



The Turning Point:

Need to Know Handbook for
Procuring, Fueling and
Maintaining Compressed
Natural Gas Bus Fleets



About this Handbook

This handbook comprises an easy to understand compendium of current, best in class information on deploying CNG buses to transit fleets. The data, assessments and analysis provided in this handbook are drawn from government, industry and transit agency reports, technical studies, surveys, and other archival materials. The handbook also draws on more than 30 interviews conducted with executives, managers, technicians, and other professionals at transit agencies and other government organizations, associations, bus manufacturers, and companies active in the CNG bus market in North America.

The handbook has been commissioned by Trillium CNG™, a leading provider of compressed natural gas (CNG) fueling services as well as a single-source provider of CNG fueling facility design, construction, operation and maintenance. Trillium specializes in fueling transit and other fleets that require the highest-performance CNG fueling and infrastructure solutions.



For over 20 years, Trillium CNG's team of knowledgeable professionals has exceeded customers' expectations by delivering superior quality, reliability and dependability resulting in bottom-line savings. Trillium's consultative approach to problem solving, proprietary equipment and 24/7 maintenance ensures peace-of-mind that every aspect of the CNG infrastructure will be taken care of.

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AFV Intelligence is a strategic advisory firm helping businesses, governments and nonprofit organizations develop, plan and deliver strategic and technological solutions to improve their performance in clean energy, sustainable building, and zero and low emission alternative fueled vehicles and advanced transportation technologies.



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Preface and Summary: Need to Know Information

Transit agencies serving urban, suburban, and rural communities in the United States plan on purchasing more than 10,000 new fixed-route buses over the next three years.¹ Buses represent the biggest capital expense for transit agencies. When choosing a bus propulsion system, transit agencies have a wider choice of transportation energy technology platforms today than ever before: they can choose from buses fueled by diesel, natural gas, hybrid-electric systems, or buses powered solely by electricity stored in batteries.

This handbook has been prepared to provide need-to-know information on buses fueled by compressed natural gas (CNG) – the best practices and costs involved in purchasing, operating and maintaining them, their reliability and on-road performance and emissions, and how CNG buses compare to diesel and hybrid buses on these metrics. The handbook is a concise yet comprehensive “all in one place” compendium of key information and data on CNG bus transportation presented in an easy to understand format.

The handbook provides key information on CNG bus transportation presented in an easy to understand format

The number of buses transit agencies have planned for procurement, the wider choice of bus fuel technology platforms, the low emissions properties of CNG, and an ultra-competitive natural gas price paradigm make it more important than ever for transit managers and those who sit on the governing boards of transit agencies to be informed on rolling stock procurement, operations, and maintenance issues as these pertain to CNG fueled buses.

Key Takeaways

Key takeaways presented in this handbook include:

Key Takaway 1. CNG buses have emerged as the preferred propulsion technology for transit agencies seeking to deploy alternative fueled bus fleets.

Transit providers are increasingly opting for buses powered by alternative fuels instead of the diesel buses that have long dominated transit bus market. To paraphrase more than one transit administrator, when making bus procurement decisions, *it's important to get it right*. For a growing number of transit providers, getting it right means investing in alternative fueled buses that run on CNG.

¹ AFV Intelligence, *2014 Transit Bus Census and Alternative Fuels Digest*, <http://www.afvintelligence.com/>.

Between 2006 and 2012, the percentage of the nation's transit bus fleet fueled by natural gas rose from 15.2 percent to 20 percent. Whereas natural gas fuels 20 percent of the transit buses operating in the U.S. today, 104 of 252 transit properties surveyed, or 41 percent, reported they are considering purchasing CNG buses in their upcoming procurement cycles over the next three years.

Key Takaway 2. Dramatically lower natural gas fuel prices and the lower emissions properties of natural gas present a turning point at which transit agencies can optimize fleet economic and environmental sustainability through CNG bus deployments.

