City of Philadelphia
Alternative Fuels Analysis Report

Prepared for:

Alternative Fuels Technical Assistance Program

Pennsylvania Department of Environmental Protection

DRAFT

June 30, 2018

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1.0 INTRODUCTION

The City of Philadelphia owns and operates a fleet of approximately 5,400 vehicles. The City has taken some steps to acquire a limited number of efficient or alternative fuel vehicles, but currently does not have a "clean fleet plan." However, the City's aggressive environmental commitment to reduce citywide carbon emissions 80 percent by 2050, necessitate that a clean fleet plan be developed in order to inform future fleet purchasing and management decisions. This report examines the fleet on a broad level and makes recommendations for areas to evaluate during the development of the City's clean fleet plan.

2.0 EXISTING FLEET STATISTICS

The City provided current data on fleet makeup and overall fuel usage by department for fiscal year 2017 (fiscal year ending June 30th). Table 1 lists the number and age of vehicles by department, the amount of gasoline and diesel used in FY2017 sorted by the total gallons of fuel used, and the CO_2 emissions resulting from this fuel use.

Table 1 – Vehicle Count and Age, FY2017 Fuel Usage by Department, and CO_2 Emissions

Department[1]	Number of Vehicles	Average Age	Gasoline (gal)	Diesel (gal)	CO_2 Emissions (tonnes)[2]
Police Department	1,556	4	1,894,572	31,651	15,264
Streets Department	811	6	186,928	1,352,837	14,387
Philadelphia Water Department	896	6	388,721	379,637	6,693
Fire Department	354	8	86,375	552,140	5,952
Parks and Recreation	318	8	144,822	74,348	1,853
Commerce / Division of Aviation	310	9	109,151	90,855	1,729
Office of Fleet Management	116	11	79,475	29,867	913
Managing Director's Office	131	7	61,737	28,239	757
Department of Human Services	105	6	69,875	113	553
Sheriff's Office	69	5	55,644	13,090	564
Prisons	67	6	56,568	6,410	508
Department of Public Health	117	6	51,554	2,285	429
Department of Public Property	82	6	42,262	9,112	421
Department of License and Inspections	63	6	20,930	12,992	289
Free Library of Philadelphia	36	6	18,994	3,181	180
First Judicial District of Pennsylvania	80	7	21,502	5	170
District Attorney Office	41	6	20,355	0	161
Office of Innovation and Technology	27	4	10,138	3,822	117
City Council	17	2	10,257	0	81
Mayor's Office of Community Services	6	5	4,971	249	42
City Commissioners	6	7	3,306	0	26
Mayor's Office	3	1	3,264	0	26
Office of Inspector General	8	4	2,467	0	19
City Controller	7	11	1,262	0	10
Department of Revenue	5	4	912	0	7
City Planning Commission	7	9	440	0	3
Procurement Department	1	5	411	0	3
Department of Records	2	1	59	293	3
Office of Behavioral Health	4	1	336	0	3

Commission on Human Relations	2	11	330	0	3
Department of Finance	3	4	329	0	3
City Representative	2	8	128	0	1
Mayor's Office of Labor Relations	2	13	62	0	0
TOTAL	**5,254**		**3,348,134**	**2,591,127**	**51,170**

Note 1: This table does not include 18 vehicles for the Office of Homeless Services, and 6 vehicles for the Department of Animal Control and Care.

Note 2: "Tonnes" refers to a metric tonne, which is equal to 2,205 lbs.

The CO_2 emissions listed in Table 1 assume that all diesel fuel is B5 (5% biodiesel blend), and all gasoline is E10 (10% ethanol blend).

Figure 1 shows the vehicle count by model year. Vehicle lifecycle depends on multiple factors, and varies by department as shown in Table 1.

Figure 1 – Vehicle Count by Model Year

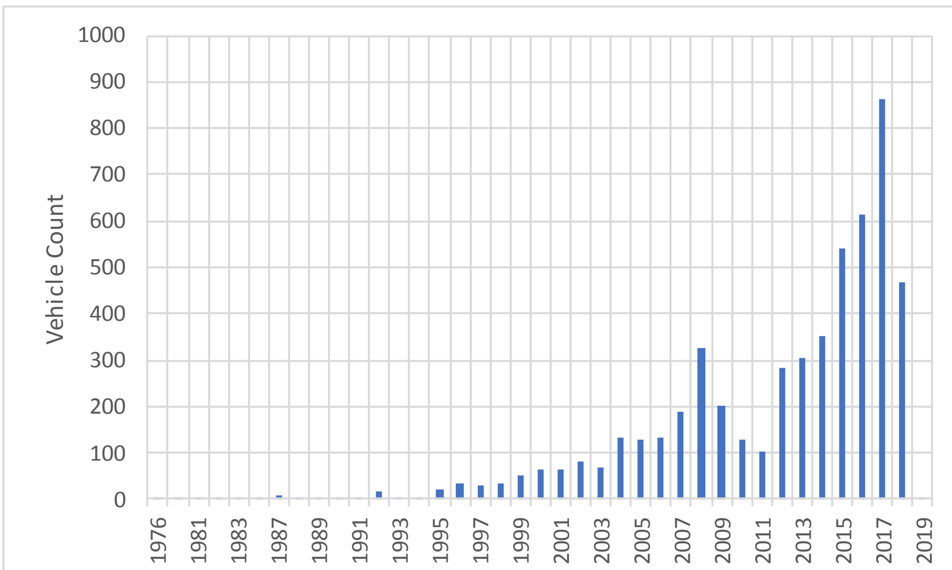

Table 2 breaks down the fleet by fuel type and highlights the alternative fuel and low emissions vehicles that are currently owned by the City.

