Sustainable technology integration:

Exploring alternative energy solutions

GREEN TRUCK ASSOCIATION

An Affiliate Division of

NTEA

THE ASSOCIATION FOR THE WORK TRUCK INDUSTRY

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Overview

Incorporating alternative energy/advanced technology into commercial vehicles has become practical in recent years as a result of the commercial development of viable transportation fuels and powertrain alternatives, and the trend is continuing to build momentum. In fact, the sheer number of sustainable equipment suppliers and offerings displayed at work truck industry trade shows indicates the ground gained by this initiative. Even with fluctuations in the price of carbon-based fuels, it appears there will be a continued desire in the industry to take advantage of the opportunity alternative fuels create.

Therefore, with the new alternatives, the industry will be challenged to find the right match between mission requirements and advanced solutions to meet the goals and performance demands of commercial applications. This applies to all entities (including suppliers, integrators and consumers of alternative energy/advanced technology). Ultimately, the vehicle must do the same amount of work it did without the integration of alternative fuels and advanced technology without creating operational burdens. Though seemingly obvious, this objective can be more difficult to achieve than it appears on the surface.

Objective

This review is designed to highlight some key considerations when evaluating alternative energy/advanced technology solutions in 2018. These resources can prove costly, with implications throughout a vehicle's life cycle. **This report is not intended to favor any given technology, especially as each application has its own unique variables. Instead, it is intended to provide general guidance as to some of the factors to consider when exploring alternative energy/advanced technology options in a commercial application**.

Trends

Anecdotal evidence supports the following trends

- Longer vehicle replacement cycles
- Increased awareness of the need to match energy efficient technologies to individual fleet drive and duty cycles (access details on Green Truck Association's **data logger drive and duty cycle analysis program**)
- Recognition of the fact implementation of any technology must have a real return on investment (ROI) to be successful
- Integration of multiple technologies in a single vehicle application
- Willingness to revisit technologies which previously failed to produce desired results — as technology and infrastructure for all production-ready alternatives have evolved

Technology

While many alternative energy/advanced technologies are available (and even more are maturing to satisfy the growing need), this study highlights a few of the common technologies currently available on the market, including:

- Gaseous fuel solutions
  - Propane autogas
  - Liquefied natural gas (LNG)
  - Compressed natural gas (CNG)

- Electric variants
  - Battery electric
  - Two hybrid electric versions
    - Plug-in
    - Standalone
- Hydrogen fuel cell vehicle (a newer offering)

As more fleet customers seek to integrate alternative energy/advanced technology into their operations, it's important to review all relevant factors (especially financial variables) and understand alternative fuel/driveline system selection strengths and limitations.

Corporate strategy

Many companies have committed to green initiatives or strategies related to alternative energy. Companies with this focus tend to be innovators and early adopters, leading deployment and integration of advanced technology into their respective fleets.

Other companies may not have a published strategy, but still may have alternative energy integration goals. In either case, it's important to identify the purpose — e.g., cost savings, regulated criteria, carbon emissions reduction, or a combination of these or other factors — as the identified purpose(s) can help drive the integration decision.

A. FACTORS: The alternative energy technology right for you

When considering the right alternative energy/advanced technology for your business, it is helpful to consider the following factors.

1. Vehicle brand preferences

Many customers have an established contractual relationship with a vehicle brand or, sometimes, primary and secondary preferences. All vehicle manufacturers take slightly unique approaches to developing alternative energy/advanced technology offerings — especially fuel system and driveline modifications. These options, upfitter rules and best practices can influence end-user buying decisions in different ways.

2. Model preferences

The same factors affecting OEM brand selections can influence vehicle model or type choices. It's possible specific vehicle brands and their models may not be available for the alternative energy/advanced technology solutions the end customer hopes to pursue.

3. Body preferences

Customer work truck mission requirements shape the truck body selected. Accommodations for alternative fuels and powertrains may require customization of the specific body chosen. It's helpful for customers to first conduct a needs analysis for the body and required equipment. Then, they can review body mounting parameters for the chassis to determine if accommodations and customization are required from both a mounting and vehicle certification stance.

4. Range factors

A primary issue, especially with alternative fuels, is a vehicle's daily range. This single element can drive vehicle type, tank capacity and alternative fuel conversion costs. End users often cannot afford the productivity loss created by the need to refuel twice a day.

5. Payload considerations

Along with range issues, payload becomes a decision driver: If a conventional internal combustion engine (ICE) driveline is operating above 85 percent of gross vehicle weight rating (GVWR) and/or 85 percent of storage space, additional fuel storage to ensure equivalence to ICE range can limit the onboard space and available payload the conventional truck provides.

6. Drive and duty cycle

Understanding your drive and duty cycles is important when implementing advanced technologies. Simply put, a drive cycle defines **how** a vehicle is used, while a duty cycle explains **how much** a vehicle is used. When defining your fleet's drive and duty cycles, remember vehicles can have different profiles that vary across time.