Historically, deployments of natural gas buses were driven primarily by the goal of reducing the tailpipe emissions of regulated pollutants. Natural gas remains a cleaner burning low emissions fuel, but sound financial management is as much a part of a transit agency's mission as sound environmental practice. Today, growing deployment of CNG buses is being driven in many cases by natural gas prices that are dramatically lower than the price of diesel. When measured on a gallon equivalency basis, the average retail price today of purchasing compressed natural gas fuel is about 40 percent less than purchasing diesel. Transit agencies typically purchase fuel at less than retail prices, and energy market projections point to natural gas remaining a significantly less expensive fuel with lower price volatility than diesel for decades to come. By converting their bus fleets to run on CNG, transit agencies can dramatically lower their operating costs and have a much higher level of certainty as to what their longer term operating costs will look like than they can using diesel. The intrinsically beneficial environmental properties of CNG buses coupled with historically low natural gas prices now and in the future present a turning point for transit agencies seeking to modernize their fleets.

While natural gas fuels 20 percent of the transit buses operating in the U.S. today, 104 of 252 transits surveyed, or 41 percent, reported they are considering purchasing CNG buses in their upcoming procurements over the next three years.

Key Takaway 3. CNG bus propulsion is a safe, mature technology with the current generation of CNG buses performing on par with or exceeding the performance of diesel buses.

CNG is a safe transportation fuel. Unlike diesel, which pools on the ground and can lead to groundwater pollution, CNG rises and evaporates when released. The Federal Transit Administration says, "There are no significant environmental hazards associated with the accidental discharge of CNG."²

² U.S. Department of Transportation, Federal Transit Administration, August 1995, *Summary of Assessment of the Safety, Health, Environmental and System Risks of Alternative Fuels*, Report FTA-MA-90-7007-95-1, http://ntl.bts.gov/lib/000/400/422/20021101_alt_fuel.pdf.

The inherent non-toxicity of natural gas, the narrow concentrations in which natural gas must be present in air to ignite, and certified, risk-tested fuel storage cylinders make CNG a fuel no more dangerous and in a number of respects safer than diesel as a transit bus fuel. The six cylinder 8.9 liter ISL G natural gas engine installed in today's heavy-duty CNG buses are outfitted with hardened valves and valve seats that protect against valve recession that was sometimes experienced in older models of CNG engines. Because CNG is primarily composed of methane, the cleanest burning fossil fuel, CNG buses do not require the use of complex and costly selective catalytic reduction (SCR) or a diesel particulate filter (DPF) after treatment systems that need to be installed in diesel buses. Many transit maintenance directors say that they expect the long-term cost of maintaining CNG bus propulsion systems to be lower than those for new diesel buses and the service reliability of the propulsion systems of current generation CNG buses to increase in comparison to diesel bus reliability.

Key Takaway 4. Due to the significant price spread advantage of using CNG as a bus fuel instead of diesel, transit fleet CNG conversions typically produce rapid payback with fuel savings that increase as the number of buses deployed increases

Transit agencies deploying CNG buses incur incremental costs for bus procurement and fueling and maintenance infrastructure that exceed the cost of deploying diesel buses. However, the significant price spread advantage of using CNG as a fuel instead of diesel typically produces rapid payback and long-term fuel cost savings to the transit agency. The initial purchase price of a 40-foot current generation CNG bus is about \$40,000 more than the price of a similarly configured diesel bus. The incremental cost of installation of CNG bus fueling and maintenance infrastructure declines as the number of buses to be fueled and maintained increases, and can range between \$25,000 and \$50,000 per bus for a fleet of 100 CNG buses. But because of the low cost of CNG, deploying a fleet of CNG buses instead of diesel buses can produce payback periods of between two and six years for buses that operate for a typical 12-year service life. The return on investment from deploying CNG buses improves as the number of buses deployed, the mileage the buses operate, and the amount of CNG fuel a bus fleet consumes increases.

Deploying a fleet of CNG buses instead of diesel buses can produce payback periods of between two and six years for buses that operate for a typical 12-year service life.