Table 2 – Vehicle Count by Fuel Type

Fuel	Vehicle Count
Gasoline	2,657
Diesel	1,471
Gasoline / E85	956
Hybrid	142
Plug-in Hybrid	29
EV	23

Although the City owns a significant number of vehicles which are able to utilize E85 (Ethanol blend up to 85%), it is unclear whether the City has separate fuel tanks at any of its fueling stations which would allow for E85 to be dispensed.

The 142 hybrid vehicles are primarily the Ford Escape, Ford C-Max, and Ford Fusion. A hybrid vehicle is able to capture energy from vehicle braking for later use, but it does not have a connection allowing it to be charged from a utility power supply.

The 29 plug-in hybrid vehicles include only the Ford Fusion Energi and the Ford C-Max Energi. A plug-in hybrid vehicle captures energy from braking, but also is able to be recharged from utility power supply. Plug-in hybrids generally have larger battery capacity than hybrids and are able to operate on electricity only for a short range, generally 20-30 miles, and then they utilize a gasoline engine to deliver additional range.

The 23 electric vehicles include 5 electric motorcycles used by the Fire Department, and 7 Chevrolet Bolts used by a variety of departments. The remaining electric vehicles are golf-cart type vehicles for off road use. Electric vehicles generally have larger battery capacity than hybrids, due to the lack of a gasoline engine (the range of a 2018 Chevrolet Bolt is 238 miles).

2.1 Car Sharing

The City participates in a car sharing program which is operated by Enterprise. This program allows city employees to access a variety of passenger vehicles which are located at designated parking spaces throughout the city. For the 12 months ending in April 2018, the program had 790 registered drivers, and total mileage of 205,684. There were 7,183 trips, with an average trip distance of 29 miles.

Some of the benefits of the car sharing program cited by City staff were a reduction in maintenance and acquisition costs for light duty vehicles, as dedicated City owned vehicles are able to be offset by fewer Enterprise-managed shared vehicles. Because the vehicles are used by both city employees and the general public, they accumulate more quickly than a passenger vehicle would which was assigned to a particular City department. This results in a newer fleet, as cars are replaced more often by Enterprise than would be the case for these cars in the city fleet. Due to federal emissions standards, newer vehicles are generally more fuel efficient, so the car sharing program can provide fuel savings compared to the use of older passenger vehicles. Enterprise pays for the fuel, so that fuel savings do not provide a direct financial benefit to the City, but the reduced fuel usage does result in reduced carbon emissions, which is one of the City’s primary environmental goals.

3.0 PAST EXPERIENCE WITH ALTERNATIVE FUEL VEHICLES

3.1 B20 Diesel Blend

B20 diesel (20% biodiesel) was tested with part of the fleet 5-8 years ago. For the most part, it was a success, however, there was one type of truck which suffered significant breakdowns in the fuel injection pumps, and therefore, the project was discontinued.

3.2 Compressed Natural Gas

Approximately 10 years ago, the City ended a previous attempt to operate natural gas vehicles in its fleet. At the time, the reason for ending the use of CNG was a lack of infrastructure for CNG vehicles. Since then, the CNG vehicle market has advanced, especially for heavy duty trucks. The current presence of several publicly accessible CNG fueling stations in and around the City provides assurance that CNG fuel can be accessed when needed.

4.0 CURRENT ALTERNATIVE FUEL PROJECTS

The City is currently in progress with several fleet related projects aimed at improving the sustainability of vehicle operations.

4.1 EV Deployments

The Office of Fleet Management (OFM) has taken an indirect approach with regard to the installation of EV "charging stations" (technically known as Electric Vehicle Service Equipment). In order to ensure that EVs will be meaningfully used by the departments receiving the vehicles, departments can request a vehicle and a charger which OFM provides, but requires that the receiving department select a location and install the charger themselves. OFM hopes that requiring this level of interest and involvement from the receiving department will make it more likely that the department actually wants to utilize an EV, compared to a conventional vehicle for which fueling infrastructure is already present.

OFM has plans to purchase 25 EVs in 2019, as well as some plug-in hybrids for non-pursuit police purposes, and some Ford Fusion hybrids for use as unmarked police cars.

4.2 Compressed Natural Gas

The City has started a project to convert a fleet of 30 trash trucks (Department of Streets) to compressed natural gas (CNG). Due to the size of the City, there is no central trash truck facility, but rather, the approximately 341 trash trucks in the City are based out of numerous facilities which are local to the areas served. The CNG project currently in progress is located near the Philadelphia International Airport. This region was selected because there is a publicly accessible fast fill CNG station located adjacent to the airport which is suitable for use by the trash trucks. This fast fill station would be utilized until the City has completed construction of its own time fill station at the trash truck overnight parking area, and this fast fill station could also be used as a backup fueling source if the City's time fill station was unavailable due to maintenance or a malfunction.

