

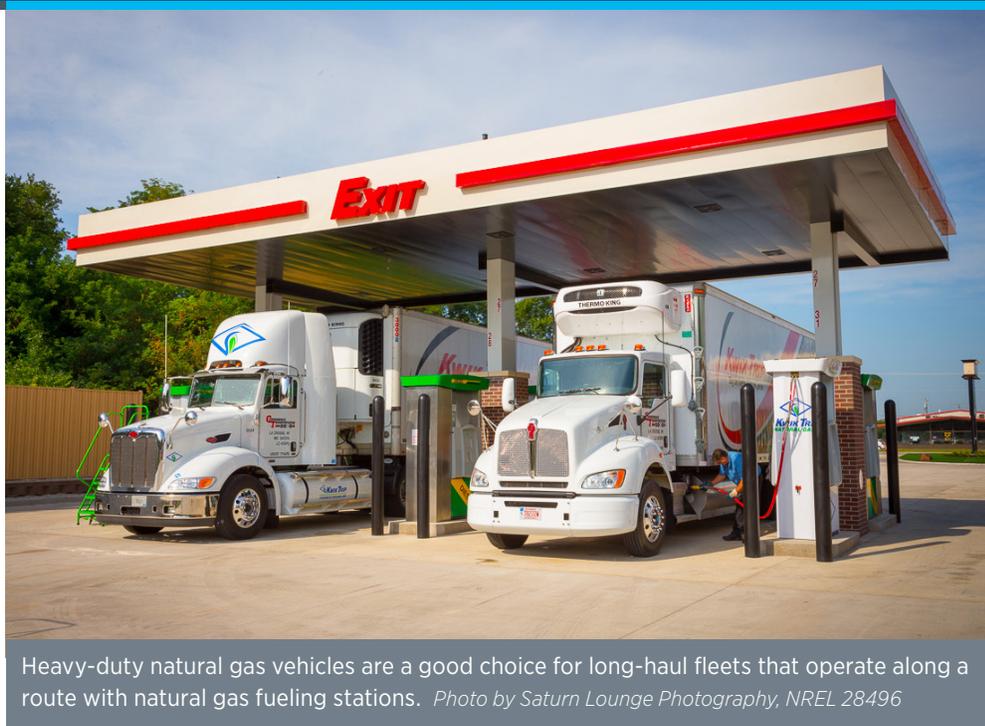
Natural Gas Basics

Natural gas powers about 150,000 vehicles in the United States and roughly 22 million vehicles worldwide.¹ Natural gas vehicles (NGVs) are a good choice for high-mileage fleets—such as buses, taxis, and refuse vehicles—that are centrally fueled or operate within a limited area or along a route with natural gas fueling stations. The advantages of natural gas as an alternative fuel include its domestic availability, established distribution network, relatively low cost, and emissions benefits.

What is natural gas?

Natural gas is an odorless, gaseous mixture of hydrocarbons—predominantly methane (CH₄). The fuel is widely used for heating and cooking, electric power production, and industrial use. Although it is a proven, reliable alternative fuel that has long been used to power vehicles, only about one-tenth of 1% of natural gas is currently used this way. Because it is a gas, it must be stored onboard a vehicle in either a compressed gaseous or liquefied state. Compressed natural gas (CNG) is typically stored in a tank at a pressure of 3,000 to 3,600 pounds per square inch.

Liquefied natural gas (LNG) is super-cooled and stored in its liquid form at -260°F in insulated tanks. Because liquid is more dense than gas, more energy can be stored by volume. This makes LNG favorable for trucks that need a longer



Heavy-duty natural gas vehicles are a good choice for long-haul fleets that operate along a route with natural gas fueling stations. Photo by Saturn Lounge Photography, NREL 28496

range. Natural gas is sold in units of gasoline- or diesel-gallon equivalents, which is based on the energy content of a gallon of gasoline or diesel fuel.

How and where is natural gas produced and distributed?

