local utilities can also be a source of both CNG and LNG. Many utilities produce LNG in order to store excess natural gas in the summer months for use in the winter and are willing to sell both CNG and LNG as transportation fuel. Some utilities are already seeking out discussions with the trucking community as they consider building fueling stations. Because natural gas rates from utilities are regulated, they can provide some of the least expensive fuel available.

Until more natural gas refueling infrastructure is built, fleets may consider building their own refueling stations. A CNG or LNG fueling station can cost between $400,000 and $1.5M.

Groups such as Clean Energy or Vocational Energy will partner with fleets to design and build, and in some cases, operate and maintain a station.

Fleets can pay for the capital cost of a station or Clean Energy will pay for a station and recoup the cost over 10-15 years. To be economically feasible, fleets should be using 25,000 to 30,000 gallons of diesel per month, minimum, assuming the station is in a desirable location with public access. Twice that amount of fuel would be needed for a dedicated fleet location.

Mobile LNG fueling units are also available for fleets operating on temporary jobs. These units hold approximately 3,000 DGE. This is about half the volume of a delivered load of LNG fuel, so it is not economical in the long term. Like all LNG storage tanks, they will vent if not used or refilled every 4-5 days.

Figure 11. Proposed 2012-2013 LNG Fueling Station Network.
Clean Energy

Safety:

Natural gas is noncorrosive and nontoxic. Because it is lighter than air, it will rise under normal atmospheric conditions rather than pooling like a liquid fuel. This eliminates the potential for ground or water contamination and reduces the probability of a fire in the event of a leak, but creates additional hazards for the area around the ceiling of confined spaces. LNG and CNG are about as flammable as diesel, but ignite only under concentrations between 5-15%.

Truck cabs are equipped with methane detectors to alert drivers if gas has vented into the cab. These warnings need to be taken seriously in order to avoid drowsiness and associated safety issues.

Natural gas vehicles are safe and have a proven track record. Based on a survey of over 8,000 natural gas fleet vehicles traveling nearly 180 million miles, there were a total of seven fire incidents in the natural gas fleet, only one of which was directly attributable to a failure of the natural gas system.

Natural gas vehicles, fuel systems, maintenance facilities, and refueling facilities are heavily regulated from a safety standpoint.

CNG and LNG fuel tanks and fuel systems undergo rigorous safety testing and must comply with federal standards. They are made of high-strength materials designed to withstand impact, puncture and, in the case of fire, their pressure relief devices (PRDs) provide a controlled venting of the gas rather than letting the pressure build up in the tank. CNG tanks are designed to "leak before breaking" so that if a tank stays in service beyond the design life, and experiences excessive fill cycles, they will only fail by leakage.

The fuel systems in a natural gas vehicle must conform to NFPA standards for safe design, installation, inspection, and testing. The CNG vehicle fuel containers must meet the Federal Motor Vehicle Safety Standard.

LNG has its own safety considerations

- *Flammable:* While it is not flammable as a liquid, if exposed to air, LNG will rapidly expand to 600 times its original liquid volume, so small leaks can present a significant fire hazard near the leak.
- *Large Expansion Ratio*: When warmed, LNG can build to extremely high pressures (over 3,000 psi) if trapped in lines causing lines to fail. Care must be taken in the design of piping systems and during maintenance operations to assure that liquid cannot become trapped between two valves.
- *Cryogenic Temperatures*: Liquid LNG is stored at very cold temperatures (-260˚ F) so presents a risk of "cryogenic burning" if skin comes in contact with a pressurized liquid stream or by touching a fuel line. Eyes and skin should be covered when working on LNG systems.

There are also special fire safety requirements for repair garages servicing CNG or LNG vehicles. Fleets servicing their own vehicles will require upgrades to comply with these requirements.

- Natural gas presents an asphyxiation hazard at concentrations higher than 21%. Because this can present a hazard in indoor environments, shops require an air evacuation system.
- LNG does not have an odor, so an approved gas detection system in the garage as well as lubrication or chassis repair pits is required.
- No open flame heaters or heaters with exposed surfaces hotter than 750˚ F are allowed.
- The area within 18" of the ceiling is designated a Class I, Division 2 hazardous location. This means modified lighting and electrical systems may be required unless ventilation with at least four air changes per hour is provided.

Repair garages servicing CNG vehicles that are not performing major fuel system repairs may only require explosion proof lighting.

NFPA 30A and state fire, mechanical, and electrical codes provide guidance, but allow for site specific modifications. The local fire department is generally the Authority Having Jurisdiction (AHJ).

Fleets that have on site natural gas refueling equipment must comply with NFPA codes 52, 55, and 57 for equipment requirements, design, construction, site, ventilation, installation, testing, emergency equipment, and maintenance and with code 52 and 57 for LNG fire protection, personnel safety, security, LNG fueling facilities and training. See Appendix for a list of National Fire Protection Administration Codes related to CNG and LNG vehicles, facilities, and fueling equipment.

Figure 12 summarizes the advantages and disadvantages of natural gas fuel from a safety perspective.

Natural Gas Safety Pro's	**Natural Gas Safety Con's**
Non-toxic and non-corrosive	Asphyxiation hazard in enclosed spaces (air evacuation and methane detection systems are required)
Does not pool on the ground: - Reduced fire hazard at ground level - No ground or water contamination - Flammable only at concentrations between 5% and 15%	Rises "lighter than air": - Increased fire hazard indoors at ceiling level (modified lighting and electrical systems may be required)
- Rigorous design and testing standards - Safe and proven track record for vehicles	Heavily Regulated
	- Rapid expansion creates significant fire (i.e. explosion) hazard near a leak - Very high pressures can build if gas becomes trapped between two valves causing lines to fail (follow proper maintenance procedures) - LNG: cryogenic burn can occur if skin is exposed to liquid gas or fuel line (cover eyes, skin)

Figure 12. Pro's and Con's of Natural Gas from a Safety Perspective.

3. Fuel Prices

The price differential of natural gas to diesel is the single most important factor to consider in modeling the business case for converting a fleet to natural gas. Retail prices at the pump are generally listed in diesel gallon equivalents (DGE's) to account for the lower energy content of natural gas compared to diesel. The commodity futures market trades wellhead natural gas in MMbtu's or Mcf units. Figure 13 shows conversion factors for comparing natural gas to diesel.

Fuel Type	Units	Conversion Factor
Wellhead Gas	1000 ft^3 (Mcf)	Mcf x 5.8 = equivalent energy in a barrel of oil
Wellhead Gas	MMbtu	$ MMbtu x 1.028 Btu per ft^3 = $ Mcf
CNG	Gallons	Gallons CNG x 0.16 = diesel gallon equivalent (DGE)
LNG	Gallons	Gallons LNG x 0.58 = diesel gallon equivalent (DGE)

Figure 13. Conversion Factors for Comparing Natural Gas to Diesel.

Until 2005, crude oil prices and U.S. natural gas prices moved together, supporting the conclusion that the two commodities were connected. However, current spot prices and futures markets show a persistent disparity between oil and gas prices.

The commodity futures market predicts natural gas prices to be 65-70% less expensive than oil on an energy equivalent basis over the next five years. Figure 14 compares historical spot prices and commodity futures for West Texas Intermediate (WTI) Crude Oil and Henry Hub wellhead natural gas.

The U.S. Energy Information Administration predicts that crude oil prices will increase to about 2.8 times the price of natural gas by 2035 on an energy equivalent basis. Recognizing the extreme volatility of oil prices and the difficulty in predicting future prices, they recognize that the price of oil could increase to as high as 4.8 times the price of natural gas.

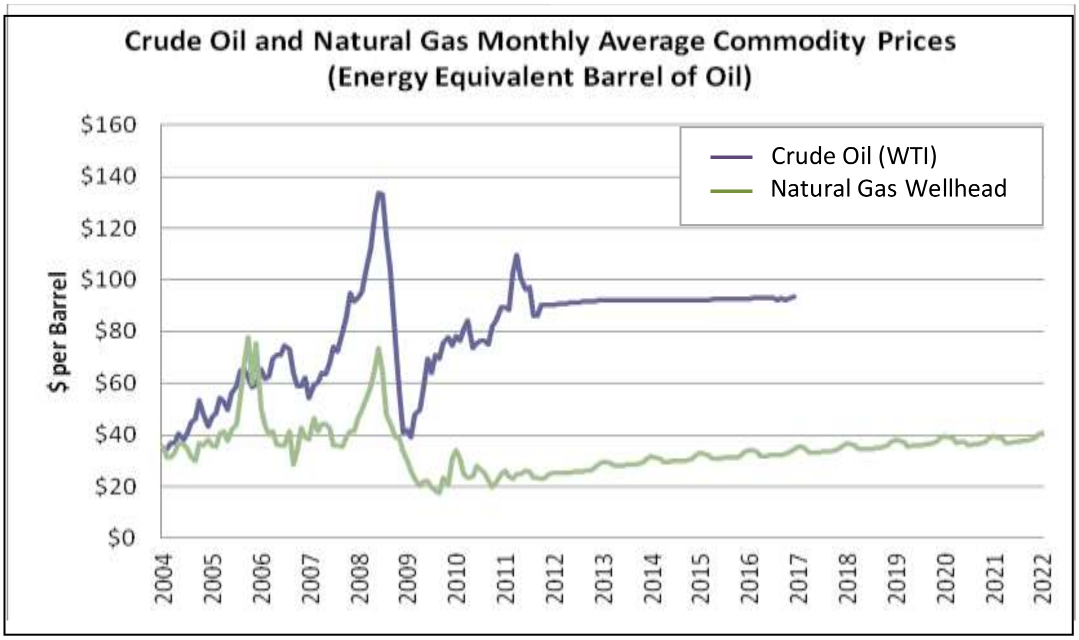


Figure 14. Crude Oil and Natural Gas Monthly Average Historical and Commodity Futures Prices.

Sources: Historical: U.S. Energy Information Administration
Gas: Henry Hub NYMEX Gulf Coast Spot Price
Oil: Crude Oil (West Texas Intermediate) Spot Price
Futures: NYMEX Near-Month Contracts www.cmegroup.com
Gas: Henry Hub Natural Gas Trade Date 09/12/11
Oil: Crude Oil (West Texas Intermediate) Trade Date 09/12/11

Conversely, if demand for natural gas increases as it enters the transportation, liquid fuels, and overseas markets, then the price of natural gas could increase to a point where oil is only 1.1 times the price of natural gas.

The price differential at the retail end is slightly narrower than the commodity prices, accounting for the cost of refinement, distribution, and refueling infrastructure.

Recent retail, at-the-pump sale prices (October 2011) at 320 CNG stations shows CNG an average $1.65 less expensive than diesel (42% less) and LNG $2.10 less expensive (53% less). These average prices are somewhat misleading as retail prices vary regionally. At a given location, LNG is generally 50 cents more expensive than CNG. Figures 15 and 16 show the price differential of CNG and diesel (October 2011) for the continental U.S.

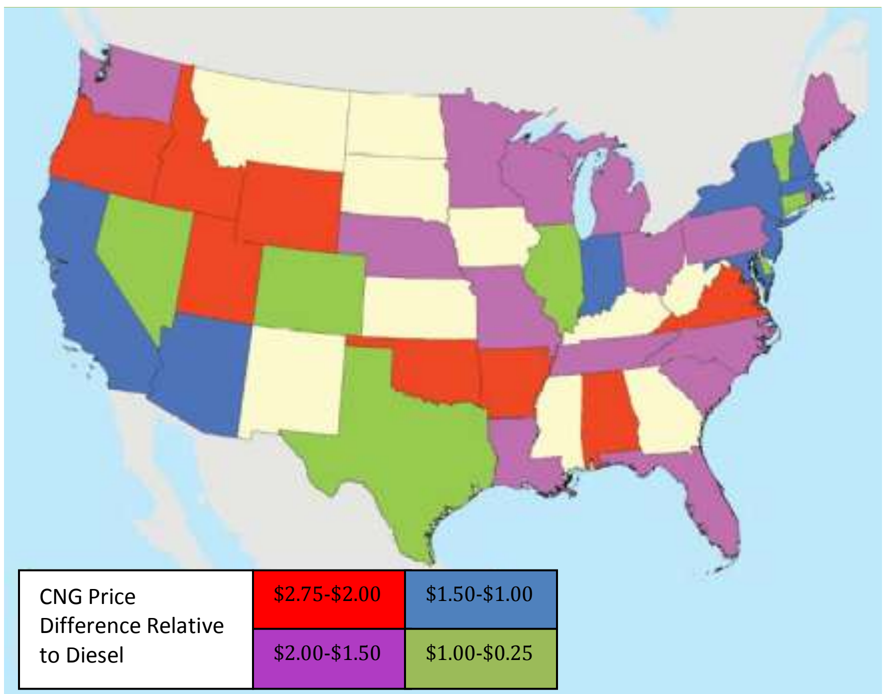


Figure 15. CNG and Diesel price difference Clean Cities Alternative Fuel Price Report Oct 2011

	Natural Gas (CNG) Information Reported by Clean Cities ($/DGE)		Diesel Information Reported by Clean Cities ($/gal)	
	Average Price/ Standard Deviation	Number of Data Points	Average Price/ Standard Deviation	Number of Data Points
New England	$2.74 / 1.00	14	$3.91 / 0.19	43
Central Atlantic	$2.54 / 0.64	76	$3.80 / 0.23	50
Lower Atlantic	$1.80 / 0.54	10	$3.71 / 0.17	50
Midwest	$1.94 / 0.53	28	$3.72 / 0.15	112
Gulf Coast	$1.96 / 0.62	7	$3.65 / 0.13	23
Rocky Mountain	$1.66 / 0.66	70	$3.85 / 0.15	29
West Coast	$2.69 / 0.59	120	$4.06 / 0.28	56
NATIONAL AVERAGE	**$2.33 / 0.77**	**325**	**$3.81 / 0.23**	**363**

Figure 16. CNG and Diesel Retail "at the pump" sale prices. September 30th - October 14th, 2011
Includes federal and state motor fuel taxes
A total of 12 LNG price points were collected with an average fuel price of $2.17 per DGE
Clean Cities Alternative Fuel Price Report October 2011

4. Summary of Economic and Operational Factors:

Natural gas is likely to remain significantly less expensive in future years, but a number of economic and operational challenges exist for the use of natural gas as a transportation fuel in heavy trucks.