The maintenance garage where these trash trucks will be serviced is being upgraded so that it complies with all codes for servicing natural gas vehicles. Completion of these facility modifications is expected by the end of 2018.

The time fill station will initially be constructed to accommodate 30 trucks, but space at the site will be reserved to allow expansion so that up to 45 trucks could be fueled.

5.0 BARRIERS AND OPPORTUNITIES IN TRANSITIONING TO A CLEAN FLEET

The size and diversity of the City's fleet and users, provides both an opportunity and barrier to implementing future alternative fuel projects. The current structure is generally, that each department and location where vehicles are based has its own gasoline and/or diesel storage which provides convenience and simplifies fueling.

One example of opportunity and barrier is: an installation of a CNG fast fill station would have the potential to provide significant fuel cost savings. The significant capital cost of the CNG fast fill station needs to offset enough gasoline and diesel to have a reasonable payback. This would mean that a centrally located facility with multiple departments fueling at the one location would provide the best project. The opportunity is that the City has several vehicle types across different departments where CNG vehicles are commercially available and cost effective. However in talking to stakeholders it was expressed that there would be reluctance for multiple fleets to use a common fueling station.

The rapid change in EV technology is also both an opportunity and barrier to implementing alternative fuel projects. While there are limited or no vehicles available today in the Class 3 to Class 7 categories or police SUV cruisers, those EV vehicles are under different stages of development. In this case the question is whether to delay implementing a CNG project to wait on the EV technology to be developed, or to implement a CNG project that may provide significant benefits but be obsolete in 10 years.

6.0 METRICS FOR EVALUATING OPTIONS FOR THE CLEAN FLEET PLAN

As the City moves forward with developing a clean fleet plan, it is important that it work with stakeholders to specify and prioritize its goals. The goals should be assigned weighting based on value that the stakeholders attach to each selected goal. The following is a list of stated and potential goals and benefits which the City may wish to prioritize when implementing fleet decisions:

- Reduce the costs of fleet operation and maintenance
- Reduce CO_2 emissions
- Reduce criteria pollutant emissions
- Improve road safety
- Lead by example, in promoting clean transportation options
- Support the development of a regional clean economy
- Improve the City's resiliency to weather events
- Work towards social justice for all residents of the City
- Align with other sustainability trends

The following sections discuss in more detail quantifying these potential goals.

6.1 REDUCE THE COST OF FLEET OPERATIONS AND MAINTENANCE

Many alternative fueling options reduce both operating and maintenance costs. The caveat is that generally, the alternative fuel vehicles have significantly higher capital costs. EVs and CNG have significant fuel cost savings over gasoline and diesel. EVs eliminate the need for oil changes, fuel and air filters and engine tune ups. CNG vehicles generally can go longer between oil changes and are predicted to have lower fuel and emissions system maintenance costs. The unknown for EVs is battery life. Currently there are multiple grant opportunities and incentives to help offset the added capital cost for alternative fuel vehicles and it is expected that as the technologies mature and are more widely adopted the difference in purchase price between alternative fuel vehicles and conventional fuel vehicles will be reduced. **A simple metric for this goal would be comparing life cycle costs of vehicles and fueling infrastructure of alternative fuel vehicle options**

6.2 GREENHOUSE GAS EMISSIONS

The City has committed to an 80% reduction in carbon emissions citywide by 2050. While the majority of emissions are due to buildings and industry, transportation emissions must also be reduced if the goal is to be met.

Table 3 lists the CO_2 emissions due to the combustion of various fuels (not taking into account extraction or transport of the fuels). Because fuels are measured differently, they are compared on the basis of a Gasoline Gallon Equivalent (GGE) which is equal to the lower heating value of gasoline, approximately 114,000 Btu/gal.

Table 3 – CO_2 Emissions for Combustion of Various Fuels

Fuel	kg CO_2 per unit volume	kg CO_2 per GGE	CO_2 Reduction Relative to Gasoline
Gasoline E10 (gal)	7.9	7.9	-
Diesel B5 (gal)	9.5	8.5	-
Natural Gas (Mcf)	54.4	6.8	14%
Propane (gal)	5.7	7.7	2%
Electricity (kWh)	0.4	4.2	47%

Notes: Gasoline, Natural Gas, and Propane data are from Instructions for Form EIA-1605, Voluntary Reporting of Greenhouse Gases, April 25, 2007. Electricity data is from 2014v2 EPA eGrid data for subregion RFCE, using value for Total Output Emission Factor. Electricity emissions include EPA estimated line losses of 4.97%. Diesel engines have a higher thermal efficiency than gasoline engines, thus the greater CO_2 emissions per GGE of diesel does not necessarily mean higher emissions overall. Electric GGE calculation is derived from a comparison to a gasoline vehicle and includes a battery charging efficiency of 85%.