For example, if your drive cycle data documents a vehicle operating primarily at high speeds (open highway) with minimal stops and limited idling time, adapting a hybrid powertrain or an advanced idle management system may not be practical. Conversely, the use of an aero package, combined with low rolling resistance tires and a thorough chassis weight reduction plan, may provide significant benefits. Also, if, based on your duty cycle analysis, a truck you want to convert to CNG would need to refuel during a typical day of operation, then you should consider the need for your own fast-fill (as opposed to time-fill) compressor station or access to another fast-fill facility.

7. Available systems and technology

The cost to create, validate and certify an alternative energy/advanced technology system for any vehicle platform is quite extensive. For this reason, system providers carefully review the market volume potential, weighing it against development costs to ensure their companies receive payback. In addition, OEM factors already discussed play a role in which systems can and will enter the market.

Therefore, it is important that when considering alternative energy/advanced technology, you consider the impact of such technology on the entire vehicle. For example, a potential purchaser of alternative fuels technology would want to consider whether or not a hardened engine package is available from the chassis manufacturer to account for the higher combustion temperatures and lower lubricity of alternative fuels. For vehicles that have LNG and CNG conversions, this has been an issue.

8. Model year changes

It's very important to consider the changes in vehicle model years and the implications for alternative energy/advanced technology systems. OEMs often make subtle changes to engine and powertrain operations, requiring recalibration on a model year basis. Investment, time and testing are required for all affected model years on each system provider. Some experienced manufacturers estimate that, depending on engine family changes, the recertification process can cost up to $300,000 if CARB certification is included. As vehicles must be available for this development, there is a lag between when a model year vehicle starts production and system conversions become available. Engine series consolidation across platforms is improving the situation a bit — an engine conversion can be developed and relatively easily transferred to other vehicle platforms.

9. Funding and grant options

In the last several years, funding to support alternative energy/advanced technology systems and fueling infrastructure has varied greatly at the federal, state and local levels. Viable sources to explore available incentives include federal and state government advocacy like the U.S. Department of Energy (DOE), California Air Resources Board (CARB), Clean Cities, and associations such as NGVAmerica, Propane Education and Research Council (PERC), CALSTART, and others. We suggest planning alternative energy/advanced technology implementation without incentives and consider them a bonus of reduced payback or higher ROI. Consider planning a project with payback of no more than four years and then try to use incentives to reduce this time. In addition, it's helpful to verify existence of fueling or charging stations on-site or nearby before initiating a project. If infrastructure is not in place and/or the project's financial viability relies on incentives, successful implementation may be jeopardized.

DOE is an excellent resource, featuring state and federal incentives by alternative fuel type. Learn more at DOE's Alternative Fuels Data Center (**afdc.energy.gov/laws**).

10. ROI factors

Many variables affect the financial success of a project. While this study is not intended to perform ROI calculations, it's beneficial to review key drivers. For any financial analysis, it's important to be as conservative as possible on all assumptions.

Relevant factors

- Replacement cycle time
- Lease length
- New versus existing vehicles
- Cost of alternative fuel conversion
- Fuel costs (price differential)
- Annual miles driven
- Reduction or increase in maintenance costs
- Routes requiring most fuel
- Vehicles consuming maximum fuel
- Applicable incentives

In terms of ROI, when dealing with a fixed-life asset like a vehicle, consider how long a customer plans to maintain ownership. As already mentioned, customers are replacing vehicles less frequently overall. A program's success will depend on positive cash flow before a vehicle replacement. In many cases, today's fleet customers are keeping their vehicles five to seven years. Many sources indicate five-year vehicle leases are more common. When considering these timeframes, it's becoming more popular to obtain positive cash flow by looking only at fuel savings during vehicle life. Numerous online ROI calculators can help you determine project payback.

B. CERTIFICATIONS, STANDARDS AND LABELING

There are several certification, standards and labeling requirements that need to be considered with respect to alternative energy/advanced technology vehicles. Some of these are discussed below. **However, this document does not cover all standards, certifications and labeling requirements related to upfitting or working on vehicles. Therefore, if you are unsure of all standards, certifications and labeling requirements applicable to your work truck endeavors, Green Truck Association recommends engaging an expert on the type of alternative energy/advanced technology vehicle in question to determine necessary requirements and verify compliance**.

1. Alternative energy system certification

Currently, we are aware of three elements of alternative energy systems that require a certificate held by the system manufacturer:

- Tailpipe emissions certificate
- Evaporative emissions certificate
- Onboard diagnostics (OBD) monitoring certificate and compliance

2. Emissions certification

Tailpipe emissions compliance demands either engine or chassis certification, depending on weight class. For vehicles with a GVWR of more than 14,000 pounds, engine certification is most common. However, the chassis is still certified to evaporative emissions, and OBD requirements must comply.

It's important to understand emissions certification in the vehicle operating area. It is also important to understand the differences between the Environmental Protection Agency (EPA) and CARB, because cost and/or technology may prevent companies from obtaining both of these certifications. In addition, you should be aware that these two agencies have different certification protocol.

3. FMVSS

When implementing alternative energy and advanced technology systems, Federal Motor Vehicle Safety Standards (FMVSS) must be considered.