Figure 17 presents a summary of the factors discussed in previous chapters.

These assumptions are used in our financial model to determine savings for converting a fleet to run on natural gas. Advantages of natural gas over diesel are shown in green, disadvantages in blue, and factors that are neutral in grey.

Fuel	Diesel	LNG	CNG
Natural gas contains less energy per gallon	128,700 Btu/ gal	74,700 Btu/ gal	20,300 Btu/ gal
Fuel prices are listed in energy equivalent "Diesel Gallon Equivalents" DGE's	1DGE	1.72 gal 0.23 cu ft	3.7 gal 0.49 cu ft
Natural gas is likely to remain substantially less expensive than diesel in the foreseeable future	$4 / DGE $0.68/ mile	$2.50/ DGE $0.42-$0.47/ mile	$2.50/ DGE $0.42-$0.47/ mile
Natural gas is produced domestically and prices are not impacted by foreign supply	Extremely volatile price	Less price volatility	Less price volatility
Natural gas is lighter than diesel	6.8 lbs/ gal	3 lbs/ gal	1 lbs/ gal
Natural gas has more energy per pound	18,250 Btu/ lb	28,266 Btu/ lb	28,266 Btu/ lb
Eliminate environmental risk of fuel spill	Pools on ground	Evaporates	Evaporates
Natural gas has a risk of explosion (enclosed spaces)	Non-explosive	Explosive	Explosive
LNG tanks vent after sitting 4-5 days	Does not vent	Vents- lost fuel	Does not vent
It is more difficult to steal natural gas			
Truck	**Diesel**	**LNG**	**CNG**
Natural gas trucks are more expensive (primarily due to fuel system)	--	Spark $30-40,000 HD $60-70,000	$30-40,000
Salvage value end of useful life	25%	25%	25%
Depreciable life of tractor	48 months	48 months	48 months
Engine	**Diesel**	**Spark** 8.9L, 11.9L	**Compression**
Spark-Ignited natural gas engines are less fuel efficient compared to a new diesel engine	--	10% less	--
Available natural gas engines have limited hp	600 hp max	400 hp max	475 hp max
Maintenance costs are higher for spark engines (spark plugs and specialized oil)	--	Up to $0.03/ mi	--
Spark-ignited engines do not require DPF or urea diesel after-treatment systems	$0.04-$0.05/ mi	200 lbs. lighter maintenance free	$0.04-$0.05/ mi
Natural gas engines are quieter than diesel		10 dB quieter	10 dB quieter
Operations	**Diesel**	**LNG**	**CNG**
Operating range is limited to available infrastructure, wheelbase, and tank configurations	Max 200 +200 = 400 DGE; Typical 50-100 DGE	Max 75 +75 = 150 DGE usable; Typical 50-75 DGE	Max 75 +40+40 = 126 DGE usable; Typical 75-80 DGE
Cost of additional fueling stop	--	$25 per stop	$25 per stop
Available payload is usually diminished	--	50 to 600 lbs heavier	400 to 1,600 lbs heavier
Maintenance shops require safety upgrades (lighting, venting, gas detectors)	--	Up to $200,000 per bay	Up to $200,000 per bay
New technology presents a risk	Stable technology	New technology	New technology

Figure 17. Summary of Economic and Operational Factors. Pro's (green), Con's (blue), and Neutral (gray)

Price of Natural Gas:

Natural gas price is listed in DGE to account for the reduced energy content of natural gas compared with diesel. It is currently $1.50-$2.25 less expensive than diesel and is likely to remain less expensive in the foreseeable future. Prices currently range between $1.85 and $2.20 per DGE. We assumed $2.50 per DGE in our model as a conservative estimate.

Additional Cost of Natural Gas Heavy Trucks:

A natural gas heavy truck with the ISL-G 8.9L spark-ignited engine is $30,000-$40,000 more expensive than a comparable diesel. LNG is slightly less expensive than CNG because the robust tanks required for CNG are more material intensive than the thermos design for LNG. A truck with the ISX-G 15L engine is $70,000 more expensive than a comparable diesel and is available with LNG only. Natural gas engines are approximately $10,000 more expensive than a comparable diesel engine. The higher cost of the truck is primarily due to the cost of the fuel system and in the case of compression-ignited engines, the diesel after-treatment system. Prices have come down substantially in the last few years due to economies of scale.

Fuel Economy Penalty:

Spark ignited engines are 10% less fuel efficient than a comparable new diesel engine. The Westport HD 15L compression-ignited engine has approximately the same fuel efficiency as a comparable new diesel engine.

A truck that averages 6 mpg will save 21 cents per mile in fuel costs with a spark-ignited engine (10% loss in fuel economy) and 26 cents per mile with a compression ignited engine (no loss in fuel economy).

Operating Range:

The operating range that can be achieved with a given natural gas tank must account for three factors: 1.) Account for the reduced energy content of natural gas compared to diesel by using the rated capacity listed in diesel gallon equivalents (DGE). 2) Deduct approximately 10% from a CNG tank to determine "usable fuel." CNG does not flow at low pressures so there is always some residual fuel in the tank that cannot be used. LNG tanks require vapor space which reduces the effective storage space, however, this is already accounted for in the listed DGE capacity, so does not need to be discounted. 3.) Spark ignited natural gas engines suffer a 10% fuel economy penalty. Compression ignited engines (HD 15L) get the same fuel economy as diesel.

Standard tank configurations provide a range of 250-350 miles with CNG and 300-375 with LNG.

Some fleets are experimenting with using additional tanks for increased range, but this adds another $20,000-$30,000 to the price of the truck. For CNG, the maximum tanks used to date include three 25 gallon tanks behind the cab (75 DGE) and two side-rail tanks (41 DGE) which gives a total *usable* fuel capacity of 143 DGE and (700-800 mile range), but this configuration is very heavy (nearly 3,000 pounds full of fuel). For LNG, two 150 gallon tanks (75 DGE each) would give an 810 mile range (assuming 6 mpg with diesel reduced by 10%, 5.4 mpg for a spark ignited engine).

Westport's 15L HDPI requires additional space for the diesel tank, DEF tanks, and hydraulic pump inside the LNG tank. Currently, the largest LNG tank available with the integral LNG pump is a 120 LNG tank, so the 150 gallon tank is not an option. Maximum fuel capacity with dual 120 gallon tanks is 116 DGE. However, there is no fuel economy penalty with this engine and 5% diesel provides additional energy (730 mile range with dual 120 gallon tanks).

Weight Penalty:

The total "tires to tailpipe" weight of a natural gas truck depends upon the type of engine (ISL-G 8.9L or HD 15L), the type of fuel (CNG or LNG) and size of fuel tanks (depending on needed fuel capacity).

The table below shows the estimated weight differential of the most common natural gas configurations based on variables: engine, after-treatment, fuel system, and fuel. Actual weight differential will vary by a few hundred pounds, depending on which diesel truck is used as a base case. A good rule of thumb says that an LNG or CNG truck will be 300-600 pounds heavier. However, the weight can be very close to diesel weights if the natural gas truck is configured with lightweight components.

Fuel Type	CNG	CNG	LNG	LNG	LNG
Engine	8.9L "spark"	8.9L "spark"	8.9L "spark"	11.9L "spark"	HD 15L
Tank Configuration and Nominal Capacity	(5) 15 DGE Behind Cab 75 DGE	(2) 41.2 DGE Side-Rail 82.4 DGE	(1) 150 gal Side-Rail 75 DGE	(1) 150 gal Side-Rail 75 DGE	(1) 120 gal Side-Rail 58 DGE
Usable Fuel (DGE)	68 DGE	74 DGE	75 DGE	75 DGE	58 DGE
Fuel Economy Penalty	10%	10%	10%	10%	No
Range (6mpg)	367 mi	400 mi	338 mi	338 mi	365 mi
Engine Weight	1,625 lbs (vs. 1,800 lbs diesel)	1,625 lbs (vs. 1,800 lbs diesel)	1,625 lbs (vs. 1,800 lbs diesel)	2,700 lbs (vs. 2,888 lbs diesel)	3,243 lbs (vs. 3,286 lbs diesel)
Fuel System Weight (Full Fuel)	2,050 lbs (vs. 510 lbs diesel)	1,650 lbs (vs. 510 lbs diesel)	1,400 lbs (vs. 510 lbs diesel)	1,400 lbs (vs. 510 lbs diesel)	1,802 lbs (vs. 510 diesel)
After-Treatment System Weight	100 lbs (vs. 550 diesel)	100 lbs (vs. 550 diesel)	100 lbs (vs. 550 diesel)	100 lbs (vs. 550 diesel)	550 lbs (vs. 550 diesel)
Weight Differential of Variables (engine, fuel system, after-treatment)	-175 +1,540 -450	-175 +1,140 -450	-175 +890 -450	-188 +890 -450 lbs	-43 +1,292 -0
Total Weight Differential natural gas vs. diesel	915 lbs heavier	515 lbs heavier	265 lbs heavier	252 lbs heavier	1,249 lbs heavier

Figure 18. Estimated range and weight differential for common natural gas configurations.
(Compared to diesel truck with 75 gallon fuel tank - weight differential will vary depending on base truck).

1. Range assumes 6mpg for diesel and LNG HD 15L compression ignited engine and 5.4 mpg for 8.9L and 11.9L spark-ignited engines

2. Fuel system for HD 15L LNG configuration assumes LNG fuel system weighs 1,400 lbs full fuel, 45 gallon diesel tank and accessories weighs 96 lbs and diesel weighs 6.8 lbs per gallon (1,802 lbs total).

3. Weight differential is compared to a 75 gallon diesel tank (81 lbs) and diesel weighs 6.8 lbs per gallon (510 lbs).

4. After-treatment system for spark ignited engines is a simple 3-way catalyst (100 lbs) and for compression (HD 15L) and diesel engines includes DPF, SCR, and urea storage with solution (550 lbs).

LNG Venting, Weathering, and Tank Issues:

Venting or "off-gassing" occurs when LNG warms and expands to the point that the tank releases excess pressure to the atmosphere through the pressure relief valve. This equates to lost fuel and reduced savings. It also negates the environmental benefit of using natural gas because methane is 25 times more potent as a greenhouse gas than carbon dioxide.

If new cold LNG fuel is added to the system on a daily basis this is not a problem, so LNG should only be used in operations where the truck has very little down time. Gas will warm to the point that it will begin to vent only after about 4 to 5 days of not being refilled. The tanks are designed to release this pressure, so it is not a safety issue.

The super-insulation properties of an LNG tank gradually degrade over time, decreasing the amount of time that a tank can sit idle without venting. When the amount of pressure that builds over the course of a day exceeds 40 psi, the vacuum in the tank needs to be re-evacuated. This generally occurs after about 5 years and every 1-2 years thereafter. Loss of vacuum can also occur if there is damage to the tank from a collision or other accident.

If venting occurs on a regular basis, "weathering" can become an issue. When LNG vents, the lighter methane molecules vent first. Over time, the residual fuel will contain a higher proportion of heavier butane, propane, ethane, and helium, than would otherwise exist and will be of lower fuel quality.

There have been some reports of LNG fuel lines freezing and causing problems. However, this is thought to be related to LNG pump replacement where the LNG pump is removed and the empty LNG tank becomes exposed to the environment, not from everyday use.

Venting and icing is not an issue with CNG.

Fuel Quality:

As with diesel, fuel quality is important. Fuel should have a high methane content, or drivers may feel loss of power. Impure fuel can cause plugged filters.

