

Natural Gas Vehicle Basics

Natural gas powers about 175,000 U.S. vehicles and more than 23 million vehicles worldwide.¹ Natural gas vehicles (NGVs) are a good choice for high-mileage (high fuel-use) fleets—such as buses, medium- and heavy-duty trucks, 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 production, 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, less than 1% of natural gas is currently used this way.² Because it is a gas, it must be stored on board a vehicle in either a compressed or liquefied state. In the United States, compressed natural gas (CNG) is typically stored in a tank at a pressure of 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 denser than gas, more energy can be stored by volume. This makes LNG favorable for trucks that need a longer driving range. CNG 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. LNG is sold as a liquid gallon, where 1.5



Heavy-duty NGVs for long-haul fleets that operate along a route with natural gas fueling stations. Photo from Saturn Lounge Photography, NREL 28496

gallons of LNG contains the energy equivalent of a gallon of gasoline.

How and where is natural gas produced and distributed?

Most natural gas is drawn from wells or extracted in conjunction with crude oil production. U.S. production of natural gas has increased significantly in recent years. Most U.S. natural gas is produced in North America. The United States has a vast 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 is ready for use in vehicles or for distribution through existing pipelines. RNG qualifies as a renewable fuel under the federal Renewable Fuel Standard (RFS) and a low-carbon fuel under California's Low Carbon Fuel Standard.

In 2018, more than 305 million gasoline-gallon equivalents of RNG received credits under the RFS.³ This constitutes significant progress toward renewable goals, despite the fact that RNG production is still a small fraction of estimated potential. Learn more about RNG on the Alternative Fuels Data Center (AFDC) (afdc.energy.gov/rng).

Are NGVs safe?

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, so it takes significantly more heat for the fuel to ignite without a flame or spark. This makes unintentional ignition less likely. In addition, because it is lighter than air, natural gas dissipates quickly.

NGV fuel tanks 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.⁴ 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 fueling equipment.⁵ A list of applicable codes and standards is available on the AFDC (afdc.energy.gov/pdfs/48611.pdf).

¹ "NGV America – Vehicles." Accessed January 2020. www.ngvamerica.org/vehicles.

² "Natural Gas Consumption by End Use," U.S. Energy Information Administration. Accessed January 2020. www.eia.gov/dnav/ng/ng_cons_sum_dcu_nus_a.htm.

³ "Spreadsheet of RIN Generation and Renewable Fuel Volume Production by Fuel Type for the Renewable Fuel Standard," U.S. Environmental Protection Agency. Accessed January 2020. www.epa.gov/fuels-registration-reporting-and-compliance-help/spreadsheet-rin-generation-and-renewable-fuel-0.

⁴ U.S. Department of Transportation, National Highway Traffic Safety Administration, *Compressed Natural Gas Fuel Container Integrity*, 49 C.F.R. 571.304 (Oct. 1, 2011).

⁵ "NFPA 52: Vehicular Natural Gas Fuel Systems Code," National Fire Protection Association. Accessed January 2020. nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards/detail?code=52.



CNG vehicles are fueled with easy-to-use, pressure-sealed fueling dispensers. Photo by Dennis Schroeder, NREL 48723

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 tanks. For used vehicles, it is important to know when the fuel tanks were last inspected, the expiration date, if the vehicle has been in an accident, and whether the tanks were inspected after. CNG tanks have a useful life of 15, 20, or 25 years, depending on how they were certified by the original equipment manufacturer (OEM). All CNG tanks carry a label with the expiration date. This date may also be found on a label near the fueling connector and on the label under the hood of the vehicle.

Types of NGVs available

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 extends overall vehicle range by adding the distance that can be driven on each fuel separately.
- **Dual-fuel** vehicles use natural gas blended 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 can be more fuel-efficient than their spark-ignited, dedicated counterparts. A dual-fuel system is more complex, requiring diesel exhaust aftertreatment and onboard storage of both types of fuel at all times (whereas bi-fuel vehicles can operate on either fuel exclusively). A variety of light-, medium-, and heavy-duty NGVs are available and suitable for various applications. Buyers can purchase vehicles through OEM dealerships or have in-service vehicles converted.

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 OEMs offer dedicated engines optimized to take advantage of this higher rating.⁶ This can result in improved performance and fuel economy over nonoptimized engines. The driving range of NGVs is generally less than that of comparable gasoline and diesel vehicles because with natural gas, less overall energy content can be stored in the same size tank. Extra natural gas storage tanks or the use of LNG can help increase range for larger vehicles.

How can I find reliable and EPA-compliant vehicles?