In addition to any emissions and upfit-related requirements, FMVSS certification must be addressed for all vehicles completed prior to the first retail sale. In the commercial work truck industry, three primary forms of certification are intermediate-, final- and altered-stage. With incomplete vehicles (such as chassis-cabs, cutaways or box-delete chassis-cabs), the alternative fuels conversion installer likely would be either an intermediate- or final-stage manufacturer (if completing the vehicle by installing a body and related equipment). If alternative fuel conversion installers start with a completed vehicle (like a pickup or full van body), they will likely be considered alterers for certification purposes.

Some examples of relevant FMVSS are FMVSS 301 – Fuel System Integrity; FMVSS 303 – Fuel System Integrity of Compressed Natural Gas Vehicles; and FMVSS 304 – Compressed Natural Gas Fuel Container Integrity.

Canada Motor Vehicle Safety Standard 301.1

For vehicles operating in Canada, there is at least one specific difference from the U.S. regarding certification requirements. In most cases, Canadian Motor Vehicle Safety Standards align with the U.S. counterpart.

4. National Fire Protection Association standards

While National Fire Protection Association (NFPA) standards are not mandated by federal law, most states adopt NFPA standards, and some even have more stringent rules in place. It should be easy to find industry organizations that follow NFPA standards, and it is an indication of an organization's commitment to quality.

5. Vehicle labeling

There are many vehicle labeling elements to consider. Some labels come from OEMs and need to be left intact. Some FMVSS require new labeling by manufacturers in intermediate, altered and final stages. Labels also may be required by other governmental agencies or standards. In addition, equipment and technology manufacturers sometimes supply labels to be added to the vehicle for operational understanding and hazard or risk identification. To minimize liability and optimize operator communications, you should be familiar with all required and supplied labels, and ensure they are properly installed.

For example, in addition to the tank labeling necessary for compliance with NFPA 58, the vehicle needs to be properly labeled with the certification relative to an altered- or final-stage vehicle per FMVSS standards. EPA-related labeling also must be applied if affected as part of alternative energy installation.

6. Quality standards (For a discussion on quality standards, see Section C. 5)

7. Certified installers

Find certified installers at the Alternative Fuels Data Center (**afdc.energy.gov/laws**).

C. MAINTAINING A SYSTEMS'S SAFETY, QUALITY AND INTEGRITY

The most important concern in altering any design is to maintain a system's safety, quality and integrity. Below are some of the factors to consider to help in this task.

1. OBD requirements

With OBD-II being the latest version of diagnostics for most vehicles on the road today, it's vital to understand any impact an alternative energy/advanced technology system could have when installed. The goal of OBD-II was to access all these diagnostics through one data link connector.

Some alternative energy/advanced technology systems control their performance through a slave computer — not accessible through the vehicle OBD-II data link. Engine operating conditions can still be observed through OBD-II, but the fuel or drive system faults would then be accessible through the slave computer. While this arrangement is neither right nor wrong, it's important to be aware of the additional location to gather troubleshooting data, which may be decoupled from the vehicle system.

Each year, OBD requirements are added by engine manufacturers. Beginning in 2018, vehicles with a GVWR exceeding 14,000 pounds must comply with OBD monitoring.

2. Chassis integration and required modifications

Alternative energy/advanced technology system manufacturers and installers should be in close communication with OEMs, allowing access to the latest technical, safety and quality requirements in order to make appropriate vehicle modifications.

3. Choosing proper partners

Given safety and reliability concerns associated with adding an alternative energy/advanced technology system to a vehicle, researching the companies that will design, build, convert and install your system is always recommended. Successful integration will depend on having quality systems and processes throughout the supply chain.

Visiting system manufacturer and installer facilities is a good idea. This allows you — the potential end user — to see how the system is produced and installed, providing a reasonable understanding of involved processes. It's important to verify support structures are in place to prevent any failures in the field and, most importantly, deal with potential problems.

It's worthwhile to assess a supplier or installer on some subjective factors to boost project success, including

- Engineering capabilities and discipline
- Corrective action response
- Customer reaction

4. Design best practices

When evaluating the final design of a commercial vehicle with integrated sustainable technology, consider the following suggestions

- Design the entire integration as a whole — not in pieces
- Follow vehicle manufacturer design best practices
- Account for system durability and survivability
- Have design standards, as needed, for consistency

A commercial vehicle upfit is typically comprised of multiple components from different suppliers. Usually, the sustainable technology being integrated comes from a completely separate supplier. Building designs and upfits completely independently presents concerns. It's important to either work with an upfitter that can oversee the entire vehicle integration or engage several suppliers that overlap to ensure all components are compatible and work well together. This planning can prevent a host of issues downstream surrounding service and especially system accountability if there are performance problems in the field.

Beyond following component or technology manufacturer guidelines, it's important to make sure all vehicle manufacturer design best practices are considered. Many vehicle manufacturers publish quality standards, describing practices to follow and avoid during upfits. With sustainable technology, some vehicle manufacturers share specific guidelines that relate. These are important for upfit quality and certification testing/criteria during development.