Most natural gas is drawn from wells or extracted in conjunction with crude oil production. The production of fossil natural gas in the United States has increased significantly in recent years as advances in hydraulic fracturing technologies have enabled access to shale gas. Most of the natural gas used in the United States is produced in North America. The United States has a vast natural gas distribution system, which can quickly and economically

distribute natural gas to and from most locations in the lower 48 states.

Renewable natural gas (RNG), or biomethane, is produced from decaying organic materials like municipal solid waste from landfills, sewage from wastewater treatment plants, animal manure, or food waste. After impurities are removed, the gas produced from these operations is ready for use in vehicles or for distribution through existing pipelines. Because it is produced from non-fossil fuel sources, RNG qualifies as a renewable fuel under the federal Renewable Fuels Standard (RFS) and a low carbon fuel under California's Low Carbon Fuel Standard. Thus, RFS credits are available to offset the higher cost of RNG as compared to fossil natural gas. In 2014, roughly 20 million gasoline-gallon equivalents of RNG received credits



1. "Worldwide NGV Statistics," *NGV Journal*, accessed August 6, 2015. www.ngvjournals.com/worldwide-ngv-statistics/

under the RFS. This is less than one percent of estimated production potential. Learn more about RNG on the AFDC website (afdc.energy.gov/fuels/natural_gas_renewable.html).

Is natural gas safe for use in vehicles?

Just like conventional vehicles, NGVs must comply with all applicable regulations, including Federal Motor Vehicle Safety Standards (FMVSS). Compared to gasoline and diesel fuel, natural gas has a higher autoignition temperature (the point at which a gas or vapor can ignite in air without a spark or flame being present), making unintentional autoignition less likely. In addition, because it is lighter than air, natural gas dissipates quickly. Fuel tanks on natural gas vehicles are strong and extremely puncture resistant, and they undergo testing according to stringent standards. Once in use, they must be inspected in a qualified service facility every three years (36 months) or 36,000 miles, whichever comes first.² The National Fire Protection Association, U.S. Department of Transportation, and other organizations provide these and other safety guidelines for NGVs, as well as for natural gas fueling equipment.³ A list of applicable codes and standards is available on the AFDC (afdc.energy.gov/pdfs/48611.pdf).

Considerations for CNG tanks

When purchasing a CNG vehicle, customers should be mindful of the FMVSS inspection requirements and the useful life of the fuel tank. If the vehicle is used, it is important to determine when the tank was last

inspected and, if the vehicle has ever been in an accident, whether the tank was inspected afterwards. CNG fuel tanks have a useful life of 15, 20, or 25 years, depending on how they were certified by the original manufacturer. All CNG tanks carry a label that states the expiration date. This date can also be found on a label near the fueling connector, and on the label under the hood of the vehicle.

How do NGVs work?

A CNG fuel system transfers high-pressure natural gas from the tank to the engine while reducing the fuel pressure to meet the operating requirements of the engine's fuel-management system. Just as in a gasoline engine, the fuel-air mixture is compressed and ignited by a spark plug to produce power. LNG engines operate similarly; the LNG is converted to a gas before it is injected into the engine.

There are three types of NGVs:

- **Dedicated** vehicles are designed to run only on natural gas.
- **Bi-fuel** vehicles have two separate fueling systems that enable them to run on either natural gas or gasoline. This provides the flexibility of using either fuel or both, effectively increasing overall vehicle range.
- **Dual-fuel** vehicles use natural gas with some diesel fuel for ignition assistance, allowing them to operate much like conventional compression-ignition (e.g., diesel) engines.

Light-duty vehicles are typically configured as dedicated or bi-fuel models, and heavy-duty vehicles are configured as dedicated or dual-fuel models. Dual fuel engines are traditionally limited to heavy-duty applications and are slightly more fuel-efficient than their spark-ignited, dedicated counterparts, but a dual-fuel system is more complex and requires onboard storage of both types of fuel.

How well do NGVs perform?

