



Is Natural Gas a Viable Alternative to Diesel for the Trucking Industry?

This white paper was created for ATA's fleet members to provide an educational overview of natural gas fuel as an alternative to diesel fuel for the trucking industry. Natural gas can be an attractive alternative fuel choice for certain applications within an industry as diverse as trucking.

Natural gas is significantly cheaper than diesel fuel (on a diesel gallon equivalent energy basis); however, the transition to natural gas presents several challenges, including higher vehicle capital costs, limited engine offerings, increased vehicle weight, and the current lack of a robust refueling infrastructure.¹ Until a competitive natural gas refueling infrastructure evolves, this alternative fuel is problematic for long haul, irregular route, trucking operations, but may be a viable alternative for some centrally-fueled, regional and local trucking applications, depending upon their power requirements and their sensitivity to weight.

Natural gas engines can either be spark-ignition or compression-ignition with pilot injection (*i.e.*, ~5% diesel injection to initiate combustion), with the latter retaining the general properties of a diesel engine but requiring a second fueling system.

Natural gas can be stored on-board in either a compressed form (CNG) or in a liquefied form (LNG). Because of its lower energy density, CNG may not be practical for long-distance, irregular route, heavy-duty truck applications; however, CNG is being successfully used in short and medium range, heavy-duty applications such as refuse trucks, concrete mixers, straight trucks, and buses. LNG is cryogenically liquefied (*i.e.*, converted to a liquid by reducing its temperature to approximately -260° F) and has approximately twice the energy content per volume as CNG at 3,600 psi (although still significantly lower than diesel). LNG's energy density makes it more acceptable for longer-range routes, although the current lack of a competitive refueling infrastructure remains a concern for long-haul applications.¹ Some LNG vehicles are being used on routes with dedicated refueling infrastructure (*e.g.*, refuse trucks, port drayage trucks).

Economic Factors:

Truck Costs – Natural gas trucks sell at a premium (\$30,000 - \$90,000) compared to diesel-powered heavy duty Class 8 trucks.² Government tax incentives³ may be available to purchasers of natural gas trucks to reduce the price differential between diesel and natural gas trucks; however, these incentives generally are not sufficient to offset the price differential and

¹ *Note* the natural gas refueling infrastructure currently is inadequate to support long-haul, irregular route operations; however, natural gas producers and distributors are committed to building out a refueling infrastructure along key freight corridors.

² There are currently two natural gas engine technologies: *Spark-Ignition* and *Compression-Ignition*. A truck equipped with 9-liter *spark-ignition* engine can produce up to 320 horsepower and sells at a \$30,000 - 45,000 premium to its diesel counterpart, depending upon its CNG or LNG fuel tank configuration. A truck equipped with a 15-liter *compression-ignition* engine can produce up to 550 horsepower and sells at a \$75,000 - \$90,000 premium to its diesel counterpart, depending upon the number of LNG tanks utilized. Extra fuel storage tanks can extend the trucks' operating range, but these additional tanks increase the cost and weight of the vehicle.

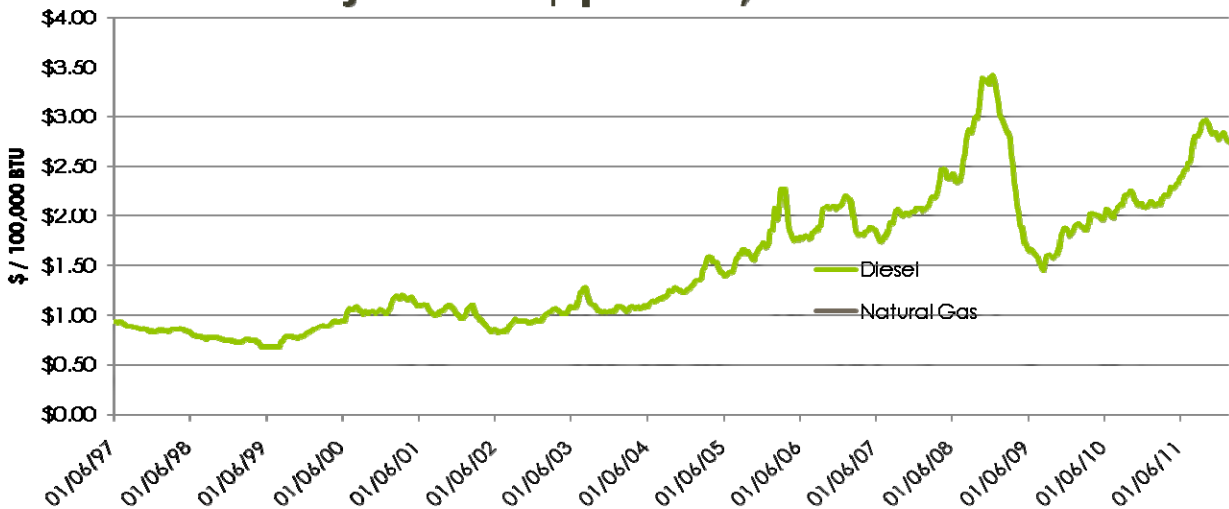
³ *Note* the federal natural gas vehicle tax credit expired at the end of 2010. A list of state vehicle and refueling infrastructure incentives is available at: <http://www.afdc.energy.gov/afdc/laws/>