All NGVs 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 conversion systems and engines, see the EPA website (epa.gov/vehicle-and-engine-certification/lists-epa-compliant-alternative-fuel-conversion-systems). Consult the Natural Gas Vehicle Conversions page and the publication *What Fleets Need to Know About Alternative Fuel Vehicle Conversions, Retrofits, and Repowers* on the AFDC for additional information on conversions (afdc.energy.gov/vehicles/natural_gas_conversions.html).

Purchasing new vehicles

To find available OEM NGVs 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/availability).

In some cases, buyers can order 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 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 vehicles. 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, warranty, and training.

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 fuel cost savings. NGVs can cost thousands of dollars more than comparable gasoline- or diesel-powered vehicles. The price depends on the fuel tank capacity, number of tanks required, and whether the vehicle is purchased new from an OEM or is an in-service vehicle that has been converted. The maintenance and operation costs are similar to those of their gasoline or diesel counterparts.⁷ For dedicated NGVs, maintenance costs

⁶“AFDC Fuel Properties Comparison,” Alternative Fuels Data Center. Accessed January 2020. afdc.energy.gov/fuels/fuel_properties.php.

⁷“Alternative Fuel Life-Cycle Environmental and Economic Transportation (AFLEET) Tool 2018,” Argonne National Laboratory. afleet-web.es.anl.gov/afleet.

can be significantly lower because they do not require complicated exhaust aftertreatment systems. Fleet managers will also need to consider both the cost of fueling infrastructure, if they do not have access to existing fueling sites, and the potential cost of any upgrades that may be required to their garage/shop facilities. For more information, see the publication *Compressed Natural Gas Vehicle Maintenance Facility Modification Handbook* (afdc.energy.gov/cng-handbook).

Tax credits and other incentives may also be available to help reduce costs.

Is it easy to fuel an NGV?

CNG vehicles are fueled with easy-to-use, pressure-sealed dispensers. The time it takes to fill a tank depends on several factors, including how the fueling station is configured. Time-fill stations fuel vehicles automatically overnight, taking advantage of smaller, 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 interactive animation on the AFDC (afdc.energy.gov/cng-animation).

LNG stations operate similar to gasoline and diesel stations because they deliver liquid fuel to the station via tanker trucks. Fueling LNG vehicles requires specific procedures, training, and protective equipment, but the process is not difficult.

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

How much does natural gas fuel 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. Fleet managers should carefully consider their options when deciding whether to build a private fueling station or use public fueling sites.

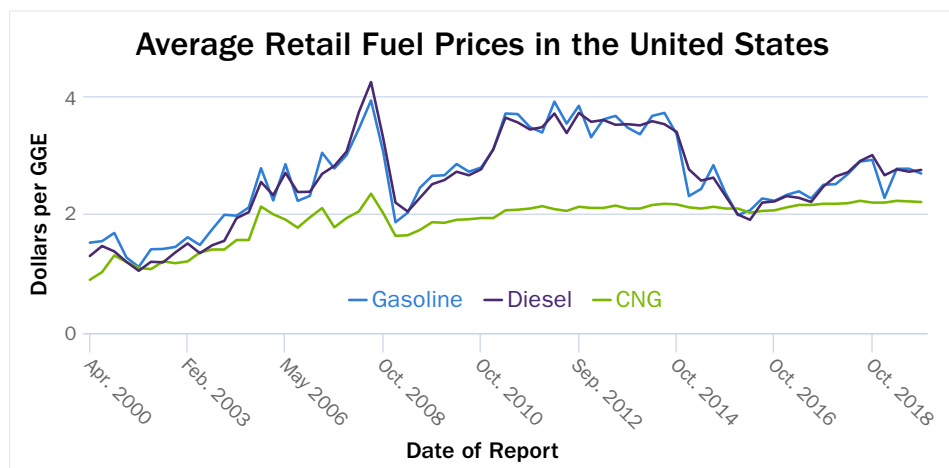


Figure 1. Average retail fuel prices in the United States for gasoline, CNG, and diesel in dollars per gasoline gallon equivalent (GGE). Source: AFDC Average Retail Fuel Prices in the United States, afdc.energy.gov/data/10326.

Public fueling stations

There are more than 1,000 public natural gas stations across the United States, including more than 900 offering CNG and more than 50 offering LNG. To find stations in your area, visit the Alternative Fueling Station Locator or download the Station Locator mobile app from the AFDC (afdc.energy.gov/stations). Fleet managers are often able to negotiate long-term competitive or bulk pricing with natural gas fuel suppliers.

Private fueling stations

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

For current price information, refer to the Alternative Fuel Price Report (afdc.energy.gov/fuels/prices.html).

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.