Loss of flexibility:

Loss of flexibility and loss of a "go anywhere" fleet is a concern for a fleet that converts to natural gas. Fleets want to be able to respond to customer needs wherever those might be. Until widespread infrastructure is developed, natural gas fleets will be limited to operations within range of a limited number of natural gas fueling stations.

Limited engine options:

There are currently only two natural gas engines available for heavy trucks: the Cummins Westport 8.9L spark-ignited engine and the Westport 15L compression-ignited engine (LNG only, heavier, and more expensive). Medium duty delivery trucks are currently limited to the ESI Navistar 7.6 L engine. A typical 80,000 GVW truck is pushing the limits of the 8.9L engine and is limited to flat terrain. However, the 11.9L spark-ignited engine will be available 1st quarter of 2013 and will fit a much larger number of heavy truck applications. As demand for natural gas trucks increases, more options will become available. Additional engines are also currently under development (Figure 7).

Limited Space for Tanks and Other Equipment:

LNG and especially CNG tanks take up more space than diesel tanks. This can limit the amount of space available on the truck for pumps or other equipment that might be required. On a 3-axle tractor, side-rail mounted CNG/ LNG tanks can fit on as short as a 177" wheelbase, but this is very tight and makes tank servicing more difficult. A 190" wheelbase is a more typical wheelbase for side-rail mounted tanks. Some drivers have complained that it is difficult to see when backing up with the "back-of-cab" CNG tanks.

Maintenance Costs:

Maintenance costs are $0.025 to $0.03 more per mile for the spark-ignited engines (due to spark plugs, overhead valve adjustments, and specialized oil). However, they require no diesel after-treatment system maintenance ($0.04-$0.05 per mile), so overall represent a cost savings of approximately $0.01-$0.02 per mile.

Maintenance for a compression-ignited engine is the same as for a diesel engine, but with approximately $0.01 per mile in additional fuel filters and inspections. However, less DEF is used compared to a diesel, so this additional cost may be negated.

Shop Upgrades:

Upgrades required for shops servicing natural gas vehicles can be substantial. Natural gas compliant shops may be required to have methane detection systems, automated ventilation systems, and explosion proof lighting. This can cost up to $200,000 per bay depending on local code requirements. Shops servicing only CNG vehicles that are not doing major fuel system repairs may require only explosion proof lighting, however this will vary depending on local fire code requirements.

Many fleets choose to operate under full service lease agreements or outsource the maintenance of natural gas trucks in order to remove the uncertainty of maintenance costs and shop upgrades. Outdoor, unenclosed shop bays may be another practical alternative.

Leasing:

Natural gas trucks are available under a full-service lease. This reduces the burden of the high incremental cost and the uncertainty around maintenance and shop upgrades and allows for immediate savings for high mileage fleets. It also allows fleets to test natural gas in their operations now, while they wait for the 11.9L engine to become available. However, the monthly lease charge for a natural gas truck can be nearly double that of a comparable diesel truck and operating charge is $0.03 per mile higher.

Refueling:

Refueling with LNG is as fast as refueling with diesel, but safety equipment (gloves, goggles, apron) is required to protect skin from cryogenic burns that would result from contact with the super-cooled fuel.

CNG filling times depend upon the size of the compressor and high pressure storage tank. New stations with large compressors and storage tanks can pump at 8 gallons per minute, but filling time will increase if a number of CNG trucks refuel back-to back. At older CNG stations or stations with smaller compressors, it can take 30 minutes or more to fill as the compressor fires up to trickle fill the tanks to full capacity.

Dedicated Fleet Refueling Stations:

A fleet that is interested in refueling "on-site" should be using approximately 250,000 DGE per year for CNG and 500,000 DGE per year for LNG in order to make the investment in a refueling station economically viable and in the case of LNG, to minimize venting issues. A delivery of LNG to the refueling station should be made about every 3-4 days to minimize venting issues and lost fuel. If other fleets are involved, or if the station is in a desirable location for public-private use, then lower volumes may be viable (i.e. the station could be built at no cost to the fleet by the natural gas fuel supplier).

Side Benefits:

Ultimately, the decision to invest in natural gas is an economic and functional decision, but there are a handful of side benefits to its use.

- Engines are quieter (about 10 decibels) than a diesel.
- There is no need for #1 diesel in the winter which is a more expensive and less efficient fuel than #2 diesel.
- It is much more difficult to steal natural gas, as can sometimes be a problem with diesel.
- It adds a new dimension to customer relations. Fleets can help customers reduce costs and meet their sustainability goals. Bio-methane sourced from landfill gas, wastewater treatment, and farm waste presents an opportunity to be "carbon negative" and in some cases partner with customers to use their waste as fuel.
- If future air quality regulations become more stringent, natural gas has more potential to improve air quality cost-effectively compared to diesel.

5. Lynden Inc. Case Study: What Set of Conditions Make the Business Case for an Investment in Natural Gas Heavy Trucks?

The large fuel price differential between natural gas and diesel is very attractive, but is it enough to overcome the economic and operational factors that come with natural gas heavy trucks?

Lynden Inc., a Pacific Northwest-Alaska based transportation company partnered with the National Energy Policy Institute on this project to develop a financial model and gain insight into the economic and operational conditions that would lead a heavy truck fleet to invest in natural gas trucks.

The Lynden family of companies capabilities include: truckload and less-than-truckload transportation, scheduled and charter barges, rail barges, intermodal bulk chemical hauls, scheduled and chartered air freighters, domestic and international air forwarding, international ocean forwarding, customs brokerage, trade show shipping, remote site construction, sanitary bulk commodities hauling, and multi-modal logistics.

About the Model:

We use a profit-and-loss model to find annual cost or savings per mile, per truck, and per fleet. The model accounts for the economic and operational factors summarized in figure 17.

1. **Fuel price.** We modeled for cost of diesel at $3, $4, and $5 per gallon while leaving the cost of natural gas constant at a conservatively estimated $2.50 per diesel gallon equivalent (DGE).
2. **Weight differential**. Weight differential comes from OEM quotes and compares natural gas to a comparable new diesel truck using design specifications for trucks used in each operation. The additional weight of a natural gas truck translates to a percentage of reduced payload and additional miles needed to travel per year to make up for the loss in payload (cost per mile estimated at $3.10 per mile). We used full fuel weights and full urea (diesel after-treatment system) weights.
3. **Fuel Economy and Operating Range.** Operating range is based on "usable" fuel and accounts for a 10% fuel efficiency penalty for spark-ignited engines. For the HDPI engine, there was no fuel economy penalty. Each additional fuel stop needed to compensate for reduced fuel range is estimated to cost $25 to account for additional time and labor.
4. **Price differential, depreciable life, and salvage value of the truck.** Truck prices came from actual OEM quotes and compare natural gas to a comparable new diesel truck including Federal Excise Tax (FET). We assumed a depreciable life of 4 years for the truck (conservative estimate) and equal salvage values (25%) for diesel and natural gas trucks at the end of their useful life.
5. **Maintenance costs.** We assumed maintenance costs to be equal between natural gas and diesel trucks. This is based on a $0.03/ per mile increased cost for spark-ignited engines (spark plugs and specialized oil) and a $0.01-$0.04/ mile savings by eliminating maintenance costs associated with diesel after-treatment systems.
6. **Shop upgrades.** We did not include the cost of maintenance shop upgrades in this model. Costs vary greatly depending on the size and location of the shop and options for outsourcing maintenance may be more practical.

Lynden Scenario Operational Characteristics (we modeled 3 operations, a total of 5 scenarios):

1. In-City Less-Than-Truckload (LTL) Pick-Up and Delivery: CNG
2. Milk Tanker Farm Pick Up: CNG and LNG
3. Truckload and Less-Than-Truckload Line Haul: LNG 11.9L "Spark" engine and LNG 15L HDPI

Key variables are summarized in figure 19; results are presented in figures 20-26.

LTL Pick-Up & Delivery (CNG):

This is a 15 tractor fleet based in the Seattle area. The 69,000 GVW tractor with semi-van trailer operates within a 50 mile radius to provide pick-up and delivery service from a central terminal and travels an average 14,000 miles per year. There are currently four CNG fueling stations in the Seattle area with enough space available for a truck to refuel. CNG quote is for an 8.9L spark-ignited engine. This operation is not weight sensitive because truck is rarely loaded to full capacity, so the weight penalty was removed from the model for this scenario.

Farm Pick Up (CNG & LNG):

Tractors with tank trailers pick up milk from the dairy farm and deliver to the processing plant. The 8 truck fleet carries loads up to 105,500 GVW within a 30 mile radius of the terminal on flat terrain. The 8.9L engine is beyond its upper limit for this application. Each truck averages 60,000 miles per year. Refueling infrastructure is currently not available, but annual fuel use and terminal location make this a potentially feasible public/private refueling site. We compared the diesel to CNG and LNG trucks. This is an extremely weight sensitive operation.

Line Haul (LNG):

Line haul refrigerated trucks with team drivers specialize in transporting seafood and other refrigerated freight from the Pacific Northwest to Central and Southern California, Portland, Boise, Salt Lake City, Denver, Minneapolis, Chicago, and Boston. GVW is 80,000 pounds and trucks average 150,000 miles per year. The 11.9L engine is at its upper limit for this application. For the model, we assume LNG refueling infrastructure is available for these corridors. We compared the diesel and LNG 11.9L engine and HDPI 15L. This operation is also weight sensitive.

	LTL Pick Up & Delivery CNG	Farm Pick Up CNG	Farm Pick Up LNG	Line Haul LNG 11.9	Line Haul LNG HDPI
Engine Size	8.9L	8.9L	8.9L	11.9L	HDPI
Fleet Size	15 trucks	8 trucks	8 trucks	50 trucks	50 trucks
Annual miles per truck	14,000 miles	60,000	60,000	150,000	150,000
MPG Diesel **MPG Natural Gas**	5.91 mpg 5.32 mpg	4.7 mpg 4.23 mpg	4.7 mpg 4.23 mpg	5.89 mpg 5.28 mpg	5.89 mpg 5.89 mpg
Additional Cost of Natural Gas Tractor	$29,000	$40,000	$43,000	$34,000	$67,000
Additional Weight of Natural Gas Tractor	n/a	1,556 lbs	555 lbs	68 lbs	500 lbs
Payload Diesel **Payload Natural Gas**	n/a	75,000 lbs 73,444 lbs	75,000 lbs 74,450 lbs	45,000 lbs 44,932 lbs	45,000 lbs 44,500 lbs
Tank Size Diesel	50 gallons	75 gallons	75 gallons	90 gallons	90 gallons
Tanks Size NG Nominal **Tank Size NG DGE** **Tank Size NG Usable**	(2) 25 DGE 50 DGE 45 DGE	(5) 15 gallon BOC 75 DGE 68 DGE	150 gallon 75 DGE 75 DGE	150 gallon 75 DGE 75 DGE	120 gallon 58 DGE 58 DGE
Range Diesel **Range NG**	296 miles 240 miles	353 miles 288 miles	353 miles 296 miles	531 miles 396 miles	531 miles 354 miles

Figure 19. Operational Characteristics for 5 Lynden Scenarios Diesel vs. Natural Gas

Model Summaries:

LTL In City Pick Up and Delivery 8.9L - CNG Incremental Annual and Per Mile Cost Comparative Model			
Assumptions:	**$3**	**$4**	**$5**
Diesel Price per Gallon	$3.00	$4.00	$5.00
CNG Price per Diesel Gallon Equivalent (DGE)	$2.50	$2.50	$2.50
Difference in Fuel Price per Diesel Gallon Equivalent (DGE)	$0.50	$1.50	$2.50
Incremental Cost of CNG Tractor Unit, net of incentives	$ 29,000	$ 29,000	$ 29,000
Miles per Year Per Tractor	14,000	14,000	14,000
Payload, in Pounds	45,000	45,000	45,000
Range in miles (natural gas tractor vs. 295 miles diesel)	239	239	239
Fleet Size, in Units	15	15	15
Unit Costs Scenario:	**$3**	**$4**	**$5**
Operating Costs			
Incremental Fuel (Savings)/Cost	$ (527)	$ (2,900)	$ (5,273)
Incremental Maintenance (Savings)/Costs	$ -	$ -	$ -
Additional Fuelings	$ 275	$ 275	$ 275
Payload (Savings)/Cost	$ -	$ -	$ -
Capital Costs			
NG Tractor Annualized Incremental Cost	$ 5,438	$ 5,438	$ 5,438
Shop	$ -	$ -	$ -
Incremental Annualized (Savings)/Cost	$ 5,185	$ 2,812	$ 439
Incremental (Savings)/Cost Per Mile	$ 0.37	$ 0.20	$ 0.03
Fleet Costs Scenario:	**$3**	**$4**	**$5**
Operating Costs			
Incremental Fuel (Savings)/Cost	$ (7,910)	$ (43,503)	$ (79,096)
Incremental Maintenance (Savings)/Costs	$ -	$ -	$ -
Additional Fuelings	$ 4,125	$ 4,125	$ 4,125
Payload (Savings)/Cost	$ -	$ -	$ -
Capital Costs			
NG Tractor Annualized Incremental Cost	$ 81,563	$ 81,563	$ 81,563
Shop	$ -	$ -	$ -
Incremental Annualized (Savings)/Cost	$ 77,778	$ 42,185	$ 6,591
Incremental (Savings)/Cost Per Mile	$ 0.37	$ 0.20	$ 0.03