may contain operating restrictions, such as requiring the truck to spend a certain amount of time in a specific geographic area. It is difficult to predict the residual value of a natural gas truck, as the market for such vehicles is not mature. Natural gas conversion kits are available for passenger cars and light duty trucks; however, no such kits are available for Class 8 trucks.

Fuel Price – Natural gas is domestically sourced and can improve U.S. energy security by reducing dependence upon imported petroleum. The shale gas revolution taking place in the U.S. has resulted in a dramatic reduction in the price of natural gas. Throughout 2010, LNG sold at a significant discount to ultra low sulfur diesel (ULSD) (approximately \$1/gallon cheaper than ULSD on a diesel gallon BTU equivalent basis).⁴ CNG prices ranged from \$1.50 to \$2.00/ gallon cheaper than diesel on an energy equivalent basis, with significant differences depending upon the region of the country.⁵ For purposes of generating revenue for the Highway Trust Fund, natural gas is taxed at an equivalent rate to diesel at the federal level.⁶

Natural Gas vs Diesel

Adjusted to \$ per 100,000 BTU



Fuel Economy – Spark-ignited natural gas trucks are less fuel efficient than their diesel counterparts. Spark-ignited natural gas engines have a reduced fuel economy of 7% to 10%, while compression-ignition natural gas engines have about a 1% - 2% fuel economy penalty.

Weight Differences – Fuel tanks used to store both LNG and CNG are heavy; however, spark-ignition natural gas trucks utilize a 3-way catalyst for emissions control and do not require diesel emissions aftertreatment devices (e.g., PM traps, EGR and SCR systems), which helps to offset the increased weight from the natural gas on-board storage tanks. Reconciling the weight

⁴ LNG fuel vendors offer both “cold” and “warm” fuel (-260°F to -220°F), with warmer fuel translating into less usable fuel for consumption.

⁵ See www.cngprices.com

⁶ The natural gas federal tax credit of 50 cents per diesel gallon equivalent will expire at the end of 2011.

difference between a diesel truck and a natural gas truck depends largely upon the natural gas fuel storage tank configuration.⁷

Weight Comparison between Natural Gas and Diesel Fuel Storage Systems:

Tank Type and Rated Capacity	Amt. of Gas Actually Stored ⁸	Diesel Equivalent (energy stored) ⁹	Nat Gas tanks (full)	Diesel tank (full) ¹⁰	Fuel Storage Weight Comparison ¹¹
LNG 119 gal.	102 gal.	63 gal.	870 lbs.	480 lbs.	390 lbs.
LNG 149 gal.	128 gal.	78 gal.	1,093 lbs.	588 lbs.	505 lbs.
CNG 5, 15 gal. tanks	75 gal.	68 gal.	2,025 lbs.	516 lbs.	1,509 lbs.
CNG 2, 41 gal. tanks	82 gal.	74 gal.	1,650 lbs.	559 lbs.	1,091 lbs.

Factoring in the weight differential from the emissions aftertreatment equipment for spark-ignition natural gas engines, the weight of an LNG-fueled truck is roughly equivalent to a diesel powered truck; while a CNG storage solution results in a significant weight penalty (approximately 1,200 lbs.). Heavy trucking applications (80,000 GVW) on varied terrain may choose the compression-ignition 15-liter natural gas engine solution, which utilizes a small amount of diesel fuel to ignite the natural gas and therefore requires a diesel particulate filter and selective catalytic reduction aftertreatment technology, adding additional weight and expense to this alternative.