Table 3, it is apparent that simply converting large portions of the fleet to (fossil) natural gas would not achieve the City's greenhouse gas goals, because natural gas is still a carbon intensive fossil fuel. Electricity, depending on how it is generated, presents a better greenhouse gas emissions profile, even with the default generation mix available in eastern Pennsylvania.

While it will not affect emissions from service vehicles a robust public transit system that is convenient for individual city worker transportation between meetings and job sites offers significant reductions in transportation costs and emission.

The City should investigate the following technologies and fuels which have the potential to achieve the desired reduction in greenhouse gas emissions:

- Renewable natural gas
- Renewable diesel (distinct from biodiesel)
- Purchase of low-carbon electricity generation (PV, wind, hydro, or biomass generation)

A simple metric is ranking of alternative fuel vehicle options based on overall CO_2 reductions from current levels.

6.3 Criteria Pollutant Emissions

Vehicle emissions in an urban setting present a health risk to certain populations. Modern diesel and gasoline engines have made significant progress in reducing emissions. Electric and fuel cell vehicles have zero tail pipe emissions, but may have emissions at the point of power generation.

Smog is generated by chemical reactions in the air which depend on heat, light, and the right mixture of pollutants, and therefore may be exacerbated in an urban area, whereas the same emissions in a rural area may not result in as significant a health risk. Still, the City should study and intentionally select the sources of electricity for any electric vehicles in order to avoid unintended consequences of increased electricity consumption on regional air quality.

Since the stated goal is improving air quality within the City, alternative fuel options should be ranked based on tail pipe emission reduction for criteria pollutants of NOx, SOx, PM, CO and Lead.

6.4 Improving Road Safety

Generally all marketed vehicles are required to meet rigid federal safety guidelines and it is unlikely that there will be a quantitative change in safety between alternative fuel vehicle types or between alternative fuel vehicles and conventional fuel vehicles. Autonomous driving vehicles may theoretically improve road safety and are mainly being developed on EV vehicle platforms. The greatest opportunity for improving road safety for the City fleet would be to reduce number of miles driven. This could be accomplished by improving access to public transit or ride sharing strategies.

No metric is suggested for ranking improving road safety for the City fleet but it seems reasonable for the Study to consider how improved public transportation could reduce the use of the City fleet.

6.5 Other Goals

Other goals can provide direct and indirect support for developing the use of alternative fuel vehicles in the City and region. To achieve City wide goals of reduction of CO_2 emissions of 80% by 2050 will require adoption of alternative fuel vehicles and vehicular carbon reduction strategies by all users throughout the metropolitan area. The "other goals" are suggested to positively impact the emissions from the overall vehicular fleet not just the City fleet.

6.5.1 Leading by Example

The clean fleet plan should keep in mind that the City's fleet is a small percentage of overall transportation activity in the City. In order to achieve the City's ambitious climate goals, it is not enough for the City's fleet to set out on a gradual path to meet the targets by 2050. If City government only, meets these targets on schedule, the question is, will business and the general public also meet these targets on schedule, or will they lag behind? In order to lead by example, as one of the larger regional fleets, the City should find ways to make bold steps forward, but also intentionally select transportation solutions for the fleet which can be replicated by residents and businesses.

6.5.2 Support the Development of a Clean Regional Economy

Examples of ways in which the City can provide support for a clean regional economy as part of an alternative fuel fleet plan are:

- Installation of EV charging stations that could be used by both City and private vehicles
- Purchase of renewable electric power for use in EV charging stations
- Purchase of renewable liquid or gaseous fuels for direct use in the fleet
- Purchase of credits or RINs for renewable fuels that helps support profitability of renewable fuels
- Service contracts for CNG vehicles that will develop private service expertise and upgrades of private facilities to accommodate CNG vehicles

6.5.3 Public Transit

Public transit improvements may have the greatest overall potential to help the City achieve stated goals of reduced emissions and improving road safety from the transportation fleet. Items such as installing bike lanes and bike sharing stations to encourage reduced vehicle use for short commutes and overall improvements in the public transportation network may want to be considered in the study

6.5.4 Sustainability Trends

Looking at the future, there are several trends which may result in changes to how the City operates its fleet. It is not enough for a clean fleet plan to simply find ways to reduce the environmental impacts of current operations. Some of these trends include:

- Separate organic waste collection which may require additional collection trucks
- Goals for reduction of overall solid waste
- Autonomous vehicles
- Wide public adoption of EVs

Autonomous vehicle technology has the potential to greatly improve the efficiency of "car sharing" type systems, because the vehicles would be able to dynamically reposition themselves when not in use, and to deliver themselves to the location of the next user. Autonomous vehicles could also be a partial solution to the problem of EV charging, because they would be able to recharge as needed in a central location. The charging location would not have to be convenient to the users, because once charged, the cars would be able to move out of the charging location and to where the next user was located.