An important best practice is to verify the system is designed for durability and survivability. Beyond standards like NFPA for CNG, key considerations include

- Proper routing of hoses and tubing
- Protection of key components from road debris and environmental hazards using coatings, shields and/or enclosures
- Adequate access for maintenance and inspection
- Exclusive use of high-quality fittings and hardware throughout the system
- Correct mounting of key components to avoid loosening

Coupling these durability items with a fully integrated system can help ensure a high-quality and reliable upfit for the vehicle life.

A final design consideration involves any standards used to safeguard upfit consistency across many vehicles. Fleets will often buy several vehicles with the same specifications — sometimes in different time periods. It's important to identify any key attributes of the upfit to carry through the design. Especially when multiple upfitters/integrators or technology providers are engaged, it's a good idea for the end customer to clarify design elements important throughout the application life (i.e., by noting in specifications or relevant drawings).

5. Quality standards

Quality takes various forms and can be held to many standards.

For example, ISO 9001 certification is a common quality standard in the vehicle industry, setting the framework for a company-wide policy. While this certification is not an industry requirement, it's a good indication of quality commitment and quality levels within supplier organizations.

Chassis manufacturers have guiding quality standards and certifications. Beyond body builder upfit guides, they provide certain requirements and/or certifications that should be fulfilled. They usually require FMVSS compliance, including crash testing and emissions and tank compliance. These standards help distinguish system upfitters.

D. ADDITIONAL CONSIDERATIONS

1. Warranty

There are two primary considerations when reviewing a system and vehicle warranty. First of all, it's necessary to understand if the alternative energy/advanced technology system will affect the vehicle warranty. In some cases, there are OEM-approved systems in which the warranty remains the same for the vehicle and is seamless to the end customer.

In addition, the system partner may offer a warranty on newly-installed components equivalent to what was removed from the original vehicle. This demonstrates why selecting a reliable system supplier is critical.

Any other situations should be closely monitored to avoid sacrificing vehicle coverage in some way.

2. Hybrid vehicles

Hybrid vehicles are normally defined as having two or more energy sources. In most (but not all) cases, hybrids capture and reuse energy from vehicle braking and/or engine output exceeding vehicle operation requirements. Currently, hybrids can be considered both electric and hydraulic.

Both technologies can be very effective in the proper drive and duty cycle, so a critical factor in hybrid utilization is properly matching the technology to the application.

The optimal choice between the various hybrid options is determined by drive and duty cycle and vehicle weight and is beyond the scope of this overview. In general, hydraulic hybrids work best in applications where the vehicle is heavy; is subject to very frequent start/stop cycles (launch/braking); and has a limited high-speed drive cycle component. Electric hybrids are typically preferred when the start/stop cycle is less frequent and there is a greater demand for extended operation at intermediate to high speeds. Due to the wide variation in hybrid technologies, to include both OEM and retrofit systems, the potential user should carefully evaluate the applications before making any decisions.

3. **Logistics and ship-thru**
   Ship-thru and freight reentry are popular options for many end users due to inexpensive transportation costs. Although there are size restrictions, the ship-thru process can help save costs, especially in more complex upfits.

4. **Upfit cost (locations)**
   Several variables affect total upfit costs. The more complex the job (i.e., number of tanks, bi-fuel versus dedicated, integration into body, etc.), the higher the cost. Number and location of available facilities are important factors to consider.

Addendum: Electric drive vehicles

An electric vehicle (EV) can be defined as an alternative fuel automobile that uses electric motors and motor controllers for propulsion, in place of more common propulsion methods (such as ICE).

EVs are different from fossil fuel-powered vehicles as they can receive power from a wide range of sources, including fossil fuels, nuclear power and renewable sources (such as tidal, solar, and wind power, or any combination of those). No matter how it is generated, this energy is then transmitted to the vehicle through use of overhead lines, wireless energy transfer (such as inductive charging), or a direct connection through an electrical cable. Electricity may then be stored on the vehicle using a battery, flywheel, supercapacitor or fuel cell.

This is actually not a new alternative source of transportation. Please note the image below left (from The Henry Ford Museum) of a Detroit Electric from 1910.

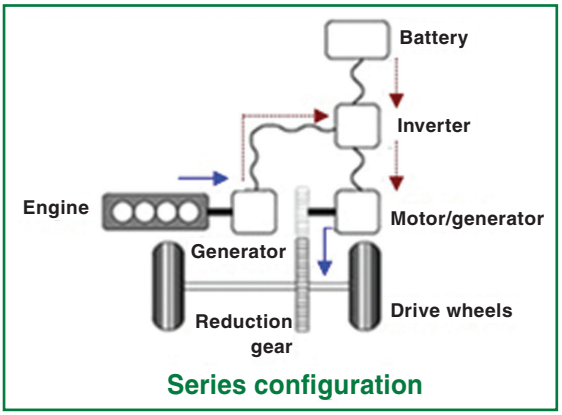
The Porsche (pictured above right) is from the Frankfurt Auto Show in 2015 and represents newer models. Technology has progressed with time, but the underlying concepts remain largely intact.