Engine Durability – Natural gas engine durability is equivalent to diesel fuel engines.

Resale - the resale market for natural gas trucks is immature and it is difficult to predict the residual value of these trucks.

Operational Factors:

Operating Range – An LNG truck equipped with two 119 gallon tanks has an operating range of approximately 700-750 miles depending on route and load characteristics. A typical 119 gallon tank can hold about 100 gallons of LNG. The difference in the rated capacity of the LNG tank and its actual capacity stems from the need to maintain vapor space in the tank. CNG fueled trucks have a more limited operating range. A truck equipped with five 15 gallon CNG tanks has an operating range of 300-350 miles. A truck equipped with an 82 gallon CNG rail mounted storage solution has an operating range of 375-400 miles. New CNG tank configurations are being introduced to reduce weight and increase vehicle operating range.

⁷ The weight savings from the elimination of the PM trap and SCR system (about 550 lbs.) is partially offset by the addition of a 3-way emissions control catalyst, which adds approximately 300 pounds for the 9 liter solution and is expected to add about 400 pounds for the 12 liter solution.

⁸ All cryogenic liquids require a specific ullage space that reduces the effective storage volume. CNG tanks experience the heat of compression during fueling, reducing the maximum capacity of the tank; the amount of CNG dispensed can vary based on the refueling compressor, the temperature of the CNG, and the rate at which the tank is filled.

⁹ 1.7 gallons of LNG is equivalent to 1 gallon of diesel (DGE) on an equivalent energy basis.

¹⁰ These figures include the weight of the diesel tank (approx 30 lbs.) and the corresponding equivalent amount of diesel fuel (7.15 pounds/gal.).

¹¹ These figures do not include the weight savings for spark-ignition engines that result from the elimination of emissions aftertreatment devices.

Refueling (LNG) – LNG trucks must be refueled at specialized stations that are configured for such trucks. Some fleets have reported that LNG fuel gauges are not always accurate, making it difficult to know when the tank is full; however, manufacturers have taken steps to correct this problem. Running out of fuel on the side of the road is a significant challenge as LNG mobile refueling typically is not an option and the truck would have to be towed to the refueling station. Since the product is dispensed at between -220 and -260 degrees Fahrenheit (e.g., warm and cold LNG), employee training on LNG refueling and the provision of personal protective equipment is necessary.¹²

Compression-ignition engines require the operator to refuel with both LNG and diesel; although the diesel only needs to be refilled about 1 out of every 20 LNG refuelings. *Note* both the refueling nozzle and tank inlet are sensitive to moisture and precautions are needed to ensure that moisture is not introduced into the tank. At -260 degrees Fahrenheit, the fueling process condenses air molecules into water/ice and can prevent a proper seal during refueling.

Refueling (CNG) – CNG trucks require specialized high-pressure refueling. Older CNG dispensers operate at a pressure of 3,000 psig, while new dispensers operate at 3,600 psig. Depending upon temperature, some members report that they have had to refuel 2 to 3 times to make sure the tank is full; however, this should not be a problem for CNG refueling stations that are equipped with temperature-pressure compensating systems and large compressors designed for truck refueling applications. Modern, properly designed CNG fueling stations are capable of dispensing CNG at rates equal to diesel dispensing systems.¹³ A minimal amount of driver training is required, but specialized personal protective equipment should not be necessary. Building an on-site CNG refueling station designed to fuel a large number of trucks in succession requires access to high volume natural gas pipelines. Each site is different and fleets should consult with a public utility or other natural gas fuel supplier to qualify the location.

Fuel Quality – As with all fuel (diesel, natural gas, or renewable fuels), operators must ensure that they refuel with high quality fuel. Using a reputable fuel vendor is an important component of ensuring that only high quality, clean, dry fuel is dispensed into the truck. Consult the engine manufacturer to confirm that the available fuel supply meets the manufacturer's specifications.