7.0 CONCLUSIONS AND RECOMMENDATIONS FOR DEVELOPING A CLEAN FLEET PLAN

To achieve the stated goal of developing a clean fleet plan will give the City direction in order to take meaningful steps to reduce emissions and assist in achieving the City's climate goals. Steps for developing the Clean Fleet Plan should include:

- Meeting with City stakeholders to establish goals for the project
- Ranking and weighting of the established goals
- Summarize existing conditions of the City fleet
    - Make and class of vehicle by department
    - Age and mileage of vehicles
    - Annual fuel type and use by vehicle category
    - Describe how each department houses vehicles
- With stakeholder input predict change in fleet profile 7 years in the future
- Provide analysis of alternative fuel options by vehicle type use and class (options evaluated should include: CNG, EV, LNG, propane and renewable diesel)
    - Capital cost comparison of alternative fuel vehicle options
    - Operating & maintenance cost comparison of alternative fuel vehicle options
    - Environmental impact comparison of alternative fuel vehicle options
    - Fueling station infrastructure and operating costs for alternative fuel options
- Quantify and summarize changes to existing city owned or contracted service garages associated with alternative fuel types
- Provide a summary of market trends in alternative fuels and vehicles, including announced vehicles in development
- Provide recommendations for preferred alternative fuel vehicle type by department, category and use, and recommended alternative fueling infrastructure

- Provide analysis of the recommendations for preferred alternative fuel vehicle type by department, category and use, and recommended alternative fueling infrastructure, including capital cost, operating and maintenance cost, and emissions reduction from present vehicle and fuel use
- Summarize current grant and incentive programs available to support alternative fuel vehicle projects
- Presentation of the final report to City Stakeholders

Because of the fleet size and diversity there are multiple scenarios and options that need to be considered. It is crucial for developing a plan that can be successfully implemented that stakeholders buy into the goals of a project.

Appendix A – Discussion of Alternative Fuel Vehicles and Fueling Stations

A.1 Compressed Natural Gas

A.1.1 CNG Vehicles

Compressed Natural Gas (CNG) powered vehicles are designed to have similar range and performance to their gasoline or diesel fueled counterparts, but they do have a few components that are distinctly different. Similar to a gasoline engine, natural gas is injected into the cylinder and a spark is used to ignite it. Some automakers have produced dedicated CNG vehicles, but in most cases, including with Ford, the OEMs do not produce CNG vehicles, but instead provide a "gaseous fuel prep" option which makes certain engine modifications on a gasoline powered vehicle to allow for future installation of an aftermarket CNG fuel system by a vehicle upfitter. Ford's gaseous fuel prep option includes hardened valves, valve seats, pistons, and rings, because natural gas has a higher combustion temperature than gasoline. Without the gaseous fuel prep option, a gasoline engine could still be able to be converted to CNG, but it could suffer accelerated wear.

The other major component that is different than a gasoline powered vehicle is the CNG storage tank. Instead of a steel or plastic tank that contains a liquid fuel, CNG tanks are steel or composite cylinders that are designed to withstand the impact of a collision while containing the CNG at pressures up to 3,600 psig. To protect the CNG tanks during a collision, they are typically provided with a steel cover or mounted between the structural members of the vehicle frame. In the case of bi-fuel vehicles, where the liquid fuel tank is left in place, the CNG tanks are typically mounted in the cargo area of the vehicle, which decreases the usable cargo space. This is also sometimes necessary to achieve an acceptable range for the CNG vehicle due to the lower energy density. An exception to this mounting technique is the full size transit bus or trash truck where the tanks can be mounted on the roof of the vehicle.

In order to ensure the safety and integrity of the CNG fuel tanks, tank inspections by a qualified technician are required every 3 years or 36,000 miles, whichever comes first. Additionally, tanks have a useful life of 15-25 years, and this is clearly labeled on each tank in the form of an expiration date[1]. Figure 2 shows an example tank label, for a tank with a 20 year useful life span.

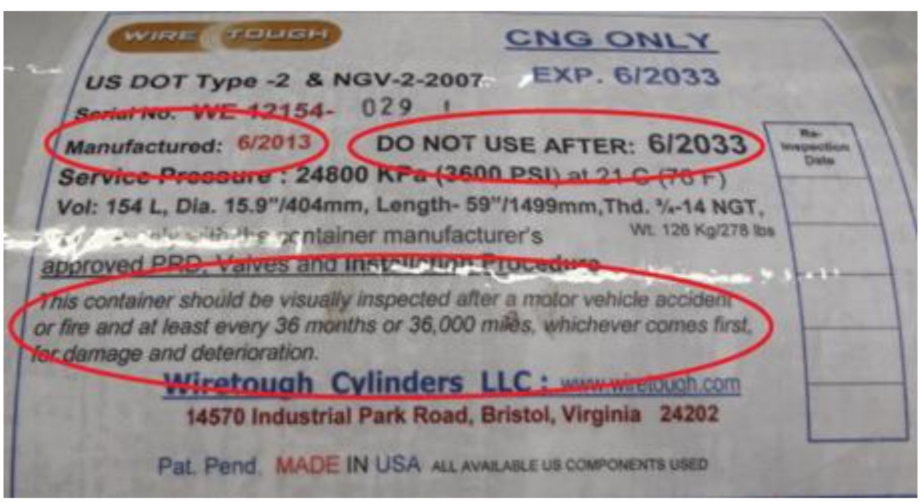

Figure 2 – Example CNG Tank Label

Image credit: U.S. Department of Energy

[1] https://www.afdc.energy.gov/vehicles/natural_gas_cylinder.html

A vehicle with a CNG fuel system can still be serviced by mechanics with no special CNG training, as long as they don't work on the fuel system. For example, the vast majority of vehicle maintenance does not involve the CNG system, including spark plugs, lights, tires, brakes, transmission, engine oil, air filter, and exhaust.