Figure 20. Comparative Model Summary: In-City Pick Up & Delivery 8.9L Spark-Ignited CNG vs. Diesel

Farm Pick Up - 8.9L CNG 75 DGE - Incremental Annual and Per Mile Cost Comparative Model			
Assumptions:	**$3 / gal**	**$4 / gal**	**$5 / gal**
Diesel Price Per Gallon	$ 3.00	$ 4.00	$ 5.00
CNG Price per Diesel Equivalent Gallon (DGE)	$ 2.50	$ 2.50	$ 2.50
Difference in Fuel Price per Diesel Equivalent Gallon (DGE)	$ 0.50	$ 1.50	$ 2.50
Additional Cost of CNG Tractor Unit	$ 40,000	$ 40,000	$ 40,000
Miles per Year Per Tractor	60,000	60,000	60,000
Payload, in Pounds (natural gas tractor vs. 75,000 lbs. diesel)	73,403	73,403	73,403
Range in miles (natural gas tractor vs. 353 miles diesel)	288	288	288
Fleet Size, in Units	8	8	8
Per Tractor Costs Scenario:	**$3 / gal**	**$4 / gal**	**$5 / gal**
Annual Operating Costs (per tractor)			
Incremental Fuel (Savings)/Cost	$ (2,837)	$ (15,603)	$ (28,369)
Incremental Maintenance (Savings)/Costs	$ -	$ -	$ -
Cost of Additional Fuelings at $25 each	$ 950	$ 950	$ 950
Payload (Savings)/Cost of additional miles $3.10 per mile	$ 3,960	$ 3,961	$ 3,961
Capital Costs (per tractor)			
NG Tractor Annualized Incremental Cost	$ 7,500	$ 7,500	$ 7,500
Shop	$ -	$ -	$ -
Incremental Annualized (Savings)/Cost	$ 9,574	$ (3,192)	$ (15,958)
Incremental (Savings)/Cost Per Mile	$ 0.16	$ (0.05)	$ (0.27)
Fleet Costs Scenario:	**$3 / gal**	**$4 / gal**	**$5 / gal**
Annual Operating Costs			
Incremental Fuel (Savings)/Cost	$ (22,695)	$ (124,823)	$ (226,950)
Incremental Maintenance (Savings)/Costs	$ -	$ -	$ -
Additional Fuelings	$ 7,600	$ 7,600	$ 7,600
Payload (Savings)/Cost	$ 31,684	$ 31,685	$ 31,687
Capital Costs			
NG Tractor Annualized Incremental Cost	$ 60,000	$ 60,000	$ 60,000
Shop	$ -	$ -	$ -
Incremental Annualized (Savings)/Cost	$ 76,589	$ (25,537)	$ (127,663)
Incremental (Savings)/Cost Per Mile	$ 0.16	$ (0.05)	$ (0.27)

Figure 21. Comparative Model Summary: Farm Pick Up 11.9L Spark-Ignited CNG vs. 11.9L Diesel

Farm Pick Up - 8.9L LNG 75 DGE - Incremental Annual and Per Mile Cost			
Comparative Model			
Assumptions:	**$3 / gal**	**$4 / gal**	**$5 / gal**
Diesel Price Per Gallon	$ 3.00	$ 4.00	$ 5.00
LNG Price per Diesel Gallon Equivalent (DGE)	$ 2.50	$ 2.50	$ 2.50
Difference in Fuel Price per Diesel Gallon Equivalent (DGE)	$ 0.50	$ 1.50	$ 2.50
Additional Cost of LNG Tractor Unit	$ 42,500	$ 42,500	$ 42,500
Miles per Year Per Tractor	60,000	60,000	60,000
Payload, in Pounds (natural gas tractor vs. 75,000 lbs. diesel)	74,445	74,445	74,445
Range in miles (natural gas tractor vs. 353 miles diesel)	317	317	317
Fleet Size, in Units	8	8	8
Per Tractor Costs Scenario:	**$3 / gal**	**$4 / gal**	**$5 / gal**
Annual Operating Costs (per tractor)			
Incremental Fuel (Savings)/Cost	$ (2,837)	$ (15,603)	$ (28,369)
Incremental Maintenance (Savings)/Costs	$ -	$ -	$ -
Cost of Additional Fuelings at $25 each	$ 475	$ 475	$ 475
Payload (Savings)/Cost of additional miles $3.10 per mile	$ 1,376	$ 1,377	$ 1,377
Capital Costs (per tractor)			
NG Tractor Annualized Incremental Cost	$ 7,969	$ 7,969	$ 7,969
Shop	$ -	$ -	$ -
Incremental Annualized (Savings)/Cost	$ 6,983	$ (5,783)	$ (18,548)
Incremental (Savings)/Cost Per Mile	$ 0.12	$ (0.10)	$ (0.31)
Fleet Costs Scenario:	**$3 / gal**	**$4 / gal**	**$5 / gal**
Annual Operating Costs			
Incremental Fuel (Savings)/Cost	$ (22,695)	$ (124,823)	$ (226,950)
Incremental Maintenance (Savings)/Costs	$ -	$ -	$ -
Additional Fuelings	$ 3,800	$ 3,800	$ 3,800
Payload (Savings)/Cost	$ 11,010	$ 11,012	$ 11,014
Capital Costs			
NG Tractor Annualized Incremental Cost	$ 63,750	$ 63,750	$ 63,750
Shop	$ -	$ -	$ -
Incremental Annualized (Savings)/Cost	$ 55,865	$ (46,261)	$ (148,387)
Incremental (Savings)/Cost Per Mile	$ 0.12	$ (0.10)	$ (0.31)

Figure 22. Comparative Model Summary: Farm Pick Up 11.9 L Spark-Ignited LNG vs. 11.9L Diesel

Line Haul - 11.9L Spark-Ignited 75 DGE - LNG Incremental Annual and Per Mile Cost			
Comparative Model			
Assumptions:	**$3**	**$4**	**$5**
Diesel Price Per Gallon	$3.00	$4.00	$5.00
LNG Price per Diesel Gallon Equivalent (DGE)	$2.50	$2.50	$2.50
Difference in Fuel Price per Diesel Gallon Equivalent (DGE)	$0.50	$1.50	$2.50
Additional Cost of LNG Tractor Unit, net of incentives	$ 35,000	$ 35,000	$ 35,000
Miles per Year Per Tractor	150,000	150,000	150,000
Payload, in Pounds (natural gas vs. 45,000 lbs diesel)	44,932	44,932	44,932
Range in miles (natural gas tractor vs. 531 diesel)	398	398	398
Fleet Size, in Units	50	50	50
Unit Costs Scenario:	**$3**	**$4**	**$5**
Operating Costs			
Incremental Fuel (Savings)/Cost	$ (5,650)	$ (31,073)	$ (56,497)
Incremental Maintenance (Savings)/Costs	$ -	$ -	$ -
Additional Fuelings	$ 2,350	$ 2,350	$ 2,350
Payload (Savings)/Cost	$ 703	$ 703	$ 703
Capital Costs			
NG Tractor Annualized Incremental Cost	$ 6,563	$ 6,563	$ 6,563
Shop	$ -	$ -	$ -
Incremental Annualized (Savings)/Cost	$ 3,965	$ (21,458)	$ (46,882)
Incremental (Savings)/Cost Per Mile	$ 0.03	$ (0.14)	$ (0.31)
Fleet Costs Scenario:	**$3**	**$4**	**$5**
Operating Costs			
Incremental Fuel (Savings)/Cost	$ (282,486)	$ (1,553,672)	$ (2,824,859)
Incremental Maintenance (Savings)/Costs	$ -	$ -	$ -
Additional Fuelings	$ 117,500	$ 117,500	$ 117,500
Payload (Savings)/Cost	$ 35,132	$ 35,141	$ 35,149
Capital Costs			
NG Tractor Annualized Incremental Cost	$ 328,125	$ 328,125	$ 328,125
Shop	$ -	$ -	$ -
Incremental Annualized (Savings)/Cost	$ 198,271	$ (1,072,907)	$ (2,344,085)
Incremental (Savings)/Cost Per Mile	$ 0.03	$ (0.14)	$ (0.31)

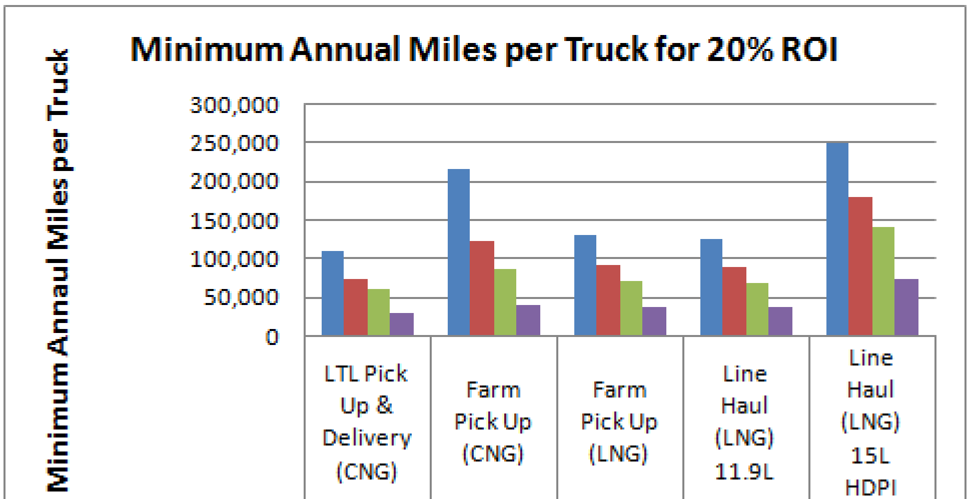
Figure 23. Comparative Model Summary: Line Haul 11.9L Spark-Ignited LNG vs. 11.9L Diesel

Line Haul 15L HDPI 58 DGE - LNG Incremental Annual and Per Mile Cost			
Comparative Model			
Assumptions:	**$3**	**$4**	**$5**
Diesel Price Per Gallon	$3.00	$4.00	$5.00
LNG Price per Diesel Gallon Equivalent (DGE)	$2.50	$2.50	$2.50
Difference in Fuel Price per Diesel Gallon Equivalent (DGE)	$0.50	$1.50	$2.50
Additional Cost of LNG Tractor Unit, net of incentives	$ 67,000	$ 67,000	$ 67,000
Miles per Year Per Tractor	150,000	150,000	150,000
Payload, in Pounds (natural gas tractor vs. 45,000 lbs diesel)	44,500	44,500	44,500
Range in miles (natural gas tractor vs. 531 miles diesel)	354	354	354
Fleet Size, in Units	50	50	50
Unit Costs Scenario:	**$3**	**$4**	**$5**
Operating Costs			
Incremental Fuel (Savings)/Cost	$ (12,070)	$ (37,494)	$ (62,917)
Incremental Maintenance (Savings)/Costs	$ -	$ -	$ -
Additional Fuelings	$ 3,525	$ 3,525	$ 3,525
Payload (Savings)/Cost	$ 5,167	$ 5,167	$ 5,167
Capital Costs			
NG Tractor Annualized Incremental Cost	$ 12,563	$ 12,563	$ 12,563
Shop	$ -	$ -	$ -
Incremental Annualized (Savings)/Cost	$ 9,184	$ (16,239)	$ (41,663)
Incremental (Savings)/Cost Per Mile	$ 0.06	$ (0.11)	$ (0.28)
Fleet Costs Scenario:	**$3**	**$4**	**$5**
Operating Costs			
Incremental Fuel (Savings)/Cost	$ (603,493)	$ (1,874,679)	$ (3,145,865)
Incremental Maintenance (Savings)/Costs	$ -	$ -	$ -
Additional Fuelings	$ 176,250	$ 176,250	$ 176,250
Payload (Savings)/Cost	$ 258,332	$ 258,340	$ 258,349
Capital Costs			
NG Tractor Annualized Incremental Cost	$ 628,125	$ 628,125	$ 628,125
Shop	$ -	$ -	$ -
Incremental Annualized (Savings)/Cost	$ 459,214	$ (811,964)	$ (2,083,142)
Incremental (Savings)/Cost Per Mile	$ 0.06	$ (0.11)	$ (0.28)