Duty Cycle - As with diesel engines, operators should work with their truck dealer or manufacturer to select the appropriate engine for their expected duty cycle and durability expectations. Currently, 7.6- and 8.9-liter spark-ignition engines with up to 320 HP are available. OEMs expect to introduce 12- and 13-liter spark-ignition engines with up to 400 HP in the 2012–2013 time frames. As mentioned above, a 15-liter compression-ignition engine is available for applications requiring more power and torque.

Natural Gas Re-Fueling Infrastructure:

Today, over-the-road fleets that operate CNG or LNG vehicles must plan ahead to ensure they have access to natural gas fueling outlets. Many of the natural gas refueling stations in this country are owned and operated by municipalities and are not designed to accommodate trucks or provide fast refueling operations (5-10 minutes per truck).¹⁴

¹² Currently, there are two different LNG storage tank designs. The most common LNG storage tanks receive fuel at above 60 psig. The compression-ignition engine solution, which uses LNG storage tanks with built-in high pressure fuel pumps, may be refueled with colder LNG at less than 20 psig (increased fuel density), which can extend the vehicle operating range by up to twenty percent. This high-pressure LNG storage tank solution will not work with spark-ignition engines.

¹³ “Fast-fill” CNG systems may impact operating range as the heat of compression during refueling causes the gas to expand and have less energy on a volumetric basis. *See* chart on page 3, *supra*.

¹⁴ The Department of Energy hosts a natural gas fuel locator at: www.afdc.energy.gov/afdc/locator/stations

To support long haul, irregular route operations additional infrastructure is required for refueling, as very few truck stops currently dispense LNG or CNG. Building out a natural gas refueling infrastructure along key freight corridors will take time.¹⁵ A competitive fuel model would require the presence of multiple entities selling LNG/CNG in the same geographic area. While competition exists in the natural gas industry, the high barriers to entry for building retail refueling stations may slow the development of a competitive refueling infrastructure.

Permitting a natural gas refueling station (especially an LNG station) may be challenging, as most fire marshals are not yet familiar and comfortable with the construction and operation of these facilities. This is not an insurmountable problem, but will require some time and effort to make state and local officials comfortable with the refueling project.

Natural gas can be a viable alternative for centrally-fueled fleets that return to their base of operations each day. One large ATA member with a hub and spoke network is dispensing LNG at its hubs to refuel its Class 8 tractors that move between hubs and CNG for its local delivery trucks. .

- *LNG Refueling Station Costs* – Establishing a LNG station capable of handling Class 8 trucks can cost \$1 million or more. With current technology, LNG fueling time can be equivalent to diesel refueling. Large commercial-scale LNG stations with 6 lanes can cost \$2.5 million or more.¹⁶
- *CNG Refueling Station Costs* – Refueling a CNG truck can take between 5 and 30 minutes depending upon the capacity of the station's compressor. A CNG refueling station can cost \$2 - \$4 million for a fast-fill system capable of refueling 4 trucks simultaneously. A CNG fast-fill station can generally fuel vehicles in 5 minutes each (50 gallons/truck) at a steady rate depending on the capacity of the compressor(s). There also is a less-expensive slower-fill option for fleets that can refuel trucks overnight. CNG refueling station costs generally increase as the size of the truck fleet being refueled increases.

Environmental Implications:

Criteria Pollutants – PM and NOx emissions from natural gas-fueled trucks are similar to post 2010 diesel trucks. Spark-ignition natural gas engines meet the EPA 2010 emission standards without the use of a diesel particulate filter or selective catalytic reduction emissions aftertreatment system through the use of a three-way "passive" catalyst aftertreatment system. Compression-ignition natural gas trucks require the use of a diesel particulate filter and selective catalytic reduction emissions aftertreatment system in order to meet EPA's 2010 emissions standards.

Ultra Fine Particulates – There is insufficient data to compare the emissions of ultra-fine particulate matter between natural gas and diesel engines.

Greenhouse Gas (GHG) Emissions – On a "well-to-wheel" basis, natural gas engines emit fewer carbon (GHG) emissions than comparable diesel engines; however, the magnitude of this

¹⁵ At least one company has announced plans to build a plant that converts natural gas into diesel fuel. This alternative would rely on U.S. natural gas supplies, while obviating the need for a new refueling infrastructure. See www.sasol.com.