Unlike gasoline and diesel vapors, natural gas is lighter than air. This property generally requires some ventilation modifications to maintenance facilities where CNG fuel systems are serviced. This ensures that any releases of natural gas are safely dispersed and do not come into contact with ignition sources. Natural gas does not present any environmental ground or surface water contamination hazards, as gasoline does, should it leak out of a tank during storage or fueling.

A.1.2 Time Fill CNG Fueling Stations

Natural gas is distributed in a network of pipelines owned and maintained by utility companies, natural gas producing companies, or other entities. Although large transmission lines can operate at higher pressures (up to 1,500 psi), distribution lines typically operate at much lower pressures (60 psi or less), thus requiring compression of the natural gas for vehicle fueling. A connection to a gas distribution line and a compressor are common to all types of fueling stations. CNG is measured in GGE (Gasoline Gallon Equivalent), where 1 GGE is 5.66 lb. of CNG, which has an equivalent amount of energy as 1 gallon of gasoline.

Time fill stations include a gas dryer, compressor, temperature compensation panel, and high pressure CNG distribution system as shown in Figure 3. These stations are commonly called time fill stations because the system requires an extended period of time, which is usually in the 8-10 hour range, to complete vehicle fueling. This fueling time makes the system most suitable for fleets that are stored in a single location at the end of each day and parked until the next morning. The gas dryer removes excess moisture from the natural gas to prevent complications from freezing of critical fuel delivery components onboard the vehicle. Several different dryer designs are available; however, the most common uses a regenerative desiccant bed. The desiccant absorbs the moisture from the natural gas while the compressor is in operation and then the desiccant is dried or "regenerated" when the compressor is not in operation. Some models are equipped with two separate beds that alternate so that one bed is always available for gas drying while the other regenerates.

The second main component in a time fill station is the compressor. Like the dryer, there are several different compressor configurations available depending on the pressure of the gas supply and the requirements of the fleet. All natural gas compressors require multiple stages of compression to prevent the natural gas and the compressor from reaching excessive temperatures and to maintain an optimum level of efficiency. A reciprocating compressor is typically used for CNG compression. Power for the compressor is provided by a large electric motor (approximately 50 HP), but can be operated by an engine powered by natural gas or other fuels where electricity is not available. The size of the compressor is determined by the size of the fleet, type of vehicles being fueled, the amount of natural gas to be delivered, and the amount of time available for refueling.

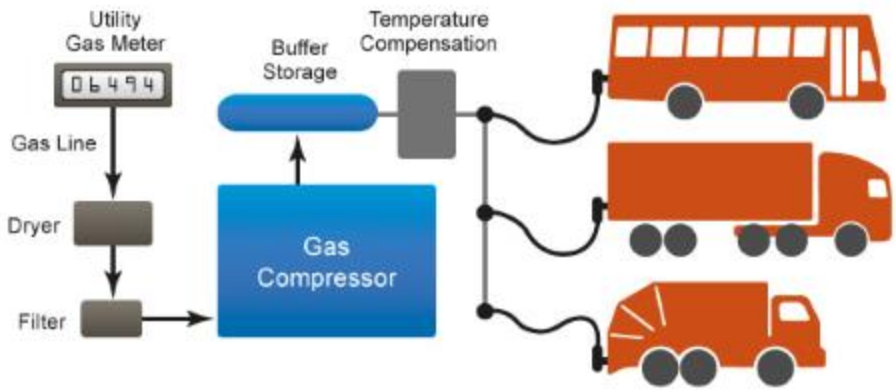

Figure 3 – Time Fill Station Diagram

Image credit: U.S. Department of Energy

During normal operation of the time fill system, the compressor operates continuously, to slowly bring all the connected vehicles up to 3,600 psi. Each vehicle has a check valve on its tank, and thus, CNG flows first to the vehicle with the lowest CNG tank pressure. Eventually, the pressure in all of the vehicles will equalize and the compressor will power off once the pressure is brought up to 3,600 psi.

A.1.3 Fast Fill CNG Fueling Stations

Fast fill stations are similar to slow fill stations in equipment configuration. The main differences include high pressure CNG storage and a larger CNG compressor. The larger compressor (typically around 200 HP), and compressed gas storage allows the station to operate similarly to a gasoline fueling station where fueling time is in the range of 5 to 10 minutes per vehicle. Figure 4 shows the general layout of a fast fill station.