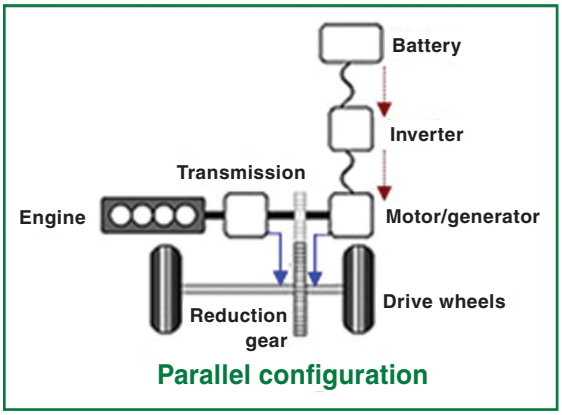
Alternative energy storage devices and a variety of other improvements have been incorporated in recent years — most notably in supercapacitors and batteries.

Driveline types

Series drive. Hybrids using a series drivetrain only receive mechanical power from the electric motor — run by either a battery or gasoline-powered generator.

Parallel drive. Hybrids with parallel drivetrains can allow the electric motor and ICE to provide mechanical power simultaneously or separately depending on the power demanded at any point in time.

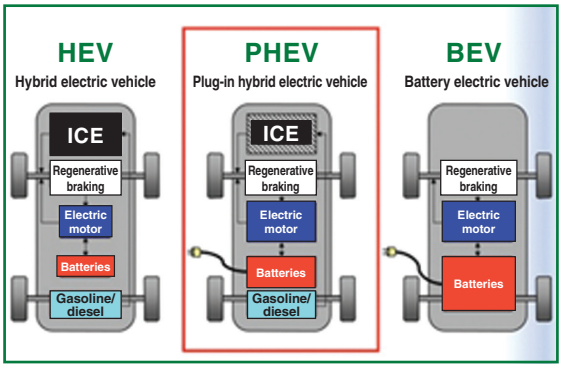




Electric cars and trucks commonly available include

- BEV: A battery electric vehicle (BEV), battery-only electric vehicle (BOEV), full electric vehicle (FEV) and all-electric vehicle use chemical energy stored in rechargeable battery packs, superconductors or fuel cells.
- HEV: Hybrid electric vehicles (HEVs) are powered by ICE or other propulsion sources that can run on conventional or alternative fuel, in combination with an electric motor using energy stored in a battery.
- PHEV: Plug-in hybrid electric vehicles (PHEVs) combine a gasoline or diesel engine with an electric motor and a large, rechargeable battery. Unlike conventional hybrids, PHEVs typically have larger stored energy sources (batteries and/or supercapacitors) and can be plugged in and recharged from an outlet, allowing them to drive extended distances using just electricity.

Core components and architecture



HEV

- This includes ICE which can run on any type of combustible fuel such as liquid (gasoline, diesel, LNG, or a variation like biodiesel or renewable diesel) or gaseous sources (natural gas, propane and hydrogen — in less common applications — are examples).
- Another common component is the regenerative braking system which allows the battery to receive the benefit of converted kinetic energy from the vehicle motion as it slows, returning some energy to the storage device.

- An electric motor (sometimes referred to as a traction motor) provides power to the wheels, a generator or both, depending on system architecture.
- An energy storage device like a superconductor or battery is included (flywheels can be used to store energy — although not commonly seen in cars and trucks).
- A fuel tank provides storage that ICE depends on for combustion (a sample of fuels stored on board is discussed below).

PHEV

- This includes ICE which can run on any type of combustible fuel such as liquid (gasoline, diesel, LNG, or variations like biodiesel or renewable diesel) or gaseous sources (natural gas, propane and hydrogen — in less common applications — are examples).
- Another typical component is the regenerative braking system which allows the battery to receive the benefit of converted kinetic energy from vehicle motion as it slows, returning some energy to the storage device.
- An electric motor (sometimes referred to as a traction motor) provides power to the wheels, generator or both depending on system architecture.
- An energy storage device like a superconductor or battery is included (flywheels can be used to store energy — although not commonly seen in cars and trucks). In the PHEV configuration, the energy storage device is typically a larger capacity device than commonly used on an HEV and smaller than required for the BEV variant.
- A fuel tank provides storage ICE depends on for combustion (a sample of fuels stored on board is discussed below).

BEV

- A common component on BEVs (like PHEV and HEV versions) is the regenerative braking system, which allows the battery to receive the benefit of converted kinetic energy from the vehicle motion as it slows, returning some energy to the storage device.
- An electric motor (sometimes referred to as a traction motor) provides power to the wheels, a generator or both, depending on system architecture.
- An energy storage device like a superconductor or battery is included (flywheels can be used to store energy — although not commonly seen in cars and trucks).