Figure 24. Comparative Model Summary: Line Haul 15L HDPI LNG vs. 15L Diesel

	In City Pick Up and Delivery CNG	Farm Pick Up CNG	Farm Pick Up LNG	Line Haul LNG 11.9L Spark	Line Haul LNG HDPI
Annual (Cost) and Savings per mile					
Diesel $3 per gallon	($0.37)	($0.16)	($0.12)	($0.03)	($0.06)
Diesel $4 per gallon	($0.20)	$0.05	$0.10	$0.14	$0.11
Diesel $5 per gallon	($0.03)	$0.27	$0.31	$0.31	$0.28
Annual (Cost) and Savings per truck					
Diesel $3 per gallon	($5,185)	($9,574)	($6,983)	($3,695)	($9,184)
Diesel $4 per gallon	($2,182)	$3,192	$5,783	$21,458	$16,239
Diesel $5 per gallon	($439)	$15,958	$18,548	$46,882	$41,663
Annual (Cost) and Savings per fleet					
Diesel $3 per gallon	($77,778)	($76,589)	($55,865)	($198,271)	($459,214)
Diesel $4 per gallon	($42,185)	$25,537	$46,261	$1,072,907	$811,964
Diesel $5 per gallon	($6,591)	$127,663	$148,387	$2,344,085	$2,083,142
Return on Investment (ROI) = annual savings/ additional cost of tractor					
Diesel $3 per gallon	(18%)	(24%)	(16%)	(12%)	(14%)
Diesel $4 per gallon	(8%)	8%	13%	63%	24%
Diesel $5 per gallon	(2%)	40%	43%	137%	62%

Figure 25. Summary of Model Results for 5 Lynden Scenarios.
(Cost) and Savings includes operating costs and annualized capital costs
ROI = annual profit/ additional cost of the natural gas tractor



	LTL Pick Up & Delivery (CNG)	Farm Pick Up (CNG)	Farm Pick Up (LNG)	Line Haul (LNG) 11.9L	Line Haul (LNG) 15L HDPI
$3.50 / gallon diesel	110,000	215,000	130,000	125,000	250,000
$3.75 / gallon diesel	75,000	123,000	93,000	90,000	180,000
$4.00/ gallon diesel	60,000	87,000	72,000	70,000	140,000
$5.00 / gallon diesel	31,000	40,000	37,000	37,000	73,000

Figure 26. Minimum Annual Miles per Truck for 20% Return On Investment for 5 Lynden Scenarios.
(Assume Natural Gas is $2.50/ DGE)

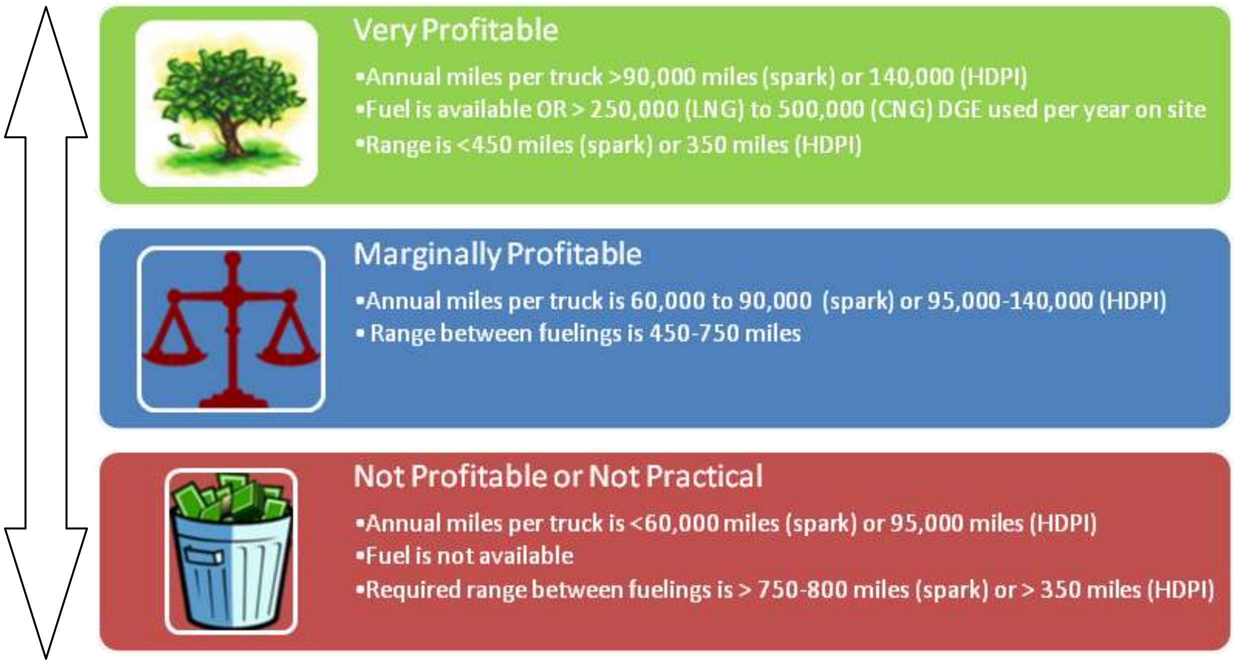


Figure 27. Operational Characteristics that are Profitable, Marginally Profitable, and Not Profitable or Practical. Assumes a $1.50/ DGE fuel price differential between diesel and natural gas.

Model Conclusions:

No model is perfect, however this model is a useful tool for predicting which operations make business sense for natural gas. Figure 26 shows the minimum number of miles per truck needed at various fuel price differentials to achieve a 20% Return on Investment (ROI) while taking into account the high incremental cost of the natural gas truck, loss of fuel economy, loss of payload, maintenance costs, and reduced operating range.

Return objectives are set by each company based on their unique circumstances such as cost of capital, amount of leverage, shareholder return expectations, and perceived risk of the investment. The Return On Net Asset threshold for four publicly traded trucking companies over the last 5 years ranged from 5.7% to 25.6% (average 12.1%.) A 20% threshold is on the high end of what a business would use as an investment criteria for this type of model, but is in line with the high perceived risk of investing in new technology like natural gas trucks.

Assuming $4.00 per gallon diesel and $2.50 per DGE natural gas (today's approximate prices), LNG fleets traveling more than 70,000 miles achieve a 20% Return on Investment. The minimum number of miles for a fleet of CNG trucks to achieve a 20% ROI ranges between 60,000 and 90,000 miles per year, depending on the actual cost of the tractors and the sensitivity of the operation to weight.

Modeling for the Westport HDPI 15L:

We also modeled the Westport HDPI 15L for the Line Haul scenario. For a truck with a single 120 gallon (58 DGE) tank, this added approximately 500 lbs and $67,000 to the weight and price of a comparable 15L diesel truck with 90 gallon tanks and required 140,000 miles per truck per year to reach 20% ROI. Adding an additional 35 DGE tank increased the incremental cost to $103,000 and added another 700 pounds. Trucks with this additional tank required 260,000 miles per truck per year to achieve a 20% ROI. The best fit for operations using the HDPI engine are those with short range, high miles, and high horsepower requirements.

Importance of Fuel Price:

There seems to be a critical point in the price difference between diesel and natural gas where diesel is between $1.25 and $1.50 more expensive than natural gas per diesel gallon equivalent (Figure 28). At these prices, small changes in the price differential have a large impact on profitability. In other words, when the price differential is between $1.25 and $1.50/DGE, natural gas suddenly becomes profitable to a relatively large number of heavy truck operations when it was not profitable before.

When the price differential increases to above $2.00 per DGE, natural gas becomes attractive to an even greater number of fleets (those traveling 30,000 to 40,000 miles per year) although the increase in the number of fleets is relatively less. At these higher diesel prices, factors such as the capital cost of the tractor and additional weight of the tractor have less of an impact on the minimum miles traveled to reach a 20% ROI threshold.

Even with very high priced diesel (price differential greater than $3.50 per DGE), there remains a bottom limit for an investment in natural gas trucks. Very low mileage fleets (those traveling less than about 20,000 miles per year) simply do not travel enough miles to reach a 20% return on their investment, unless the price of natural gas trucks decreases. Hybrid and electric trucks might better suit these types of operations.

At the other end of the spectrum, when the price differential between natural gas and diesel narrows to less than $0.75 per DGE natural gas becomes impractical because the miles required to achieve 20% ROI exceed the miles that can possibly be driven by a truck in one year.

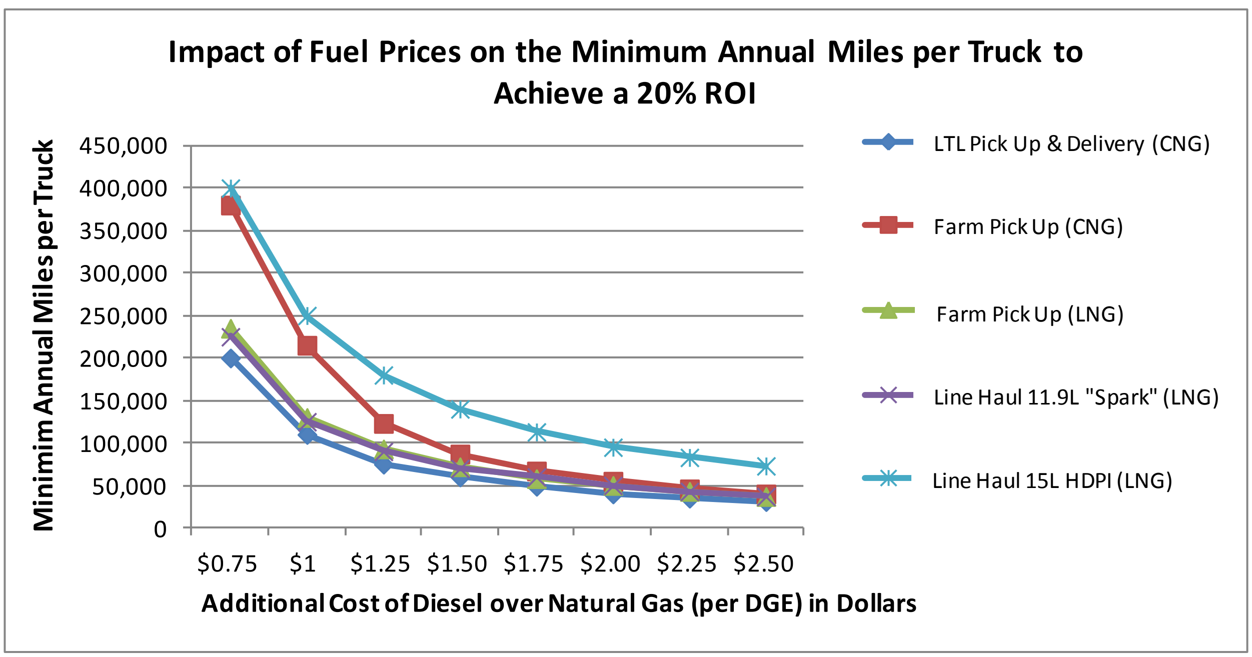


Figure 28. Impact of Fuel Prices on the Minimum Annual Miles per Truck to Achieve a 20% ROI.

Model Limitations and Alternative Approaches:

These conclusions (minimum number of miles per year per truck to be economically attractive) should be viewed as a rough estimate only. The numbers will vary by company based on the desired return on investment, truck mission and utilization, the sensitivity of the operations to truck weight, the size of the tanks required to meet a given fuel range, and the capital investment of each alternative (price of each truck).

There are limitations and alternative approaches to any model. For this paper, we used a Profit-and-Loss or Return on Net Assets (RONA) approach where the annual, pre-tax, pre-interest profit is divided into the depreciated, additional cost of a tractor over the life of that tractor. One alternative approach often used by a business to evaluate the attractiveness of an investment looks at after-tax cash flows over the life of the investment: Discounted Cash Flows Return On Investment (DCF-ROI).

In contrast to the RONA approach the DCF-ROI approach considers the impact of taxes and the time value of money. Because the RONA approach is a pre-tax measurement, the threshold of minimum return should be higher than the threshold for minimum return on the DCF-ROI approach. For instance, if one used a minimum return target of 20% for RONA, and one assumed a 40% tax rate (combined federal & state), the equivalent after tax return threshold for the DCF-ROI approach would be 12%.

While technically more correct from a finance perspective, we opted to use the RONA model in this analysis because the RONA approach is easier to model and understand.

There is value in simplicity, particularly at this stage where fleets are asking whether or not it is worthwhile to further investigate and possibly test a natural gas vehicle in their fleet rather than replace an entire fleet with natural gas trucks. Once a fleet gains some experience with natural gas trucks, then it might be more appropriate to use the more in-depth DCF-ROI approach to see if it makes sense to convert an entire fleet to natural gas.

In the end, the decision to replace a fleet with natural gas trucks is not based on a model. It is based on the reliability and operational performance of the trucks and on actual savings seen in real tests of real trucks.