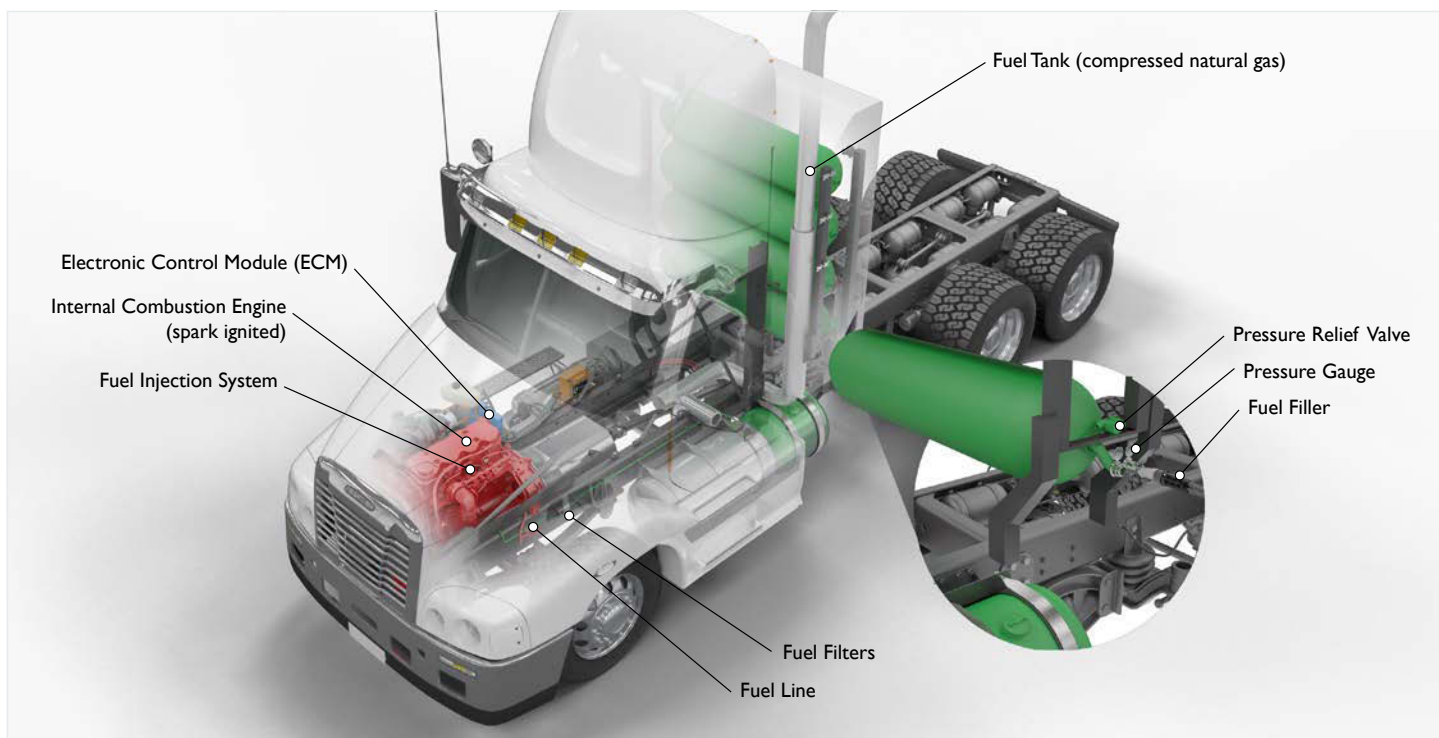
A time-fill CNG station can range in cost from tens to hundreds of thousands of dollars, while a fast-fill station may cost up to several million dollars for large truck and bus fleets. For more information, refer to *Costs Associated with Natural Gas Vehicle Fueling Infrastructure*.⁸

LNG fueling station costs are highly variable, ranging from one to several million dollars.⁷ Costs are dependent on factors such as storage capacity, station design, and the services needed to build it. 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 NGVs depends on a variety of factors. Because natural gas is often less expensive than gasoline and diesel, fleets with higher vehicle mileage (higher fuel use) 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

⁸ Margaret Smith 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/files/u/publication/cng_infrastructure_costs.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

infrastructure, thereby shortening the payback period. For more information, contact your local Clean Cities coalition (cleancities.energy.gov/coalitions) and see the AFDC Federal and State Laws and Incentives section (afdc.energy.gov/laws).

Two helpful tools include the Alternative 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 NGVs and infrastructure.

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

Tailpipe emissions from new NGVs (or any new alternative fuel vehicles) are comparable to those of gasoline and diesel vehicles from the same model year equipped with modern emissions

controls. According to Argonne National Laboratory's Greenhouse gases, Regulated Emissions, and Energy use in Transportation (GREET) model, light-duty vehicles running on natural gas can reduce lifecycle 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/ng-emissions).

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) or visit the NGV America website (ngvamerica.org). For NGV case studies, see the AFDC Case Studies page (afdc.energy.gov/case). ■

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800-254-6735 • technicalresponse@icf.com

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