All EV variants have unique advantages, and it is important for a specific user to properly evaluate how an EV's operating characteristics can complement the mission and match the needs of the role where one of these vehicles would make a good selection. Typically, these vehicles are very quiet (reducing complaints of noise pollution) and significantly lower emissions from your fleet in both greenhouse and regulated exhaust gases. Other advantages include fewer moving parts to require lubrication and service and widespread generic availability (grid availability, if not local site-specific capability) of electricity to recharge batteries. Specific charging devices (interface between the vehicle and electricity grid) will require planning with the local power provider and may demand some level of investment by the vehicle operator. Range and payload considerations are important when selecting one of these vehicles (true for other alternative propulsion solutions). Further enhancements in amount of available onboard storage capacity and falling energy storage costs (typically quoted as dollars per kilowatt hours) are improving the number and locations where these vehicle types are considered a good solution. Battery prices are now commonly quoted at under $400 per kilowatt hour (with some users now talking about $150 per kilowatt hour), when the typical price per kilowatt hour was more than $1,000 only a few years ago.

In locations around the country, federal, state and city dollars continue to be available to fund additional costs of converting to electricity as a fuel source. Funding can even be used to support local infrastructure refinements like charging stations in some locations.

Another consideration that should factor into a fleet operator's decision to adopt this vehicle strategy is knowing how the local power company generates the bulk of its electricity. Given the wave of power companies switching to natural gas to generate electricity in a move to improve stack emissions and efficiency of generation operations, it can be important to know how much source electricity emissions will limit your ability to improve your fleet's emissions profile. Fleets can buy green offsets in the marketplace which help reduce the influence of older-generation emissions issues. Many of these green offsets serve to fund construction of solar and wind energy projects which generate no stack emissions.

Addendum: Natural gas

Natural gas as a fuel

Natural gas normally consists of more than 90-percent methane with smaller amounts of ethane, propane, butane, carbon dioxide and other trace gases. The substantial methane content gives natural gas its high-octane rating (120–130) and clean-burning characteristics, allowing high engine efficiency and low emissions. Unlike gasoline and diesel, natural gas does not require refinement before use in transportation, further contributing to its lower pump price. In addition, natural gas has safety advantages as compared to gasoline and diesel. It is lighter than air (in the event of a leak, it will dissipate into the air instead of pooling on the ground) and has a very limited range of flammability (it will not burn in concentrations below about 5 percent or above roughly 15 percent when mixed with air). Gasoline and diesel burn at much lower concentrations and ignite at reduced temperatures.

As compared to diesel, natural gas has 27-percent lower carbon dioxide emissions, 15–23-percent lower greenhouse gas emissions on a well-to-wheel basis (this can be greater than 100 percent when using renewable natural gas, making it a carbon-neutral or even carbon-negative fuel), and 90-percent lower NOx emissions with new natural gas engines on the market. Beyond providing a proven technology to lower emission impacts, natural gas offers energy security, diversity and lower long-term costs when used as a transportation fuel. The U.S. is the largest natural gas producer in the world, and thanks to the shale gas revolution, there will be decades of affordable reserves. Natural gas provides fuel diversification for fleets, and, due to the historically stable price of natural gas, allows fleets to more accurately estimate fuel costs in the future. It eliminates the need for the costly emission control systems required on diesel vehicles.

Renewable natural gas offers even more greenhouse gas benefits than conventional natural gas. It is biogas or biomethane captured as organic waste breaks down above the earth's surface. This fuel is extremely clean and a low-carbon alternative harnessed directly from decaying food waste, waste water, agricultural waste and landfill gas. Renewable natural gas use in transportation continues to grow. In 2017, 24 percent of all-natural gas used in transportation was from renewable sources. Depending on the source, renewable natural gas provides greenhouse gas emission benefits of more than 100 percent.

Infrastructure

Natural gas stations provide fuel as either CNG or LNG. CNG stations use pipeline gas from the local utility and compress it on-site. LNG stations typically rely on off-site production at dedicated liquefaction facilities, and the fuel is transported and stored for use at the station. CNG and LNG stations employ different components and technologies that necessitate designs and builds particular to the fuel being dispensed.

CNG is utilized on all vehicle classes (from passenger vehicles to heavy-duty trucks), while LNG is typically just engaged on high-mileage, high fuel-use vehicles (such as long-haul trucks). Today's CNG station network supports local vehicle operation and regional trucking in many parts of the country. LNG stations are being constructed along U.S. highways to support the nation's long-haul trucking operators.

When it comes to CNG infrastructure, there are two types: time-fill and fast-fill. Time-fill is typically used for return-to-base fleets that have the ability to refuel overnight. This type of fueling costs less than fast-fill due to the amount of compression necessary. Fast-fill, on the other hand, is often used for retail customers with random arrival times and a need to fill up quickly. Fast-fill stations will often cost more than time-fill stations due to compression equipment and storage capacity. Drivers fueling at a fast-fill station will experience similar fill times to gasoline and diesel. There are examples of private fleets using a time-fill station "behind the fence" and a fast-fill station open to the public.

The U.S. has continued to see growth in the CNG infrastructure market. Since 2013, CNG stations have gained more than 35 percent, and the industry has added conventional fuel providers making CNG available at stations across the country. CNG offerings can be found at truck stops, convenience/grocery stores, and warehouses. In addition, there are local distribution and leasing companies. This continued growth has reduced the range anxiety that existed five years ago.

Vehicles

Natural gas is used as a motor fuel for approximately 170,000 vehicles in the U.S. and 25 million worldwide, offering similar power and acceleration as vehicles run by gasoline or diesel. As with all vehicle fuels, natural gas can be used safely if simple, common sense procedures are followed.