Feedback from Lynden's People:

We expect the combination of accelerating demand in emerging markets for oil overseas and abundant domestic natural gas will keep oil prices high and natural gas prices low over the long term. Get used to gas. Whether we like it or not, and I can think of a lot of reasons why not, the future is going to be natural gas and batteries. - ***Jim J.,*** **CEO, Lynden Inc.**

There are a lot of "con's". The only "pro" seems to be the price differential between natural gas and diesel. Without the model it is very hard to know the impact of all of these factors. But, there is value to looking at this. If we can get a competitive advantage, then it is worth it.

Weight is a huge concern because additional weight equates to loss of payload and additional miles (cost) to make up for lost revenue. If we could get a credit for the additional weight of running natural gas, this would eliminate the weight concern.

If we move forward with a natural gas vehicle, it will first involve a test in a lane where there is fuel. Lynden is still looking for the best place to test a natural gas vehicle: high miles, compatible with the 8.9L engine, and available fuel. If tests are successful and fuel becomes more available, then we may begin to purchase natural gas trucks as old trucks are retired.
- ***Alex M.,*** **Chief Operating Officer, Lynden Inc.**

We may make a capital investment decision based on various issues, primarily oriented towards meeting a customer's needs. From a

financial standpoint, we may take one of two approaches. The RONA approach is a pre-tax measurement of earnings generated from the associated net assets. The DCF-ROI approach measures after tax cash flow returns on an associated investment. Regardless of which approach we take, the amount of risk we perceive in making the investment may influence our decision on what minimum return we will require. Companies who are successful over the long term will generally try to achieve a return on invested capital that exceeds their cost of capital, which varies by company.
- ***Brad M. CFO, Lynden Inc.***

This may make sense financially, but it also has to work from a practical standpoint. We don't know for sure if the 11.9L engine will work for us and fuel is not yet available for our routes. ***-Jason J.,*** **President, Brown Line**

As the model points out, there could be huge potential. We need to look first at areas that have the highest miles and consume the most fuel per unit. The Farm Pick Up scenario is not necessarily the best choice because we do not know if the 8.9L will be approved for these kinds of weights, so we are looking at other scenarios. There is a lot to learn and many factors to consider so we need time to make a good decision. Lack of infrastructure means that we are limited to local routes rather than being able to respond to extraordinary events with our go-anywhere type fleet. We are always concerned with the first generation of any new engine (11.9 L Cummins-Westport in this case). As much as we like to lead our industry, the leading edge can be the "bleeding edge" if we rush. -***Brad W.,*** **President, LTI Inc.**

[After test driving a CNG 8.9L for 30 miles], the power of the truck was good considering it was an 8.9L engine. This wouldn't work for our operations, but the new 11.9L should work. The truck was quieter, you could hardly hear it running. It burns clean, the exhaust was just steam with no smell. The truck was heavy (16,000 lbs. compared to our 13,500 lbs. but was not set up with lightweight components. I wouldn't have a problem with driving these trucks in the future. ***Frank S.*** **- Driver**

From a maintenance perspective, there are a lot of unknowns (shop upgrades, maintenance technician training, shop tools, life of spark engines, tank issues, and safety concerns). Biogas is "neat", but without very expensive scrubbers, we can end up with a maintenance nightmare. Diesel is a stable technology and we understand it. ***Dave S.*** **Director of Maintenance, LTI, Inc.**

I had always thought that natural gas added a lot of weight, good to clear this up. We wet-hose (refuel on-site) to reduce man hours at the pump. This makes it challenging to test a truck without committing to a large investment (on-site refueling station) or sacrificing man hours to refuel elsewhere. ***Charlie M.,*** **Director of Maintenance, Lynden Transport**

Lessons Learned from this Exercise:

1. Look for lanes with high mileage, high fuel use per unit and available fuel for vehicle tests.
2. Don't "over spec" the tanks. These are very expensive and heavy, so should be spec'ed with the smallest tank practical to get required range.
3. Many dealerships are still learning about natural gas. California dealerships currently have more experience, especially with LNG trucks.
4. Make sure the tractor weight includes full fuel and urea for accurate weight comparison with diesel.
5. 2012-2013 is a logical time to invest in natural gas vehicles with the availability of the 11.9L spark ignited engine and infrastructure becoming available on major interstate corridors.

6. Who is Currently Using Natural Gas and What Have They Learned?

CNG is being used successfully in short and medium range applications such as refuse trucks, straight trucks, and busses. Natural gas in Class 8 tractors is only beginning to be adopted as LNG refueling infrastructure and larger natural gas engines are now beginning to become available.

There are currently about 1,800 natural gas Class 8 tractors in operation in the United States, mostly in California, Arizona, and Texas. They primarily run "return-to-base" operations with a 150 mile radius because of limited infrastructure. Most (95%) operate on LNG and some (5%) on CNG. Figure 29 summarizes some of the current users of natural gas heavy trucks.

Business	Year	Location	Natural Gas Truck Description	Commodity	Gov't Funding
Early Tests - Prototype					
Liquid Carbonic	1994	TX	4 Freightliner LNG Detroit Diesel S60G Prototype	Natural Gas	Yes
Norcal	2004	CA	14 Cummins-Westport GX LNG	Solid Waste	Yes
California-Based LNG and CNG					
Total Trans Services	2008	CA	8 Kenworth T800 LNG	Drayage	Yes
Ryder Systems Inc.	2011	CA	182 Freightliner M2 CNG 20 Peterbilt LNG	Truckload	Yes
Schneider National	2011	CA	4 Freightliner M2 CNG and LNG	Truckload, LTL	Yes
C.R. England	2011	CA	5 Kenworth T800 LNG Full service lease PacLease	Truckload, LTL	No
UPS	2011	CA to NV	48 Kenworth T800 LNG (+11 previously converted trucks)	LTL	Yes
CNG Outside of California					
Paper Transport	2010	WI to IL	7 Freightliner CNG 8.9L	Truckload, LTL	5 of 7
Ruan	2011	IN, TN, KY	42 Kenworth T440 CNG biomethane Full service lease PacLease	Raw Milk	Yes
Foodliner	2011	IL	6 Freightliner M2 CNG	Truckload Food	Yes
Hribar Logistics	2011	WI	2 Kenworth T440 CNG	Fly Ash	Yes
Saddle Creek Corp.	2011	FL	40 Freightliner M2 CNG (130 DGE) 40 more in 2012	Truckload, LTL	No
LNG Outside of California					
TriMac	2008	TX, CA, AZ	43 to date 14 Kenworth T800 LNG in 2010	LNG & Chemicals for Natural Gas Producers	Yes
Dillon Transport	2009	TX, OH	24 Peterbilt 384 LNG 8.9L	Temperature sensitive bulk liquid tanker	Yes trucks No station
Robert Transport	2010	QC (CAN)	180 Peterbilt 367 and 386 LNG 15L deployed over the next 3 years	Truckload, LTL	No
EnviroExpress	2011	CN	18 Kenworth T800 LNG	Incinerator Ash to landfill	Yes
Heckmann Corporation	2011	LA	200 Peterbilt 367 LNG on order	Water for Natural Gas Producers	No
Vedder Transport	2011	BC (CAN)	50 Peterbilt 386 LNG	Bulk Liquid and Dry Food	No
Sysco	2011	UT	9 Kenworth T800	Truckload Food	Yes

Figure 29. Examples of heavy duty truck fleets using natural gas in North America.

Initial Tests:

Not surprisingly, some of the first businesses to test LNG are those who work closely with the natural gas industry.

Liquid Carbonic, an LNG producer and distributor in Texas, worked with the National Renewable Energy Laboratory from 1994 to 1997 in the first test to run LNG in a heavy trucks fleet. This test provided a valuable example showing that LNG could be used in heavy trucks. Operating costs were substantially higher at that time, but improvements to engines and price of equipment have improved dramatically since then.

TriMac hauls LNG and chemicals used in natural gas production. In 2008, they began testing three demo tractors in Houston and one in California. They took delivery of 19 more tractors in 2010; seven haul LNG on their California to Arizona lane, one hauls LNG in their Texas lane, and 14 work local lanes hauling chemicals. They now have a total of 42 LNG tractors.

California-Based LNG:

California tax incentives and air quality rules have spurred the development of LNG infrastructure and adoption of LNG within the state. This has dramatically taken off in the last year with Ryder's natural gas leasing program and a new natural gas compliant maintenance facility in the state and a number of businesses who have taken advantage of state and federal grants.

Ryder System Inc. joined the San Bernadino Associated Government's Natural Gas Vehicle Project to purchase 202 heavy duty natural gas vehicles, upgrade three natural gas compliant maintenance shops, and build two fueling stations. The CNG and LNG vehicles are now available for lease or rent. Ryder has secured lease agreements for 87 heavy duty natural gas trucks. Customers include Staples, Pacer international, and Golden Eagle Distributors, Inc.

Schneider is testing four Freightliner M2's with 8.9L Cummins-Westport engines for use in California. Three are LNG and one is CNG. The trucks cost an up-charge of $30,000 to $40,000, most of which was covered by a California Air Resource Board (CARB) grant. They estimate the cost to upgrade their shop to be compliant with CALOSHA and FEDOSHA requirements for natural gas would cost approximately $1 million dollars per shop bay so they are outsourcing maintenance at this time. They expect an 11% increase in maintenance costs over diesel and a 7%-10% reduction in fuel economy.

C.R. England is leasing 5 Kenworth T800 LNG tractors under a full service lease from Paccar. The tractors will be used in their dedicated California refrigerated carrier operations.

LNG Outside of California:

Dillon Transport is currently running 14 Peterbilt 384 LNG bulk tankers based out of Dallas, Texas and has deployed 10 more in Lodi, Ohio. The Texas trucks haul 80,000 GVW liquid and industrial materials. Beginning in 2012 they will be used to haul product to a shingle roofing plant 125 miles away; each truck will make 2 trips per day. The high volume and short range fits well with the LNG model.

Dillon chose to use the 8.9L spark engine rather than the Westport HD 15L because they are extremely weight sensitive and wanted to eliminate the extra diesel tank and diesel after-treatment system required with the compression-ignited engine. They will be alpha testing the 11.9L spark ignited engine and think that this will be the right engine for the 80,000 GVW loads, the 8.9L engine works, but is at its upper limit with these kinds of loads.

They opted for LNG rather than CNG because the CNG would have required twice as much tank volume which would have been bulkier, heavier, and more expensive. In addition, LNG refueling is as fast as diesel, whereas CNG "fast-fill" stations will only fill quickly to 75%; the remaining 25% is filled as a trickle. They use an

81 DGE LNG tank and are experimenting with dual LNG tanks for longer hauls.

The main disadvantage of using LNG is that the trucks must get back to the station to refuel every night, "you can't just let a truck sit for 7 or 8 days" because when the fuel warms up it turns to gas, builds pressure, vents out of the tank and evaporates. This is lost fuel. In addition, the tanks work better when they are cold, the first couple of refuelings take a long time as the tank cools and "gets seasoned". For high-volume, short range applications, LNG works great.

Dillon partnered with Clean Energy to build LNG refueling stations in Texas and Ohio. They are currently using mobile refueling stations (3,000 DGE), provided by Clean Energy, until these stations are complete. Clean Energy has LNG plants in Willis, TX and Boron, CA. Fuel is trucked to fueling stations from those locations. Another potential source of LNG is local natural gas utility companies who sometimes store surplus natural gas as LNG during the summer months.

Refueling the truck is different, but simple. The tank looks like a regular diesel tank on the side of a truck. It takes about five minutes to refuel. If the fuel drips, it just evaporates - there is no diesel spill. As a side- benefit, "no one can steal your fuel" as can be a problem with diesel.

The trucks were purchased from a California dealership because the California dealers were more familiar with the natural gas trucks and Dillon Transport hopes to be able to resell the vehicles more easily in California. They would have preferred to lease until the 11.9L engine became available, but leasing was not an option at that time (it is now).

Normally, Dillon does the maintenance for their trucks "in-house", but maintenance for the LNG trucks is outsourced to a dealer who is located very near their Texas terminal. They have run accelerated oil changes (every 10,000 miles) because of the severe duty cycle for these 8.9L engines, but plan to stretch this out to every 12,000 miles. Drivers have had some anxiety over operating the new trucks and this sometimes manifests as maintenance concerns, but they have had no real issues with the trucks.

They are happy to be using a domestic fuel, believe the national security message is important, and do a lot of work for oil and gas customers in Texas, but ultimately, this was a business decision based on the price differential of oil vs. natural gas. It has also added a new dimension to their customer relations as they can help customers save money and meet their sustainability goals. Customers are now asking for it in other locations.

Robert Transport is the first genuine for-hire long-haul LNG operation in North America. They currently have 10 LNG trucks in service and plan to add at least 180 more by 2014. The trucks are Peterbilt models 386 with the Westport GX (15L) engine and two 119 gallon LNG tanks (116 DGE). The trucks run 600 miles between Mississauga, Ontario and Quebec City. Refueling infrastructure plans include three sites between Mississauga and Quebec City. Accelerated depreciation for natural gas trucks is 168% in Canada for a period of three years and helped justify the higher cost of the trucks. They needed to modify their repair garages in order to perform the maintenance on the trucks. Robert specs his trucks over a 10 year lifecycle. The trucks cost close to $225,000. They expect to break-even with the current fuel prices and save money over the long term as the price differential between natural gas and diesel diverges.