NGVs are similar to gasoline or diesel vehicles with regard to power, acceleration, and cruising speed. Natural gas has a higher pump octane number than gasoline (120+ compared to 84-93 for gasoline), and some original equipment manufacturers (OEMs) offer dedicated engines optimized to take advantage of this higher rating.⁴ This can result in improved performance and fuel economy over non-optimized engines. The driving range of NGVs is generally less than that of comparable gasoline and diesel vehicles. This is because natural gas has a lower energy content and less overall energy can be stored in the same size tank as the more energy-dense gasoline or diesel fuels. Extra storage tanks or the use of LNG can help increase range.

What NGVs are available?

A wide variety of light-, medium-, and heavy-duty NGVs are available and suitable for various applications. Buyers can purchase vehicles through OEM dealerships or have existing vehicles converted to natural gas after they've already been in service.

2. *Compressed Natural Gas Fuel Container Integrity*, 49 C.F.R. 571.304 (Oct. 1, 2011).

3. "NFPA 52: Vehicular Gaseous Fuel Systems Code," National Fire Protection Association, accessed August 6, 2015, nfpa.org/codes-and-standards/document-information-pages?mode=code&code=52.

4. *AFDC Fuel Properties Comparison* (afdc.energy.gov/fuels/fuel_properties.php).



CNG vehicles are fueled with easy-to-use, pressure-sealed fueling connectors. Photo by Pat Corkery, NREL 18188

How can I find reliable and EPA-compliant vehicles?

All natural gas fueling systems must be certified to meet U.S. Environmental Protection Agency (EPA) or California Air Resources Board (CARB) emissions standards. For a list of EPA-certified natural gas conversion systems and engines, see the EPA website (epa.gov/otaq/consumer/fuels/altfuels/altfuels.htm and epa.gov/otaq/certdata.htm#lsi). Note that, as EPA states, the list is not comprehensive and there may be certified conversions that do not appear on the list. EPA adds conversion systems upon request of the conversion manufacturer and advises checking the list periodically for updates. Customers should ask to see and verify a manufacturer's EPA or CARB certificate.

Purchasing new vehicles

To find available OEM natural gas vehicles and engines, see the AFDC Vehicle Search (afdc.energy.gov/afdc/vehicles/search) or the

Natural Gas Vehicles for America (NGVAmerica) Vehicle Availability page (ngvamerica.org/vehicles/vehicle-availability/).

In some cases, buyers can order select OEM models with gaseous-fuel “prep packages,” which allow a qualified system retrofitter or vehicle modifier (QSR or QVM) to install the EPA- or CARB-certified natural gas fuel delivery system before the vehicle is delivered to the customer.

Converting in-service vehicles

Owners should insist upon an EPA- or CARB-certified system when converting in-service vehicles. However, ensuring a high-quality conversion requires attention to numerous additional details. System manufacturers may perform the conversion themselves or work closely with a QSR/QVM. A well-qualified QSR/QVM will have established procedures and technical training for the installation process, as well as best practices. It is

important to understand these and ask to review documentation on emissions compliance as well as the conversion practices, procedures, and training. Consult the Natural Gas Vehicle Conversions page on the AFDC website for additional details (afdc.energy.gov/vehicles/natural_gas_conversions.html).

How much do NGVs cost?

The price of an NGV is higher than that of a comparable conventional fuel vehicle; however, NGVs can provide an acceptable return on investment (ROI) for many fleets because of the fuel's relatively low price. New OEM light-duty NGVs cost approximately \$6,500 to \$10,000 more than comparable gasoline vehicles, and heavy-duty NGVs cost \$30,000 or more than their counterparts. The price depends on the fuel-tank capacity and whether the vehicle is purchased from a dealer or is an in-service vehicle that has been converted. The maintenance and operation costs of NGVs are similar to those of their gasoline or diesel counterparts. Fleet managers will also need to consider both the cost of fueling infrastructure, if they do not currently have access to existing fueling sites (see page 4), as well as the potential cost of any upgrades that may be required to their maintenance facilities.

Tax credits and other incentives may also be available to help reduce the cost of fuel, vehicles, and infrastructure. See “How do I calculate the ROI for NGVs?” on page 5.