Natural gas vehicles have an excellent safety record for two primary reasons: properties of the fuel itself and integrity of the natural gas vehicle/fuel delivery system (i.e., storage containers, fuel tanks, fuel lines, valves and pressure relief devices).

CNG fuel systems store natural gas at levels of 3,000–4,000 pounds per square inch. Although the use of high storage pressures may seem unconventional, compression, storage and fueling of natural gas vehicles meet stringent industry and government safety standards. Use of high-pressure systems is not unique to natural gas vehicles. High-pressure gases are used safely every day in industrial and medical applications. Hydrogen-fueled vehicles (although currently not in widespread use) store hydrogen at pressures of 5,000–10,000 pounds per square inch.

Natural gas-powered vehicles are designed for safety in normal operation and accidents. Their fuel containers must meet rigorous requirements, including bonfire/bullet penetration tests and hydraulic burst. These assessments are part of industry standards to test CNG containers far beyond normal environmental and service damage risks.

Natural gas-powered vehicles are a growing component of U.S. fleets due to their environmental, energy security and economic benefits. They are helping lead the way in the transition away from diesel and gasoline fuels. While natural gas vehicles are as safe as diesel or gasoline-powered vehicles, proper training and vehicle maintenance (including all fuel system components and fueling facilities) is required.

Technical data, safety regulations and years of experience show natural gas vehicles are at least as safe as conventionally fueled vehicles. To learn more about natural gas vehicles, including codes and standards, visit **ngvamerica.org**.

Addendum: Propane in transportation applications

Propane fuel basics

Also known as liquefied petroleum gas (LPG) or propane autogas, propane is a cleaner-burning alternative fuel that's been used for decades to power light-, medium- and heavy-duty **propane vehicles.**

Propane is a three-carbon alkane gas (C3H8). It is stored under pressure inside a tank as a colorless, odorless liquid. As pressure is released, the liquid propane vaporizes and turns into gas that is used in combustion. An odorant, ethyl mercaptan, is added for leak detection. **See fuel properties**.

Propane has a high-octane rating, making it an excellent choice for spark-ignited internal combustion engines. It presents no threat to soil, surface water, or groundwater. Propane is **produced** as a byproduct of natural gas processing and crude oil refining. It accounts for about 2 percent of the energy used in the U.S. Of this, less than 2 percent is used for transportation. Its main uses include home and water heating, cooking and refrigerating food, clothes drying, and powering farm and industrial equipment. In addition, the chemical industry uses propane as a raw material for making plastics and other compounds.

Propane as an alternative fuel

Interest in propane as an alternative transportation fuel stems from its domestic availability, high-energy density, clean-burning qualities, and relatively low cost. It is the world's third most common transportation fuel, behind gasoline and diesel, and is considered an alternative fuel under the **Energy Policy Act of 1992**.

Propane used in vehicles is specified as HD-5 propane and is a mixture of propane with smaller amounts of other gases. According to the Gas Processors Association's HD-5 specification for propane, it must consist of at least 90-percent propane, no more than 5-percent propylene, and 5-percent other gases, primarily butane and butylene. See **fuel properties**.

Propane is stored onboard a vehicle in a tank pressurized to about 150 pounds per square inch — about twice the pressure of an inflated truck tire. Under this pressure, propane becomes a liquid with an energy density 270 times greater than its gaseous form. Propane has a higher-octane rating than gasoline, so it can be used with higher engine compression ratios and prevents engine knocking. However, it has a lower British thermal unit rating than gasoline, so it takes more fuel by volume to drive the same distance.

Access the **Clean Cities Alternative Fuel Price Report** (July 2018 edition) for important information.

According to PERC

Propane autogas emissions

On Aug. 14, 2018, Blue Bird announced receipt of U.S. EPA and CARB approvals for the Roush CleanTech Ford 6.8-liter propane autogas engine at the optional .02 NOx gbhp certification level, the lowest levels of oxides of nitrogen (NOx) available from any Class 4–7 propane vehicles in the U.S.

- The Blue Bird Vision Type C school bus is 90-percent cleaner than the current 2010 EPA emissions standard of 0.20 g/bhp/hr and 99-percent cleaner than pre-2007 school bus models.
- Propane autogas is the most cost-effective solution for NOx reduction available in school transportation today.

In 2018, West Virginia University (WVU) performed a research program for PERC to establish exhaust emissions and performance characteristics of propane-fueled vehicles/engines through in-use testing methods in comparison to vehicles/engines fueled with other common transportation fuels.

- WVU used portable emissions measurement systems on each vehicle to collect the data (CO, CO2, NOx, and total hydrocarbon emissions) as they drove predetermined test routes using hot and cold starts.
- 96-percent NOx reduction: propane versus diesel school bus (stop-and-go route)
- More than 95-percent NOx reduction: propane versus diesel school bus (cold start)
- More than 93-percent NOx reduction: propane versus diesel school bus (hot start)
- More than 13-percent CO2 reduction: propane versus diesel school bus (stop-and-go route)

Refueling

Propane autogas provides four scalable refueling options that allow fleets to tailor their refueling needs based on a variety of factors, including the fleet's size, routes, budget and available facility real estate.