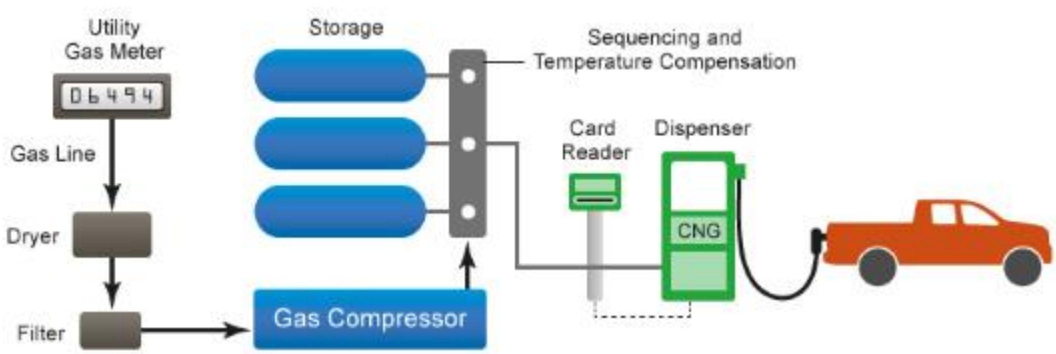

Figure 4 – Fast Fill Station Diagram

Image credit: U.S. Department of Energy

There are three fueling station configurations that are common. The first configuration uses what is commonly known as buffer storage. This configuration is used where the fast fill station is serving a fleet of large vehicles like a transit bus fleet (100 GGE capacity or larger). To provide the 5 to 10 minute fueling time, the compressor charges the buffer storage when vehicles are not being fueled. This provides a reservoir of CNG that is ready to be transferred to an empty CNG vehicle without compression. Once the buffer storage is depleted, the compressor continues to provide CNG to meet the 5 to 10 minute fueling time. However, if additional empty vehicles arrive for fueling, the fueling time is likely to increase because the compressed gas will flow to the vehicle that is less full, similar to the slow fill station. This results in the first vehicle being forced to wait for the second to be fueled until its tank reaches a similar pressure, then both buses are filled to capacity simultaneously.

To overcome this issue, the industry developed a second type of storage known as cascade storage. In this arrangement, natural gas is compressed and stored in three separate tanks at three separate pressures during fueling instead of a single tank as is done in buffer storage. When a vehicle is fueled, only one tank is discharged until the pressure in the vehicle and that tank are equalized. Then, the next tank discharges until the vehicle is filled or a second equalization pressure (higher than the first) is reached. If the vehicle is still not full to capacity, a third tank discharges to a third discharge pressure equal to the vehicle's fully charged pressure, which is usually 3,600 psi. A set of sequencing valves control the flow of CNG out of the three storage tanks to maintain the low, medium, and high discharge pressures and to meet the fueling station demand. A priority fill system directs the flow of CNG into the tanks from the compressor to maintain the low, medium, and high discharge pressures as well. This system allows the station to fill multiple vehicles simultaneously while ensuring that they are completely full.

An alternative to cascade storage uses a second compressor to provide the additional pressure required to fill vehicles to capacity simultaneously. Instead of using the bank of three storage tanks, a single storage tank is combined with a second compressor. Gas is compressed from the supply pressure to 3,250 psi in the first compressor. From there, it flows either to storage, or to the second compressor that increases the pressure to 3,600 psi. Since the second compressor is not increasing the pressure as much as the first, it can supply CNG to meet the 5 to 10 minute fueling time. This is true of the first compressor as well, since it only compresses the natural gas to 3,250 psi.

Figure 5 shows an example of a publicly accessible fast fill CNG station.

Figure 5 – CNG Fueling Station at Philadelphia Airport

Image Credit: Clean Energy Fuels

A.2 Propane

A.2.1 Propane Vehicles

Propane is a gas at room temperature and atmospheric pressure, but is stored and combusted as a liquid in vehicular applications. Unlike natural gas, which can only be liquified under cryogenic conditions, propane is easily liquefied and stored at around 150 psi. One gallon of liquid propane has approximately 84% of the energy of a gallon of gasoline.

Like CNG vehicles, a propane vehicle is often able to be ordered from the OEM with a gaseous fuel prep package, and then receives a propane fuel system by an OEM-qualified third party upfitter. This results in the full vehicle warranty being honored by the manufacturer.

Propane is slightly less complicated than CNG in terms of vehicle modifications and maintenance. Because propane is a liquid, and can be stored at relatively low pressure compared to CNG, the fuel tanks are less expensive, and can hold relatively more fuel. Like gasoline and diesel vapors, propane gas is heavier than air, and thus there are fewer to no modifications required for maintenance garages where propane vehicles are serviced. As with natural gas vehicles, the vast majority of maintenance doesn't touch the fuel system, and so servicing a propane vehicle is much like servicing a gasoline vehicle.

A.2.2 Propane Fueling Stations

Propane is distributed via transmission pipelines, railcar, and truck. For end users, propane is almost always delivered by tanker truck, and is stored in liquid form in onsite tanks. In heating applications, propane vapor is removed from the top of the tanks, and is used in gas burners, but for vehicle applications, liquid propane is pumped from the bottom of the tank under pressure into vehicle tanks.

Because propane is stored as a liquid at each site, a large compressor is not required as with a CNG fuel station. Instead, a small electric pump is used to transfer the liquid. Onsite tank storage is usually sized to store approximately 1-2 weeks of usage. Figure 6 shows a general diagram of a propane fueling station, and Figure 7 is a photo of a simple propane fueling station for a fleet, with a single dispenser.

