



Using Adsorbed Natural Gas: The Low-Pressure Fuel For Light-Duty Fleets

NGVs benefit many key stakeholders: consumers, energy providers and natural gas utility companies, automakers, and the environment.



State of alternative fuels

In today's vehicle landscape, the continued focus on reducing carbon emissions and enhancing fuel efficiency has led to viable alternative fuel technologies for most - but not all - vehicle classes. Alternative-fuel options for the light-duty segment have lagged behind those available for the heavy-duty and passenger car segments.

Electrification is well suited to small-platform vehicles like passenger cars and compressed natural gas (CNG) is applied mostly on heavy-duty applications like school buses and refuse trucks. Historically, options for large light-duty vehicles (LDVs) like pickup trucks, vans and SUVs have fallen short because the infrastructure and economics of electrification and CNG prove to be challenging - particularly in the areas of weight, cost and usability.

Now, however, natural gas has emerged as a vehicle fuel solution that is simple, readily available and affordable for LDVs like pickup trucks. By tapping into the abundant supply of natural gas in the U.S., LDVs are beginning to leverage adsorbed natural gas (ANG) vehicle technology, which costs less, is more efficient and is even more environmentally friendly than CNG and diesel alternatives.

Benefits and barriers for natural gas vehicles (NGVs) today

Consumers:

Natural gas provides long-term fuel price stability and savings.

Energy utilities:

The U.S. shale boom created an abundance of natural gas and the opportunity to develop meaningful demand that leverages the natural gas infrastructure already in place.

Automakers:

Natural gas is ideal for automakers' largest and most profitable segment: light-duty trucks. The LDV segment represents over 75% of annual sales and earns up to three times more profit than passenger sedans.

Environment:

NGVs generally emit 20% fewer greenhouse gas emissions (GHGs) than comparable gasoline and diesel vehicles on a well-to-wheels comparison.

Worldwide, we have seen the first wave of NGVs in the form of CNG. While there are roughly 24 million CNG vehicles worldwide, the U.S. has roughly 200,000 driving on our roads. Many of the challenges for CNG vehicles to date have revolved around the necessary fueling infrastructure and economics.

- **Few stations:** There are less than 1,600 fueling stations across the U.S. that are concentrated in California, Oklahoma, Texas, Ohio, Florida, Pennsylvania and New York, many of which are also private-access only.

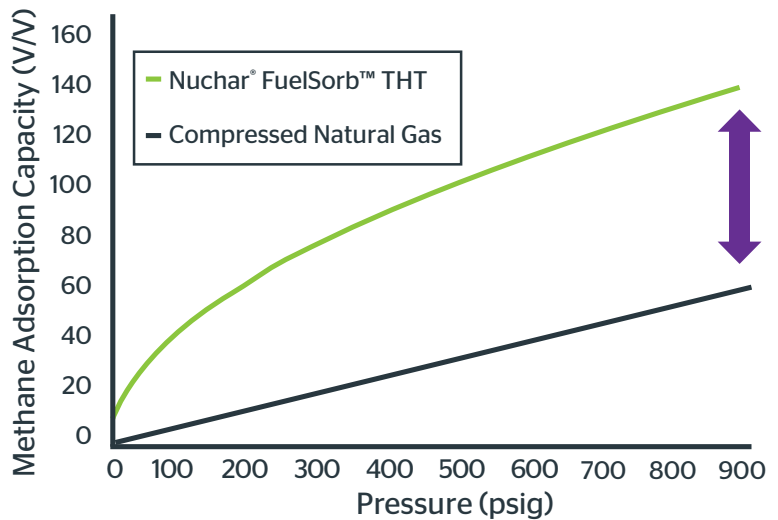
- **Expensive stations:** The cost to build a CNG stations remains around \$2 million and the costs to maintain and use the stations are high.

- **Significant energy requirement:** The energy requirement to compress privately-delivered CNG is two times more than lower-pressure alternatives like ANG require.

Adsorbed natural gas (ANG): how lower pressures have changed the game

ANG technology marks the second wave of NVGs. The methane gas adsorption science behind ANG is likely already part of the car you drive today. Proprietary activated carbon technology has been used for over 40 years in vehicles and applications around the world to capture and recover over 8 million gallons of gasoline vapor emissions every day. This same activated carbon technology has been leveraged to enable ANG.

Activated carbon monoliths made from hardwood sawdust (as opposed to coal) have performance characteristics that enable the material to more efficiently capture and release vapors. The activated carbon fills cylindrical tanks that are nested in the bed of a truck and further reduce the storage pressure of the natural gas without sacrificing the volume of gas stored. ANG's ability to operate at 900 psi - compared to CNG's 3,600 psi - increases the methane adsorption capacity inside the cylinders, meaning the ANG tanks hold twice the volume of natural gas at equivalent pressures while still allowing access to the traditional benefits of CNG at a fraction of operational pressures. ANG's lower pressures are game changing for LDVs and the technology.



- Requires only an easy-to-install, affordable fueling appliance.
- Eliminates the need for a massive CNG fueling station.
- Costs less to fuel than gasoline and diesel in the U.S.
- Combats the “range anxiety” associated with EVs.
- Has a relatively inexpensive total cost of ownership (TCO).