Key Takaway 5. Keys to planning the deployment of CNG buses include compressor type and sizing, local gas utility pipeline capacity, infrastructure redundancy and ensuring adequate onboard bus fuel storage

Most transit fleets that operate CNG buses fuel their buses using fast-fill fueling systems installed at their bus operations centers. These systems use compressors to mechanically pressurize and compress natural gas from a local utility gas pipeline, allowing CNG buses to be fueled in a comparable amount of time to diesel buses. Properly sizing compressors, using advanced technologies such as hydraulic intensifiers, having a firm understanding of local gas utility pipeline capacity and gas delivery pressures, building in redundancy in compressor capacity and back-up electrical supply for CNG fueling infrastructure and ensuring that the cylinders used to store CNG on board buses are adequate in the event that bus duty-cycle changes are keys to properly planning conversion of a bus fleet to CNG buses.

Key Takaway 6. Best practices in CNG bus fueling and maintenance infrastructure

Because gas rises, fully enclosed buildings in which CNG buses are maintained need to be outfitted with several potential hazard prevention measures that differ from the measures required for facilities where diesel buses are maintained. Improvements needed for buildings where CNG buses are maintained indoors typically include upgrades to heating, electrical, and ventilation systems and installation of gas detection devices. Modifications to interior building walls and garage doors might also be called for. In newly constructed facilities, these improvements can be incorporated into a building's initial design and construction with minimal cost impact. Existing facilities not originally designed to accommodate CNG bus maintenance and fueling can be retrofitted with the needed improvements. The improvements needed to maintain CNG buses can be installed by segregating portions of a facility, allowing retrofits to be made without interrupting ongoing bus maintenance operations.

Most transit agencies choose to procure CNG fueling stations with a specialized DBOM firm experienced in all aspects of delivering turnkey CNG infrastructure solutions.

Key Takaway 7. Turnkey contracting for CNG bus fueling and maintenance infrastructure can enhance the return on investment from a transit fleet CNG bus conversion

CNG bus fueling and maintenance facilities involve working with high-pressure natural gas systems and are more complex than the facilities needed to fuel and maintain diesel buses. Some transit agencies elect to manage in-house all or some aspects of designing, building, operating and maintaining (DBOM) the infrastructure needed for a fleet of CNG buses. Most transit agencies choose to procure CNG fueling stations with a specialized DBOM firm experienced in all aspects of delivering turnkey CNG infrastructure solutions. Turnkey contracting can provide transit

agencies better performance at lower costs and can also allow the cost of CNG infrastructure to be amortized over time through fueling contracts, enabling an agency to avoid the need to spend capital dollars or issue debt to build CNG infrastructure. There are only a limited number of firms that are qualified to operate and maintain CNG bus fueling and maintenance infrastructure. It is advisable to contract with a firm that has at least several years of qualified and demonstrable experience with well sorted, designed and constructed CNG bus fleet fueling and maintenance infrastructure. Doing so can guarantee that the agency benefits from infrastructure that lasts many years without fail and particularly with regard to infrastructure operations and maintenance, that the contractor is responsible for the infrastructure performance and alleviates the transit agency of this responsibility.

Key Takaway 8. Best value procurement practices can produce better CNG bus fueling and maintenance infrastructure solutions than low cost, technically acceptable solicitation protocols

It is common practice for transit agencies to use a “Best Value” approach to soliciting proposals when contracting for turnkey DBOM services as opposed to “Low Cost, Technically Acceptable” contracting solicitations. The flexibility provided through the use of best value contracting allows experienced companies to suggest options for trade-offs in technology and equipment to meet performance requirements, to provide more effective management plans and well trained and qualified technicians to oversee the facility, and options for accommodating future fleet growth and evolution in fueling technology used to fuel and maintain CNG bus fleets.

Best value procurement solicitations enhance transit CNG fueling and maintenance infrastructure delivery and value.