Is it easy to fuel an NGV?

CNG vehicles are fueled with easy-to-use, pressure-sealed dispensers. The amount of time it takes to fill a tank depends on several factors, including how the fueling station is configured. Time-fill stations fuel

vehicles overnight, taking advantage of off-peak electricity rates and smaller (and less expensive) compression equipment. Fast-fill stations fill vehicles rapidly using larger compression equipment and high-pressure gas-storage systems. Ambient air temperature and fill speed also affect the final fill volume in CNG vehicle tanks. See an illustrated interactive animation of these effects on the AFDC website (afdc.energy.gov/vehicles/cng_tank_animation.html).

LNG stations are structurally similar to gasoline and diesel stations because they deliver a liquid fuel. There are three options for LNG fueling: mobile, containerized, and customized large stations. In mobile fueling, LNG is delivered by a tanker truck that has on-board metering and dispensing equipment. A containerized station, or starter station, includes a storage tank, dispensing equipment, metering, and required containment (for spills or leaks). A custom station has greater storage capacity and is tailored to meet fleets' needs. Fueling LNG vehicles requires special procedures, training, and protective equipment, but the process is not difficult.

As with all vehicles, proper safety precautions must be taken when fueling NGVs.

How much does natural gas cost and where is it available?

Historically, the average retail price of natural gas has been lower and more stable than that of gasoline and diesel (see Figure 1). This makes natural gas a good option for fleets that use large amounts of fuel. However, fleet managers should carefully consider their options when establishing private fueling or using public sites.

Average Retail Fuel Prices in the U.S.

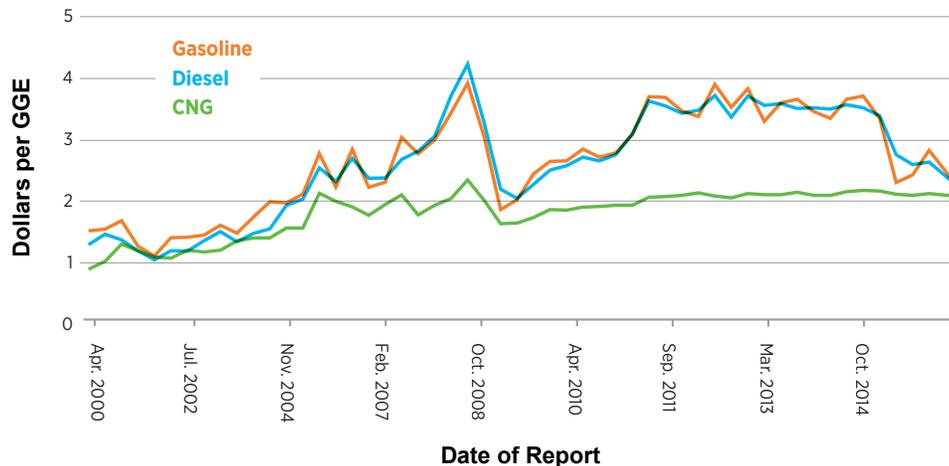


Figure 1. Average retail fuel prices in the United States for gasoline, CNG, and diesel in dollars per gasoline gallon equivalent (GGE). Source: AFDC Average Retail Fuel Prices in the U.S., afdc.energy.gov/data/10326.

Public fueling stations

There are nearly 1,000 public natural gas stations across the United States, including more than 900 offering CNG and almost 100 offering LNG. To find stations in your area, visit the Alternative Fueling Station Locator or download the Station

Locator mobile app from the AFDC website (afdc.energy.gov/stations). To obtain the best fuel price at public fueling stations, fleet managers should negotiate competitive pricing. Using stations without such an agreement may result in paying higher prices.