CNG in Close- Loop Applications:

Outside of California, natural gas use in heavy trucks has so far been limited to "closed-loop" applications, because LNG infrastructure is not yet available. In these operations trucks travel out and back to return to a "home" terminal or fueling station to refuel. CNG, however, is being used in both closed-loop and dedicated lane operations with ranges up to 350 miles. More tanks can provide even larger ranges but are heavy and expensive.

Paper Transport currently runs seven Freightliner CNG trucks with the Cummins-Westport 8.9L engine between Green Bay, Wisconsin and Chicago, IL. They are currently able to operate in a 300 to 350 mile range with the five 15 DGE CNG tanks mounted in the "behind the cab" configuration, but plan to add another 40 DGE side-rail mounted tank to further increase their range. The incremental cost of the trucks is approximately $50,000 and fuel savings are between $1.60-$2.90 per gallon. Maintenance costs are substantially higher because they are running the trucks significantly more miles than what they are designed for. Upgrades to the shop were not necessary because maintenance is contracted out to Cummins. They do not consider weight to be an issue, because the day cab is light and the engine is smaller and lighter than what they would normally use. Normally, Paper Transport would use a more powerful 13L or 15L engine for their 80,000 pound payload. The Cummins-Westport 8.9L ISL-G engine works well on the flat terrain in the Midwest, but would not be practical with this payload on hills of any significance. They have had no issues with the fuel or trucks and are "getting everything that they hoped." They received a Clean Cities grant for five of the seven trucks that they now operate and plan to add additional trucks in the future. Some will be the 8.9L engines, but most will be the 11.9L engines when they become available. Jeff Shefchik, President, says that the driving factors in using natural gas are economics (fuel savings), the environmental benefit, and the fact that natural gas is an American fuel and supports the U.S. economy.

Ruan, a bulk food transporter, and Fair Oaks Dairy farm recently announced the largest renewable CNG project in the United States. Ruan is running 42 Kenworth T440 CNG trucks with two 40 DGE side-rail tanks and 55 DGE mounted back of cab (600 mile range), the 8.9L Cummins-Westport ISL-G engine, and Allison 3000HS six-speed automatic transmission. The tractors' specifications are able to handle the 80,000-lb gross combination weight, though at its upper limit. The trucks are operated under a full service lease from PacLease.

The trucks haul raw milk from Fair Oaks Farms to processing plants in Indianapolis, Indiana, Kentucky, and Tennessee. The Indiana routes are "out-and-back", but the Kentucky and Tennessee routes are beyond the range of the fuel carried on board, so "relay-operations", where a driver hands off his entire rig, are required. The southbound driver with a load of milk trades off with a northbound driver transporting an empty milk trailer. The southbound driver takes the empty trailer back to Fair Oaks Farms, while the northbound driver takes the full load of milk south for delivery to the processing plants.

Federal and state grants helped offset the higher cost of the CNG tractors and the cost of building two CNG filling stations. In order for it to make financial sense, each tractor needs to get about 250,000 miles per year. Fair Oaks Dairy personnel preload the tank trailers for the Ruan drivers to reduce down-time at the farm.

The tractors weigh about 17,000 pounds with lightweight disc wheels, brake drums, air tanks, fifth wheels, jacketing, milk tankers, and eliminating the product pumps.

Fair Oaks Farms operates four bio-digesters that produce methane from cow manure. One of these digesters will supply methane to the new CNG filling station at Fair Oaks. As part of this project, another filling station was built 220 miles away as part of a State of Indiana effort to create a CNG corridor on I-65.

Saddle Creek Corporation has agreed to purchase 40 Freightliner M2 trucks in 2011 and 40 more in early 2012 for their Florida fleet. The trucks will use two 25 DGE CNG tanks behind the cab and two 40 DGE rail-mounted tanks and expect a usable range of 560 miles. President Mike DelBovo says, "because the cost of natural gas is less volatile than diesel, it allows us to have more control over our fuel costs and our customers to have a more stable fuel surcharge".

7. Policy Options to Support the Adoption of Natural Gas Heavy Trucks

1. **Weight Exclusion**. Trucks are limited to a certain Gross Vehicle Weight (GVW) on a given roadway. Any additional weight to the truck (e.g. natural gas fuel tanks) reduces the payload that they can carry. Fleet managers are constantly looking for ways to minimize weight and maximize payload.

A weight credit for the additional weight of natural gas truck fuel tanks would eliminate the concern and financial impact of a diminished payload. A credit for the empty weight of the CNG or LNG tanks would be easiest to determine because weight differential varies greatly depending on the diesel truck that is used for comparison. This would translate to a slight payload benefit for using natural gas because the natural gas itself is lighter (per Btu) than diesel and natural gas trucks do not require diesel after-treatment systems. This would hold no benefit for operations that are not weight sensitive (Pick Up and Delivery modeled here). Figure 31 shows a possible weight credit for various tank configurations.

2. Eliminate the Federal Excise Tax (FET) for Natural Gas Heavy Trucks: Federal Excise Tax accounts for roughly 10% of the incremental cost of a heavy duty natural gas truck. An FET exclusion for natural gas trucks reduces the high capital cost of the truck and makes an investment in natural gas trucks much more attractive. This would not impact trucks less than 33,000 GVW because they do not pay FET.

3. Ensure a minimum $1.25-$1.50 price differential between diesel and natural gas. A policy that maintains this critical price differential would ensure that the price spread between diesel and natural gas does not narrow below a point where it is not profitable for most fleets to invest in a fleet of natural gas trucks. (Figure 28). It would also reduce concern and risk associated with a large capital investment in natural gas vehicles followed by a narrowing in the price differential.

This policy could be an extension of the $0.50/DGE tax credit, although this would need to be guaranteed for at least 5 years to ensure confidence. A more effective approach could take the form of a "feebate" where a "fee" on oil pays for a natural gas "rebate" - this could be written to take effect only if the price differential between diesel and natural gas falls below the sensitive $1.50 per DGE level.

4. Tax Credits and Grants for Infrastructure and Vehicles. A tax credit for the additional cost of a natural gas tractor reduces the high cost and associated risk of investing in natural gas. Tax credits are not necessary to make an investment in natural gas attractive for high mileage fleets if the current price differential between natural gas and diesel persists. However, an 80% tax credit (as proposed in the NATGAS Act HR 1380 and S 1863) will accelerate the adoption of natural gas by high mileage fleets and make it attractive to lower mileage fleets.

The high capital cost to upgrade maintenance shops to be safe and compliant remains a financial and operational barrier. There are currently very few natural gas compliant shops available to service natural gas vehicles and it is not always practical or cost effective to travel long distances for maintenance. A tax credit for upgrades to natural gas maintenance garages would help mitigate this issue.

6. Access to Capital. The incremental cost of natural gas trucks is high because of the specialized tanks required. Most fleets have limited access to capital to make this investment. Banks may be unlikely to lend for new technologies like natural gas vehicles. In the absence of grants and tax credits, low interest loans would help fleets overcome this hurdle.

7. Biogas Support. The environmental benefit of using biogas (farm waste, wastewater treatment, and landfill gas) natural gas as a transportation fuel arguably justifies additional government support. Box 2 discusses biogas in more detail; Box 3 discusses other alternative fuel technologies.

Biogas is one of the least expensive renewable sources of energy. It is cheaper than gasoline and diesel, but more expensive than fossil sourced natural gas due to the high cost of purification. It is not likely to be able to compete with low-priced fossil sourced natural gas prices without monetizing its environmental benefit. Again a "feebate" could be used where a fee on fossil sourced natural gas and/or oil would pay for a rebate on biogas to make it cost competitive with fossil sourced natural gas.

Figure 30 shows the estimated impact of policies on the minimum number of annual miles per truck to be economically attractive.

- With no policy changes, natural gas makes sense for high mileage trucks (>90,000 miles/year).

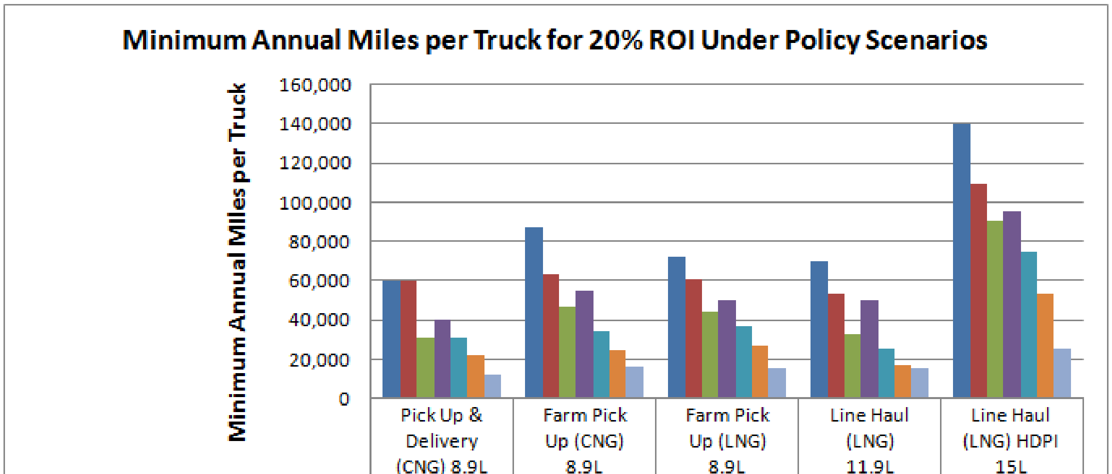
- Natural gas becomes attractive for lower mileage trucks (40,000-50,000 miles/ year) with a $0.50 per DGE tax credit for natural gas.

- A Federal Excise Tax Exclusion for natural gas vehicles reduces the minimum number of miles to between 30,000 and 50,000.

- A weight exclusion for the empty weight of CNG and LNG tanks would lower the minimum number of miles to include trucks traveling 53,000-63,000 miles per year, with a larger benefit for CNG. This would not benefit operations that are not weight sensitive.

- Combined, these policies would make natural gas attractive for trucks traveling 25,000 to 35,000 miles/ year.

- Alternatively, an 80% tax credit for the additional cost of a natural gas truck makes a spark-ignited natural gas truck attractive for low mileage fleets (those traveling around 15,000 miles/ year). It also becomes attractive for trucks with higher power requirements (HDPI 15L) traveling at least 25,000 miles per year.



	Pick Up & Delivery (CNG) 8.9L	Farm Pick Up (CNG) 8.9L	Farm Pick Up (LNG) 8.9L	Line Haul (LNG) 11.9L	Line Haul (LNG) HDPI 15L
No Policy Changes	60,000	87,000	72,000	70,000	140,000
Tank Weight Exclusion	60,000	63,000	61,000	53,000	109,000
FET Exclusion	31,000	47,000	44,000	33,000	90,000
$0.50/ DGE Tax Credit	40,000	55,000	50,000	50,000	95,000
Combined FET & Weight Exclusion	31,000	34,000	37,000	25,000	75,000
Combined $0.50 / DGE tax credit, FET, & Weight Exclusion	22,000	24,000	27,000	17,000	53,000
80% Tax Credit for Vehicle	12,000	16,000	15,000	15,000	25,000

Figure 30. Estimated Impact of Suggested Policies on the Minimum Number of Annual Miles per Truck to Achieve 20% ROI. Assumes $1.50 price differential for base case (Diesel $4.00/ gallon; Natural Gas $2.50 / DGE). Farm Pick Up and Line Haul are weight sensitive operations. Pick-Up and Delivery is not weight sensitive.

Tank Configuration	Weight Credit for Empty Tank
CNG (5) 15 gallon back of cab (75 DGE)	1,650 lbs
CNG (2) 40.5 gallon side rail mounted (81 DGE)	1,200 lbs
LNG (1) 119 gallon side rail mounted (60 DGE)	800 lbs
LNG (1) 150 gallon side rail mounted (75 DGE)	1,000 lbs

Figure 31. Proposed Weight Credit for Natural Gas Fuel Tanks (empty weight).

Biomethane or "biogas" is very attractive from an environmental perspective. Methane that would otherwise enter the atmosphere as waste from farms, landfills, and wastewater facilities can be used as a fuel in natural gas engines, thereby removing a methane source and displacing a fossil fuel source at the same time. Methane is 25 times more potent as a greenhouse gas than CO_2, so using it as a fuel dramatically reduces greenhouse gas emissions. It also allows fleets to partner with customers' sustainability initiatives by using their waste as a fuel.