¹⁶ LNG is made from natural gas at a liquefaction facility and then distributed to refueling stations. An LNG liquefaction facility can cost \$75 million for a unit capable of producing 120,000 diesel gallons equivalent per day.

advantage for natural gas varies depends upon the fuel's processing method. CNG typically has the best GHG performance, with carbon emission levels up to 28% lower than diesel. While higher than CNG, carbon emission levels for LNG are still 2% to 18% lower than diesel. LNG tends to have higher carbon emission levels than CNG as a result of the energy expended to cool gas temperatures to - 260 F.

Although natural gas has favorable GHG emission levels when used as a fuel, it has a detrimental GHG impact if leaked directly to the atmosphere. Released directly into the atmosphere, methane is 21-times more potent than CO₂ as a GHG. As LNG in fuel tanks warms and pressure within the tank increases, methane can be released to the environment through a pressure relief valve. In fact, depending upon ambient temperatures and the age and condition of the fuel tanks, an LNG truck could begin venting natural gas after several days. However, LNG tanks that are used daily should not have a significant venting issue and fleets with a strong fuel management strategy should be able to avoid venting. CNG venting should not be an issue, since ambient temperatures should not cause the pressure of the compressed gas to increase significantly. Some scientists have raised concerns with fugitive methane emissions from natural gas extraction facilities. These scientists question the amount of GHG reductions that result from switching between diesel and natural gas as a transportation fuel. Another potential source of methane emissions stems from the fact that most repair shops require the fuel tank to completely vent prior to being worked on; however, this issue can be mitigated.

Fuel Spills – If spilled, CNG and LNG will evaporate and rapidly disperse into the air, reducing the risk of groundwater contamination.

Maintenance Factors:¹⁷

Oil Change – Spark-ignited natural gas engines use a different type of oil than diesel engines, while compression-ignited natural gas engines use the same type of oil as diesel engines. Both spark-ignited and compression-ignition natural gas engines have comparable oil change intervals when compared with similarly sized diesel engines operating under the same duty cycle.

Fuel Injector Replacement – While spark-ignited natural gas engines do not require injectors, compression-ignition natural gas engines may require injectors to be replaced more frequently than diesel engines, approximately every 220,000 to 300,000 miles.

Valve Adjustments – Spark-ignited natural gas engines require valve adjustments every 50,000 miles. Diesel engines and compression-ignited natural gas engines require valve adjustments at intervals ranging from 150,000 to 500,000 miles.

Ignition Systems – For spark-ignition natural gas engines, replacement of spark plugs after 45,000 miles are required (approximately \$60 dollars for each of the 6 plugs). Ignition modules and various sensors (e.g., O₂, Manifold Absolute Pressure) add additional maintenance costs to the operation of natural gas engines.

Maintenance Intervals:¹⁸

Maintenance Item	Diesel Cummins ISL9	CNG / LNG Cummins ISLG	Diesel Cummins ISX15	Compression Ignition (diesel + nat gas)
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¹⁷ One earlier adopter of LNG tractors reported an increase in maintenance costs of 2 cents per mile over the past 10 years, with the most significant issues being injector failures at approximately 100,000 miles and a loss of vacuum on the on-board LNG fuel storage tanks.

¹⁸ Source Cummins, Inc. Note Maintenance intervals are calculated using both mileage and hours of operation. In depicting maintenance intervals, this chart assumes an average speed of 30 mph. Service intervals vary by application; operators should consult their Owner’s Manual for actual service intervals.

	(Miles)	(Miles)	(Miles)	Westport GX (Miles)
Oil & Filter	15,000	15,000	25,000	25,000
Fuel Filter	15,000 (Primary) 30,000 (Secondary)	15,000	25,000	High Pressure Diesel 125,000 Low Pressure Diesel 31,250 High Pressure CNG 125,000
Spark Plugs	N/A	45,000	N/A	N/A
Coolant Filter	N/A	N/A	50,000	50,000
Change Coolant	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

Note: There is a high pressure cylinder on some Class 8 LNG tractors that requires inspection by a certified inspector every 36,000 miles.

Training – Natural gas engines operate differently than diesel engines. In-house mechanics will require approximately 25-60 hours of additional specialized training for compression-ignition natural gas engines and 20 hours training for spark-ignited engines. Finding a qualified natural gas mechanic is more difficult than finding a diesel mechanic. The local service facility may not have the requisite experience, tools or parts to quickly perform repairs. As a result, some fleets report that downtime for repairs are significantly longer for natural gas engines.