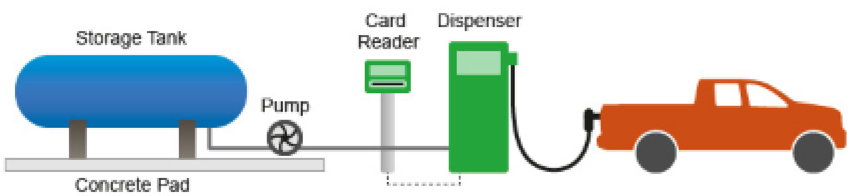

Figure 6 – Propane Fueling Station Diagram

Image credit: U.S. Department of Energy

Figure 7 – Propane Fueling Station at Customer Site

Image Credit: Pennsylvania Department of Environmental Protection

Although propane is stored as a liquid, it becomes a gas at atmospheric pressure, and thus does not pose a threat to land or water contamination should a leak or spill occur during storage or fueling.

A.3 Electricity

A.3.1 Electric Vehicles

Passenger sedans are commonly available as electric vehicles (EVs), but larger vehicles including SUVs, cargo vans, and trucks have only recently become commercially available. The cost of small EVs is competitive with gasoline vehicles, especially with current incentives, but larger EVs are not cost effective, because they require large and expensive battery packs. Currently, there are a couple manufacturers who are marketing all-electric cargo vans with a range of 50-100 miles.

A.3.2 Electric Charging Stations

There are 3 classes of EV charging equipment: Level I, Level II, and DC Fast Charge.

- Level I charging uses a standard 120 V AC receptacle, and can charge a vehicle at a rate of up to 1.9 kW.
- Level II charging operates on 240 V AC, and can charge a vehicle at a rate of up to 19.2 kW, although the majority of Level II chargers provide only 6.6 kW. An example is shown in Figure 8.
- DC Fast Charge operates at rates exceeding 20 kW. In the past, there have been several incompatible versions of this charging type. The Tesla Supercharger is one example of this. However, the current trend is towards standardization of this charging type, because this is the type of charger that is preferred to be implemented alongside major highways all across the country.

Figure 8 – Level II Fleet Charging Stations

Image Credit: U.S. Department of Energy Idaho National Laboratory

The column-mounted units shown in Figure 8 are referred to as Electric Vehicle Service Equipment (EVSE). The EVSE is connected to the AC power supply and provides a charging cable with the proper connector to interface with the vehicle's charging port. The EVSE is able to turn on and off the flow of power to the vehicle, and communicates with the vehicle to ensure that power will only flow when the vehicle is properly connected and in need of charging. If the charging cable is disconnected, or the vehicle experiences an error, the power to the charging cable will be turned off for safety.

In addition to propulsion, EVs use the battery for climate control and auxiliary features, and the use of these will affect the range. Many EVs have the option of warming or cooling the vehicle while it is still connected to the EVSE. This will utilize grid power rather than battery power, and optimizes the use of the batteries.

A.4 Hybrid Technologies

A.4.1 Regenerative Braking

When a vehicle slows down, rather than dissipating that energy as heat in the brake pads and rotors, the energy is captured by an electric motor and battery. This technique is employed by hybrids and pure EVs. In some cases, rather than an electric motor, the system consists of a hydraulic motor coupled to the drive shaft, and a hydraulic accumulator which is able to deliver and receive energy to and from the regenerative drive motor.

Unlike an EV, which must store enough charge in the battery pack to propel the vehicle the entire distance traveled, the accumulators in a hybrid vehicle with regenerative braking only have to store the amount of energy equal to bringing the vehicle from full speed to a dead stop. When the vehicle moves forward again, that energy stored in the accumulator is released in concert with the torque from the engine, and helps to bring the vehicle back up to speed. At that point, the accumulator is empty, and ready to start the cycle again. Therefore, a relatively small battery is required compared to a pure EV.

A hybrid regenerative braking upfit is available for the Ford F Series trucks as an upfit from a Ford QVM. This QVM claims that the system can reduce vehicle fuel usage by up to 20%. The actual performance will vary, and depends on the drive cycle of the vehicles. If a vehicle has many stops and starts, performance will be improved, compared to a vehicle with mostly highway driving.

A.4.2 Gasoline Electric Powertrain

Many hybrid vehicles have a powertrain which is designed to be powered primarily by an electric motor, with the capability to link directly to the engine when necessary. Normally, the engine powers a generator which charges the battery as needed, and the battery is used to power the electric motors which drive the vehicle. This configuration allows the engine to operate in a way that optimizes efficiency, rather than maximizing power output or horsepower. In a conventional vehicle, the engine experiences a wide range of loads and speeds, and this range results in reduced efficiency. A hybrid electric drive system uses the engine at its optimal efficiency point to top off the battery as needed.

A.4.3 Plug In Hybrids

A plug in hybrid has a larger battery pack to allow the vehicle to operate in an extended EV only range. Additionally, a plug in hybrid is able to obtain energy from an electric utility as well as from gasoline, compared to a non plug in hybrid which obtains all of its energy from gasoline. These features result in increased fuel cost savings, and decreased emissions. Examples of plug in hybrids are the Ford Fusion Energi, Toyota Prius Prime, and Chrysler Pacifica Hybrid.