The City of Sacramento deployed more than 100 LNG refuse trucks, as well as the fueling stations and maintenance facilities to support them. The project resulted in millions of dollars saved and more than 1,900 tons of annual greenhouse gas emissions averted. Learn more at afdc.energy.gov/case/1424. Photo by Randall Benton, courtesy of Zonar Systems

Private fueling stations

Fleet managers planning to use a high volume of fuel may consider building a new fueling station. CNG stations are typically located near existing natural gas pipeline infrastructure, whereas LNG is transported and delivered to stations much like gasoline and diesel fuel. Stations may be private access, open to fleet customers, or available to the general public.

For current information on on retail fuel prices, refer to the Clean Cities Alternative Fuel Price Report (afdc.energy.gov/fuels/prices.html). This

may cost anywhere from \$5,500 for a residential unit to \$850,000 for a station to fuel fleet vehicles. A fast-fill station may cost anywhere from \$45,000 to \$1.8 million. The wide ranges result from the many variables, such as the number and type of vehicles being fueled, required storage capacity, compressor sizes, gas pressure, equipment used, number of posts and hoses, and installation costs. For more information, refer to *Costs Associated with Natural Gas Vehicle Fueling Infrastructure*.⁵ According to the Energy Information Administration, an LNG fueling site can range from

fleets with higher annual vehicle mileage will experience shorter payback periods. Payback is therefore linked to fleet size and type. Tax credits and other incentives may also be available to help reduce the cost of natural gas fuel, vehicles, and infrastructure, thereby shortening the payback period. For more information, contact your local Clean Cities coordinator and see the AFDC Federal and State Laws and Incentives section (afdc.energy.gov/laws).

Two helpful tools include the Fuel Life-Cycle Environmental and Economic Transportation (AFLEET) tool (greet.es.anl.gov/afleet), which estimates petroleum use, emissions, and cost of ownership of light-duty and heavy-duty vehicles for a variety of fuels; and the Vehicle and Infrastructure Cash-Flow Evaluation (VICE) model (afdc.energy.gov/vice_model), which can be used to evaluate ROI and payback period for both natural gas vehicles and infrastructure.



Vehicles use the time-fill connection at the Oyster Bay, New York CNG refueling station. Photo from Greater Long Island Clean Cities, NREL 23853

report provides regional average retail prices for fueling stations and it can serve as a barometer on retail fuel pricing in your area.

How much does it cost to install a natural gas fueling station?

The cost of installing natural gas infrastructure varies based on size, capacity, and the type of natural gas it dispenses. A time-fill CNG station

\$1 to \$4 million.⁶ All infrastructure must comply with local codes and standards, and it's important to involve the local authority having jurisdiction early in the process.

How do I calculate the ROI for NGVs?