Methane Exposure – Maintenance shops that will work on natural gas-fueled vehicles may need a methane detection system and a methane evacuation system.¹⁹ Recommendations on the safe operation and maintenance of natural gas vehicles are available from the National Fire Protection Association and the Society of Automotive Engineers. One ATA member reports spending over \$150,000 on methane detectors, modified lighting and electrical systems, and an air evacuation system; another reports spending \$30,000 on facility upgrades. While all locations will need an air evacuation system, the Fire Marshall will determine whether a methane detection system is required.

Particulate Filters – Spark-ignited natural gas trucks do not require diesel particulate filters to meet EPA's PM emissions standards. Compression-ignition natural gas engines use all of the same aftertreatment systems as the base engines (e.g., diesel particulate filters and selective catalytic reduction systems).

NOx Control Systems – Spark-ignited natural gas engines utilize a 3-way catalyst for NOx control and do not require exhaust gas recirculation technology or selective catalytic reduction systems. Compression-ignition natural gas engines require NOx exhaust treatment systems (e.g., SCR or EGR).

LNG On-Board Tanks – Some fleets have experienced significant problems with LNG fuel tanks. These tanks are double-walled construction with a vacuum between the two walls (like a giant thermos bottle). The vacuum serves as a temperature barrier. In some cases, fleets reported a loss of the vacuum due to tank manufacturing issues that manifest themselves months and even years after being placed into service. This problem may not be obvious. The vacuum can be

¹⁹ Most CNG is “odorized” to facilitate leak detection. LNG is not “odorized” and requires methane detection systems to facilitate leak detection.

recreated, but the process is costly and is not a permanent solution. As vacuum pressure decreases, fuel temperature rises, causing internal tank pressure to rise. The pressure relief valve built into the tank vents natural gas into the atmosphere, which affects the amount of fuel available for use and offsets some of the environmental advantages of using LNG. Establishing a tank inspection program as part of the preventive maintenance plan can help identify tank integrity issues. Impacting a tank (such as during a collision) can also result in a lost vacuum if the outer vessel is breached. Natural gas storage tanks must be inspected and damaged tanks must be repaired or replaced.

CNG On-Board Tanks – CNG is a high-pressure system operating at a storage pressure of up to 3,600 pounds per square inch (psi). A truck CNG fuel system is comprised of tank storage, a high pressure fill system, fuel lines, engine compartment components (*i.e.*, filters) and regulators to reduce the fuel system pressure to 150 psi at the inlet connection to the engine. CNG tank inspections are required by the National Highway Traffic Safety Administration (NHTSA) every three years or 36,000 miles, whichever comes first. Tank inspections are external visual inspection only and the cylinder is not removed from the vehicle.

Crash Safety:

Natural gas vehicles are a safe alternative with a proven track record. LNG tanks usually replace the diesel saddle tanks on a truck. These tanks are constructed of stainless steel and are very durable.

LNG and CNG are less flammable than diesel fuel. Natural gas poses a danger of ignition only when present in a 5% to 15% concentration. CNG and LNG will not pool when spilled, which reduces the probability of a fire if the tank is breached.

Natural Gas presents an asphyxiation hazard at concentrations exceeding 21%. These concentration levels are a concern in confined (indoor) environments. Natural gas trucks are equipped with methane detection systems.

Useful Links:

- CNG Prices: www.cngprices.com
- U.S. Department of Energy Fuel Locator: www.afdc.energy.gov/afdc/locator/stations
- DOE-The Alternative Fuels and Advanced Vehicles Data Center: http://www.afdc.energy.gov/afdc/fuels/natural_gas.html
- DOE – State and Federal Incentives: http://www.afdc.energy.gov/afdc/incentives_laws.html
- Natural Gas Vehicle Institute (NGVi): <http://www.ngvi.com/>
- Natural Gas Vehicle for America (NGVAmerica): <http://www.ngvc.org/>
- American Gas Association (AGA): <http://www.aga.org/Legislative/issuesummaries/NaturalGasVehicles.htm>
- International Association for Natural Gas Vehicles (IANGV): <http://www.iangv.org/home.html>
- NGV Cost Analysis Toolkit for Fleets: <http://eerc.ra.utk.edu/etcfc/ngtoolkit/index.html>