The two most common propane autogas refueling options involve installing a private on-site refueling station or becoming part of a refueling network, which could be public or private.

On-site refueling

On-site propane autogas refueling stations are the most affordable to install and provide convenience and reduced downtime for fleets with a central refueling location.

On-site propane autogas infrastructure uses the same pump and motor to handle a number of tanks and dispensers without changing the electrical requirements, allowing infrastructure to grow as fleets expand.

Some propane autogas providers will install an on-site propane autogas refueling station in exchange for a fuel contract.

Public refueling network

Public refueling networks work well for fleets with limited space or fleets needing more refueling locations along their routes.

Public refueling networks are made up of existing stations owned and operated by the propane provider, and fleets can take advantage of these stations with no infrastructure investment.

Public network refueling stations are accessible 24/7 through a card-lock system and often allow fleets to identify and maintain records of vehicles by VIN, driver, fuel type, and gallons dispensed, in addition to the date and time of the transaction.

If a public refueling network is not already in place in the area, a local propane provider may create one if a fleet (or multiple fleets) in the area can provide the adequate fuel consumption to support it.

Private refueling network

Installing a private refueling network made up of multiple refueling stations works well for large fleets in need of more refueling locations along their routes or fleets with considerable service areas.

Private refueling networks provide fleets with the ability to tailor the complexity of the refueling stations and their locations based on the fleet's unique needs.

Private network refueling stations are accessible 24/7 through a card-lock system, and depending on the selected fuel management system, fleets can easily identify and maintain records of vehicles by VIN numbers, driver, fuel type, and gallons dispensed, in addition to date and time of the transaction.

PERC provides fleet owners and managers with a variety of resources on propane autogas. Access additional detail at **propanecouncil.org**.

PROPANE education & research COUNCIL

Addendum: Additional resources

Several online sources can calculate ROI for alternative energy systems and equip you and your team with important information.

Nozzle technology

- Propane autogas nozzle technology, developed in recent years, has reduced emissions released at the time of refueling, while making the refueling process much simpler and safer for operators.
- K-15 quick-connect nozzles are designed to allow drivers to simply lock the nozzle into place and begin fueling as easily as with conventional fuels.
- K-15 quick-connect nozzles may be used with one hand, and the user is not required to wear personal protective equipment.

Support tools from PERC

- PERC offers several free resources online for fleet owners and managers to familiarize themselves with propane autogas benefits while helping to ensure fleets are maximizing their ROI with propane autogas.
- **Propane Autogas Business Case Brochure**. For fleet managers wanting to learn more about propane autogas and how it can be a solution for their fleet, PERC's On-Road Business Case Brochure is a great resource. The brochure walks readers through the total cost-of-ownership advantage propane autogas has over gasoline and diesel vehicles.
- **Propane Autogas Calculator**. PERC's free Propane Autogas Calculator provides a reliable comparison of the lifetime costs and expenses which helps determine the baseline ROI of transitioning propane autogas vehicles into a fleet. Fleets simply input a few numbers, and the calculator will display the cost of propane autogas as compared to gasoline or diesel. The Propane Autogas Calculator shows the cost of the vehicle, fuel and preventative maintenance and does not account for other benefits of switching to propane, like infrastructure.
- **The Autogas Refuel**. Get the latest news and insights about operating a propane autogas fleet with The Autogas Refuel — a quarterly e-newsletter tailored to transportation professionals interested in propane autogas. Each edition of The Autogas Refuel is a must-read for propane autogas fleet owners and managers with content that includes emissions news, propane autogas case studies, videos, and more.

Many organizations offer additional information, including

- Airport authorities
- American Gas Association (**truebluenaturalgas.org**)
- CNGnow (**cngnow.com**)
- DOE's Alternative Fuels Data Center (**afdc.energy.gov**)
- DOE's Clean Cities (**cleancities.energy.gov**)
- Landi Renzo USA (**landiusa.com**)
- Major system providers, such as ROUSH CleanTech (**roushcleantech.com**)
- NAFA Fleet Management Association (**nafa.org**)
- National Association of State Energy Officials (**naseo.org**)
- National Propane Gas Association (**npga.org**)
- The Natural Gas Solution (**naturalgassolution.org**)
- NGVAmerica (**ngvamerica.org**)
- NTEA (**ntea.com/sustainabletechnology**)
- PERC (**propane.com**)
- State and local government organizations
- Transportation Energy Partners (**transportationenergypartners.org**)
- U.S. Green Building Council (**usgbc.org**)

Several trade shows and conferences focus on alternative energy. These events provide a wealth of relevant information, covering latest industry innovations. Examples include

- Advanced Clean Transportation Expo (**actexpo.com**)
- Green Truck Summit — produced by Green Truck Association (an NTEA affiliate division) and NTEA — in conjunction with The Work Truck Show® (**worktruckshow.com**)
- Other industry-focused trade shows, including beverage, convenience store market, utilities and communications events

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