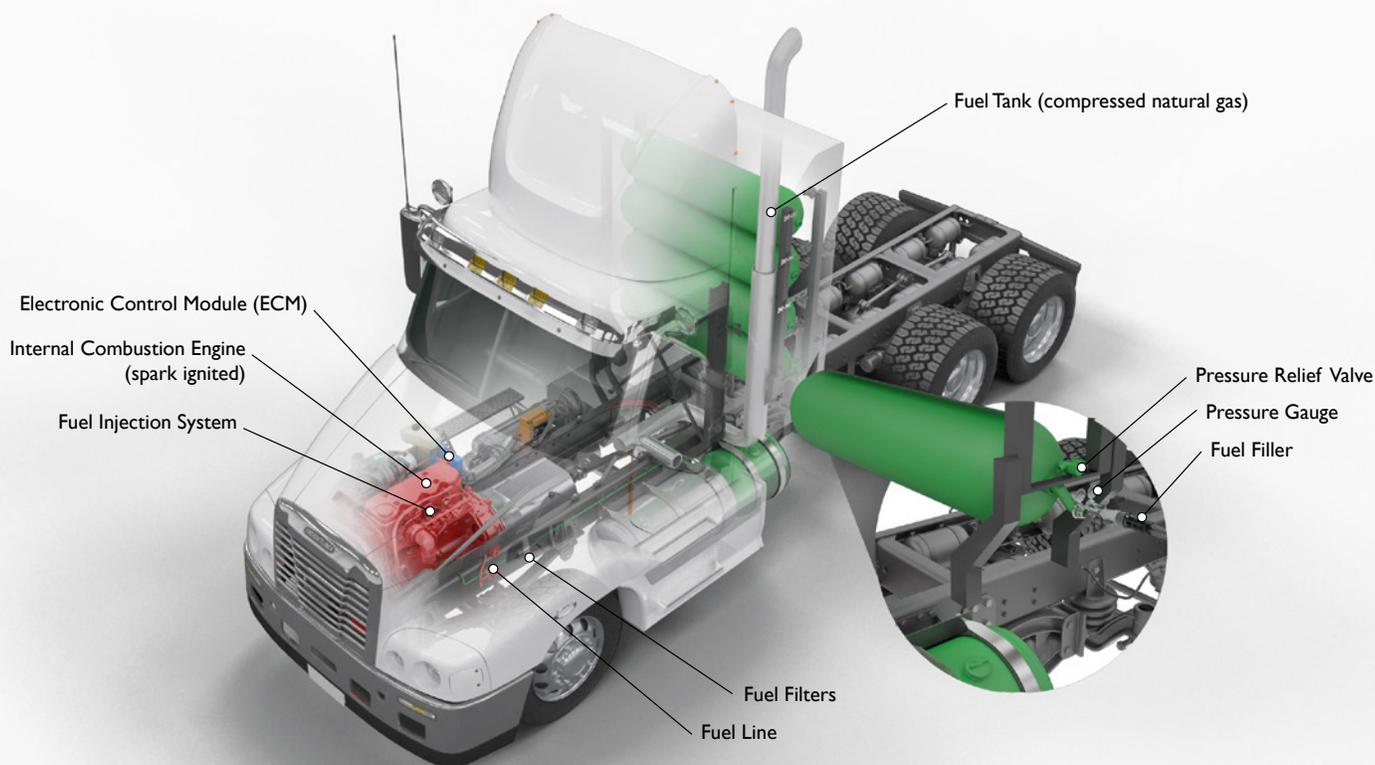
The ROI associated with natural gas depends on a variety of factors. Because natural gas fuel is often less expensive than gasoline and diesel,

How do NGV emissions compare with gasoline and diesel vehicle emissions?

All new vehicles are equipped with effective emission control systems and must meet the same emissions standards, regardless of fuel type. Consequently, tailpipe emissions from NGVs (or any alternative fuel vehicles) are comparable to those of gasoline and diesel vehicles

5. Smith, Margaret and John Gonzales, Costs Associated with Compressed Natural Gas Vehicle Fueling Infrastructure DOE/GO-102014-4471, U.S. Department of Energy Office of Energy Efficiency and Renewable Energy, 2014, afdc.energy.gov/uploads/publication/cng_infrastructure_costs.pdf.

6. "Annual Energy Outlook 2010 DOE/EIA-0383(2010)," U.S. Energy Information Administration, ntl.bts.gov/lib/34000/34000/34012/0383_2010_.pdf.



This illustration shows a typical heavy-duty, Class 8 CNG truck. The various components of the CNG fuel system are highlighted.
Illustration by Josh Bauer, NREL

equipped with modern emissions controls. According to ANL’s Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) model, light-duty vehicles running on conventional and shale natural gas can reduce life cycle greenhouse gas emissions by 11% (83% if running on RNG). In addition, because CNG fuel systems are completely sealed, the vehicles produce no evaporative emissions. For details, see the AFDC Natural Gas Vehicle Emissions page (afdc.energy.gov/vehicles/natural_gas_emissions.html).

Where can I learn more about natural gas?

To learn more about natural gas as a transportation fuel, visit the AFDC Natural Gas Fuels and Vehicles pages (afdc.energy.gov/fuels/natural_gas.html). You can also contact your local Clean Cities coordinator (cleancities.energy.gov/coalitions.html) or visit the NGV America website (ngvamerica.org) for more information. For case studies on natural gas vehicles, see the AFDC Case Studies page (afdc.energy.gov/case).



There are more than 800 public natural gas stations in the United States. *Photo from iStock, 87365495*

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