ANG technology is ideal for small (5-20 vehicles), dispersed light-duty fleets with easy access to natural gas but without scale economies to support the investment in higher-pressure CNG. LDV fleets can benefit from ANG in many ways:

■ **Environment:** Studies in California show a reduction of more than 20% in GHGs for NGVs compared to gasoline, and in excess of 100% when using renewable natural gas.

■ **Convenience:** Private fueling enabled by ANG leverages the vast natural gas infrastructure network already available in 60 million homes and over 5 million businesses across the U.S.

■ **Range:** Bi-fuel ANG trucks can serve 100% of the average daily usage miles on natural gas alone.

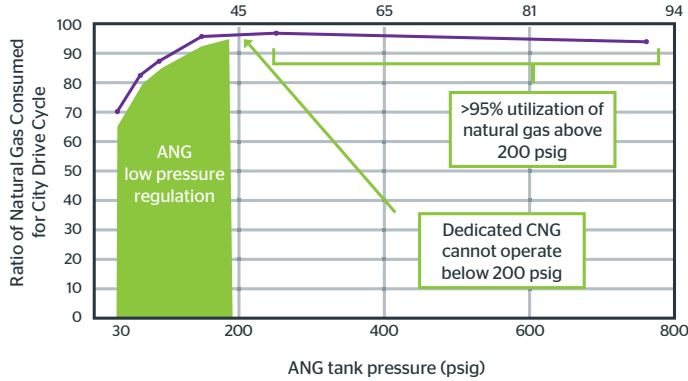
■ **Value:** The U.S. Department of Energy (DOE) alternative fuel price report shows fuel savings for natural gas users can be up to \$2.50 per gasoline-gallon equivalent (GGE) compared to conventional gasoline.



Calibration

ANG bi-fuel calibration demonstrates expanded natural gas consumption compared to CNG.

A Ford F-150 truck modified to run on bi-fuel ANG technology maintains the full vehicle warranty through Ford's qualified vehicle modifier (QVM) program.



Key purchasing and upfit notes include:

- Purchase Ford F-150 pickup trucks with the CNG engine package.

- The CNG engine package includes hardened valves and seats.

- Flexible cylinder designs allow for a range of on-board natural gas storage (from 2 to 8 GGE).

- A zero-weld, four-cylinder array rests conveniently in the tool box area of the truck bed.

- Bi-fuel trucks benefit from extended driving range, as the truck shifts seamlessly from gasoline mileage to the approximately 100 additional miles of natural gas storage on-board.

- The cylinder array design can be modified for all body and bed configurations.

Fueling

Fueling with ANG is faster and less costly to maintain compared to CNG.



Italy-based Cubogas is the main manufacturer of the Fuelmaker FMQ 2.5 ANG fueling appliance.

- Two fueling hoses (P9 nozzles) for the ability to service 2 trucks at once.

- Maintains American National Standards Institute NGV certification (5.2).

- Fuels at a rate of approximately 1 GGE per hour.

The TCO of a new FMQ 2.5 is almost \$0.89 per GGE, while a used version of the appliance has a TCO of approximately \$1.00 per GGE. Studies conducted by the Gas Technology Institute also demonstrate that even CNG fueling compressors that are repurposed to fuel at lower ANG pressures can have a TCO that falls within \$1.00 per GGE.

ANG fleet management

A fleet of ANG trucks is managed similarly to – if not the same as – other gasoline-only vehicles.



- Conduct similar overall preventative maintenance like regular oil changes and tire rotations.
- Re-certify ANG cylinders every three months or 36,000 miles with any certified CNG tank inspector.

Service for the FMQ 2.5 appliance is also straightforward.

- The compressor should be serviced around 4,000 hours of use, depending on gas quality.
- Outlet pressure should be periodically checked.
- Visual checks should be conducted on the fill hose for abrasions, cuts, swelling or any damage.
- The breather system should also be monitored for signs of any foreign debris.

Your investment in natural gas

A fleet of ANG trucks saves money for fleet owners through fuel savings and incentives.



The cost of an ANG upfit and the appliance is \$12,500 per truck. Annual fuel savings can be just over \$2,000 per year per truck and with these savings alone, fleets can see an ROI of around 6 years. This payback period decreases further to around 4 years when including currently available federal subsidy opportunities, and goes down further to just under one year with additional support from programs like the Pennsylvania Department of Environmental Protection's Alternative Fuels Incentive Grant (AFIG) Program.

The opportunity horizon for natural gas

The robust health of the NGV market is best shown by continued global adoption of the technology. There are nearly 24 million NGVs around the world and some forecast this number will be almost 40 million by 2025, showing a compound annual growth rate of about 4% each year.

ANG technology utilizing Ingevity's activated carbon represents an important opportunity for NGV adoption in the U.S. By utilizing ANG to tap into the abundant natural gas infrastructure as a network of fueling access points, the pathway for NGV adoption in the U.S. is astronomical. And for the 7 million LDVs sold in the U.S. every year that are underserved by accessible alternative fuel options, the pathway for a growing NGV future is even stronger.

About Ingevity

Ingevity provides specialty chemicals, high-performance carbon materials and engineered polymers. For over 100 years, we have been the world's leading manufacturer of activated carbon technologies for gasoline vapor emission control. Ingevity has leveraged this expertise to develop Nuchar® FuelSorb™ activated carbon monoliths that enable ANG for LDVs. For more information, visit ingevityANG.com.