Biogas, like fossil sourced methane, can be used in natural gas vehicles. Biogas has been used successfully in natural gas powered refuse trucks (landfill gas) for many years and more recently in trucks hauling milk (dairy farm waste). The perfect application for a biogas fueled truck is a return to base fleet that returns to the site of biogas production. As with any fuel, fuel quality must be ensured in order to avoid maintenance problems. Various processing techniques are used to "scrub" the biogas and remove impurities in order to bring the fuel to above pipeline quality. There is no warranty issue with using biogas in a natural gas engine.

Biogas is less expensive (per Btu) than other renewable fuels (solar and wind), but more expensive than fossil natural gas. A program called "RNG-10" under development by Clean Energy is designed to bring bio-methane to market at a more competitive price. Fleets willing to pay 10 cents more for natural gas will get credit for fueling their vehicles with biogas and cover the cost of biogas production elsewhere. This allows fleets that are not able to refuel with biogas directly to indirectly fuel their fleet with renewable biogas and reduce GHG emissions by 80-90%. This program can easily transfer to an optional surcharge for shipping customers interested in "green transportation" for their goods.

Box 2. Renewable Natural Gas: Bio-methane and Biogas.

OTHER ALTERNATIVE FUEL TECHNOLOGIES:

Hydrogen is considered the ultimate zero emissions, domestic, and renewable fuel. It can be generated by running an electrical current through water, splitting it into water and hydrogen. The electrical current can come from renewable sources of energy (solar, wind, landfill gas, or photosynthesizing microbes) and is sometimes thought of as a "battery" for its ability to store intermittent renewable sources of energy to be used later as fuel. More commonly, is it made from natural gas in a process called "steam-reformation" in which high pressure steam reacts with natural gas to form "synthesis gas" which then reacts with water to form hydrogen. When burned as a fuel, hydrogen emits only oxygen, water, and very few NO_x emissions. However, the high cost of production and vehicles means that hydrogen is at least a decade away from being commercially viable as a transportation fuel.

Hydrogen, as a transportation fuel, is faced with similar, or even more challenging issues than natural gas. 1.) It is less dense (Btu/gallon) so must be stored at even higher pressures (10,000 psi) or colder (-432˚ F) temperatures at high pressure in heavier, more expensive tanks. Hydrogen has the potential to be stored without tanks as a Polymer Electrolyte Membrane (PEM) where hydrogen atoms chemically bond to materials for storage, but this technology is still in the research and development phase. 2). It faces similar refueling infrastructure issues. 3.) It is more flammable than natural gas, so faces even more challenging safety issues.

Natural gas is considered to be the "technological bridge" to hydrogen because advances in natural gas vehicles, tanks, refueling infrastructure, safety solutions, workforce training, and business alliances directly or indirectly apply to hydrogen, lower the hurdles that must be overcome, and move it closer to being economically viable. For example, natural gas engines can burn a compressed hydrogen/CNG blend with only minor modifications; tanks used to store hydrogen use the same base technology as natural gas CNG and LNG tanks; shops that are upgraded to comply with natural gas safety guidelines, are well on their way to being hydrogen compliant as well; natural gas refueling infrastructure has the potential to be modified to fulfill hydrogen refueling needs and paves the way for similar permitting and business relationships; and as people begin to understand natural gas, hydrogen becomes easier to accept.

Hydrogen is not a near-term solution to our transportation energy needs, but will become economically feasible more quickly because of the technological and infrastructure advancements that will come with a transition to natural gas.

Hybrid-Electric Vehicles work best for low speed operations with frequent stops or engine idling such as in-city pick-up and delivery vehicles and service vehicles. They are not a practical solution for on highway heavy trucks because fuel efficiency gains are minimal at high speeds (> 35-45 mph) with little stop-and-go.

During braking, energy is captured and stored in the batteries (or in the case of hydraulic hybrids, stored as hydraulic pressure). This energy can be used exclusively to power the truck during take-off, power electrical equipment without engine idle, and to supplement diesel power during acceleration. This "regenerative braking" also extends brake life.

Hybrid tractors are usually used for applications below 33,000 GVW, but in some cases have been approved for up to 54,000 GVW. The incremental cost of a hybrid delivery tractor is similar to or slightly less than a natural gas tractor. The main benefit comes from a higher fuel economy (15-30%) compared to diesel in stop-and-go situations.

Payback on a hybrid vehicle depends on the amount of stop and go, time spent at low speeds, and time spent at idle, but under the right conditions, a hybrid truck can be a better alternative than natural gas.

Box 3. Other Alternative Fuel Technologies.

8. Conclusions

This is an exciting time for heavy-duty natural gas trucks.

1. **Refueling infrastructure is finally underway**. Clean Energy and Flying J-Pilot have partnered to build a foundational grid of LNG fueling stations for heavy -duty trucks along major interstate corridors, with $300 million dollars invested in this project. Plans are in place to have 80 new stations opened along coast-to-coast corridors by December 2012. They anticipate having an LNG filling station every 200-300 miles on major highways by June 2013 and 300-400 stations serving all regional routes by 2015.
2. **The price spread between natural gas and diesel has reached a tipping point** where natural gas has suddenly become profitable to a large number of heavy truck operations. High mileage fleets (those traveling 60,000-90,000 miles per truck per year) see an attractive ROI from fuel cost savings, even when considering maintenance costs, fuel economy penalty, loss in payload from additional weight of the tanks, and the higher cost of the tractor. This is true for both CNG and LNG trucks, but only for the lower cost spark-ignited engines. Existing compression - ignited engines are restricted to very high mileage fleets (140,000 miles per truck per year).
3. **The "game changer" 11.9L spark-ignited engine will be available in the first quarter of 2013.** This engine will fit a much larger number of class 8 truck operations than the existing 8.9L spark engine which was designed for refuse trucks and transit busses. It will not need the heavy diesel after-treatment technology and will offer a much more cost effective, lighter weight, higher fuel capacity alternative to the existing 15L compression-ignited engine. Also in 2013, the Navistar 13L dual-fuel engine will be entering test phases.

However, a handful of barriers still remain to the mainstream adoption of natural gas by heavy truck fleets.

1. **Refueling infrastructure is still limited compared to diesel.** Even with 300 new LNG refueling stations, fleets will be limited to routes where fuel is available. This means fleets using dedicated natural gas engines must sacrifice their ability to "go anywhere" to meet customer needs.
2. **Natural gas trucks are substantially more expensive than a diesel truck**. This is primarily due to the cost of the specialized CNG and LNG fuel tanks. This is a significant barrier to fleets and owner-operators with limited access to capital.
3. **The high capital cost of upgrading a maintenance shop** remains a factor that can make an investment in natural gas trucks considerably less attractive. Full service leases or maintenance packages are available, but this is not always practical for fleets in rural areas and is generally less desirable than performing maintenance "in-house."
4. **Operating range is limited by the tanks that can fit on a truck at an economical price**. This is generally the 75 DGE configuration (LNG) and 40 DGE side rail or 75 DGE back of cab (CNG). Although it is possible to fit 150 DGE (LNG, "spark" engine), 143 DGE (CNG, "spark" engine), and 116 DGE (LNG HDPI 15L) on a truck, the high cost of the additional tanks decreases the financial payback substantially. This means that until infrastructure is widely available, fleets will be limited to routes where fuel is available and centrally-fueled operations.
5. **LNG use is limited to operations where trucks are refueled every 1-2 days** so that venting of fuel is not an issue. This is not likely to be a large problem because natural

gas trucks do not make financial sense for low mileage fleets.

6. **Fleets are apprehensive about new "high risk" technology.** It takes time to learn about and carefully test a new kind of truck and fuel.

Despite these barriers, if oil prices remain high and natural gas prices remain low and stable, then high mileage fleets are likely to initiate tests of natural gas trucks where infrastructure is available in the next few years, even without government subsidies. If those tests are successful, then they will begin to purchase new natural gas trucks as old trucks are retired. Tax incentives can help accelerate this transition and make natural gas attractive to lower mileage fleets.

1. A weight exclusion for the additional weight of natural gas tanks would eliminate concern and cost associated with a loss of payload.
2. A Federal Excise Tax exclusion for natural gas trucks would reduce the incremental cost of a natural gas truck by around 10%.
3. A policy that ensures a $1.25-$1.50 price differential between natural gas and diesel would ease concern over the risk of a narrowing price spread and maintain a critical price difference for fleets who invest in natural gas trucks to achieve a desired ROI .
4. Tax credits for the additional cost of natural gas vehicles would help accelerate the transition to natural gas and make natural gas attractive to lower mileage fleets. This could be paid for via fuel tax.
5. Tax incentives or grants for upgrades to maintenance shops that service natural gas vehicles would help alleviate the high capital cost and practical issue of being able to maintain a fleet of natural gas vehicles.
6. Low-interest loans would help fleets with limited access to capital make the investment in natural gas trucks.
7. Support for biogas would help make this renewable, low carbon fuel cost competitive with fossil sourced natural gas.

In summary, conditions are right for many high mileage fleets to begin investing in natural gas in the next few years as refueling infrastructure expands, more engine options become available, and the price differential between natural gas and diesel remains persistent.

The most attractive fleets are those with high miles (>60,000-90,000 miles/truck per year), that have fuel available within a 350-450 mile operating range, and that have operations compatible with a spark-ignited engine (7.6L, 8.9L, or 11.9L) or very high miles (>140,000 miles per truck per year; 15L HDPI).

This is likely to be a gradual process that accelerates in Q1 2013 as two of the primary barriers: 1.) lack of infrastructure and 2.) limited engine options, see major breakthroughs. Where refueling infrastructure is available, fleets are likely to initiate tests of natural gas trucks and if these tests are successful (i.e. profitable and reliable), then fleets will begin to replace older diesel trucks with natural gas trucks through attrition.

Policy incentives that address remaining barriers: 1.) the high incremental cost of natural gas trucks, 2.) uncertainty over the cost and requirements of upgrades to maintenance shops, and 3.) the additional weight of natural gas fuel tanks would help mitigate these barriers and accelerate the transition to natural gas by heavy truck fleets.

Policy that is timed to coincide with the Q1 2013 release of the 11.9L engine and expanding refueling infrastructure would have the greatest impact by removing uncertainty over potential future policy and adding to the growing momentum of interest in natural gas as a transportation fuel.

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Appendix

NFPA CODE 30A: Motor Fuel Dispensing Facilities and Repair Garages		
7	Building Construction Requipments	Gas detection system required in repair garages and in lubrication or chassis repair pits; No heating equipment with tempertures > 750 degrees F
8	Electrical Installations	Repair garages for CNG vehicles the area within 18" of the ceiling is designated Class I Division 2 hazardous location unless ventilation greater than of equal to four air exchanges per hour is provided
12	Additional Requirements for NCG, LNG, Hydrogern and LPG	CNG, LNG, compressed or liquified hydrogen, LP-Gas, or combination of these are dispensed as motor vehicle fuels along with Class I or Class II liquids that are also dispensd as motoer vehicle fuels
NFPA CODE 52: Vehicular Gaseous Fuels Systems		
6	CNG engine fuel systems	Design, installation, inspection, and testing of CNG fuel supply systems for vehicular internal combustion engines
8	CNG compression, gas processing storage, and dispensing systems	Design, construction, installation, and operation of containers, pressure vessels, compression equipment, buildings and structures, and associated equipment used for storage and dispensing of CNG as an engine fuel in fleet and public dispensing operations
12	LNG Fueling Facilities	Design, siting, construction, installation, spill containment, and operation of containers, pressure vessels, pumps, vaporization equipment, buildings, structures, and associated equipment used for stroage and dispensing of LNG and L/CNG as engine fuel for vehicles of all types.
15	LNG Fire Protection	LNG fire protection personnel safety, security, LNG fueling facilities and training for LNG vehicles, and warning signs
16	Installation Requirements for ASMA Tanks for LNG	Installation, design, fabrication, and siting of LNG containers of 70,000 gal capacity and less and their associated equipment.
NFPA CODE 55: Compressed Gases and Cryogenic Fluids		
7	Compressed Gases	Storage, use, and handling of compressed gases in containers, cylindersn and tanks.
8	Cryogenic Fluids	Storage, use, and handling of cyrogenic fluids
4	Vehicle Fuel Systems	Design, installation, inspection, and testing of ING fuel supply systems for vehicle engines
NFPA CODE 57: Liquified Natural Gas Vehicular Fuel Systems		
5	LNG Fueling Facilities	Design, siting construction, installation, spill containment, and operation fo containers, pressure vessels, pumps, vapriation equipment, buildings, sturctures, and associated equipment for the strage and dispensing of LNG as and engine fuel for vehicles of all types
6	Installation Requirements for ASME Tanks	Installation, design, fabrication, and siting of LNG containers of 70,000 gal capacity and less and their associated equipment.
7	Fire Protection, Safety and Security	Fire protection, personnel safety, and trining for LNG vehicles, security, LNG fueling facilities for LNG vehicles, and warning signs.

Figure A-1. Fire Codes Related to Natural Gas Repair Garages and Fuel Systems.