Key Takaway 9. The benefits of using low priced, low emission CNG as a fuel extend beyond heavy-duty transit buses

The primary focus of this handbook is on heavy-duty CNG buses. This class of bus is most likely to be of interest to transit managers and their governing boards; almost 80 percent of the buses and vans in U.S. transit fleets are heavy-duty buses 35-foot or longer. But the information presented in this handbook is also pertinent to transit agencies that operate smaller buses and paratransit and on-demand service vehicles, as the fundamental principles that underlie the sustainable fiscal and environmental advantages of using CNG as a fuel for heavy-duty buses are mirrored when using CNG as a fuel for paratransit and on-demand vehicles.

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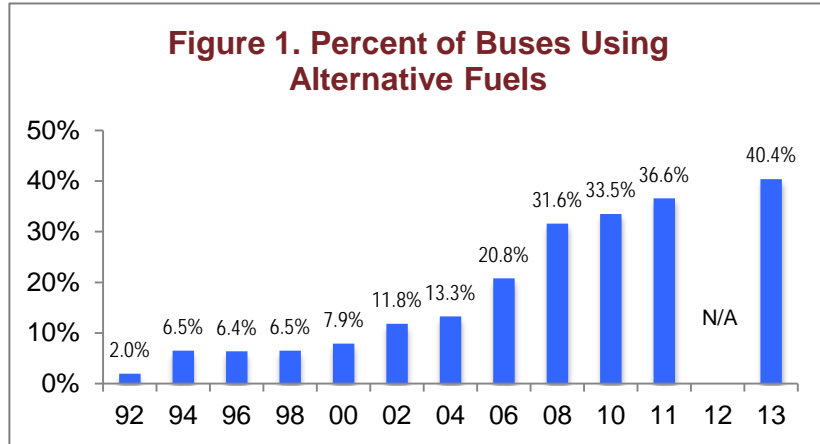
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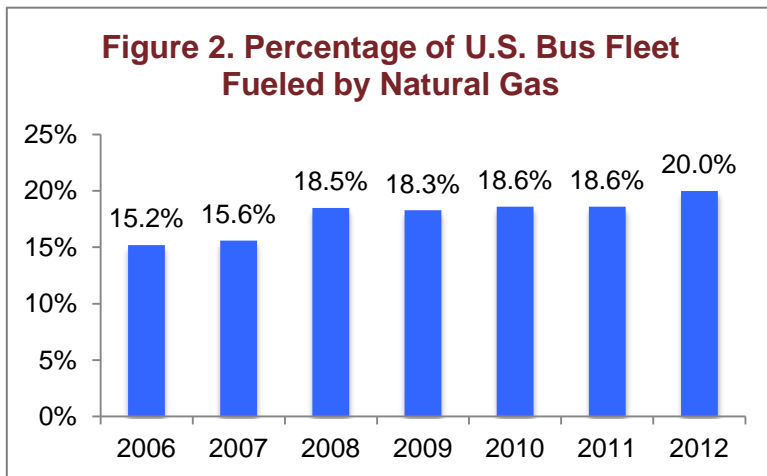
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1. A Turning Point in Bus Propulsion Technology

Rolling stock fueled by diesel has long dominated the transit bus market and continues to be the predominant fuel used. Sixty percent of buses operated by transit providers in 2013 were diesel fueled. But transit providers are increasingly opting for buses powered by alternative fuels.



Forty percent of the buses operating in the U.S. today are alt-fueled (Figure 1)³, and half of these alt-fueled buses run on natural gas, with most of the remainder being hybrid-electric buses or buses fueled by bio-diesel. The percentage of the U.S. transit bus fleet that is alternative fueled is double what it was only eight years ago, and more than five times what it was in 2000. Bus manufacturers and transit managers expect deployments of alt-fueled buses to continue to increase, and for the share of the nation's bus fleet accounted for by alt-fueled buses to continue to grow.



Bus procurement decisions are highly consequential for transit agencies, their boards of directors, and the public. Fuel typically consumes between 15 and 25 percent of the operating budget of a bus

system, when wages and benefit costs are removed; the figure was 20.7 percent in 2013 for directly operated buses.⁴ Large heavy-duty buses must have a minimum 12-

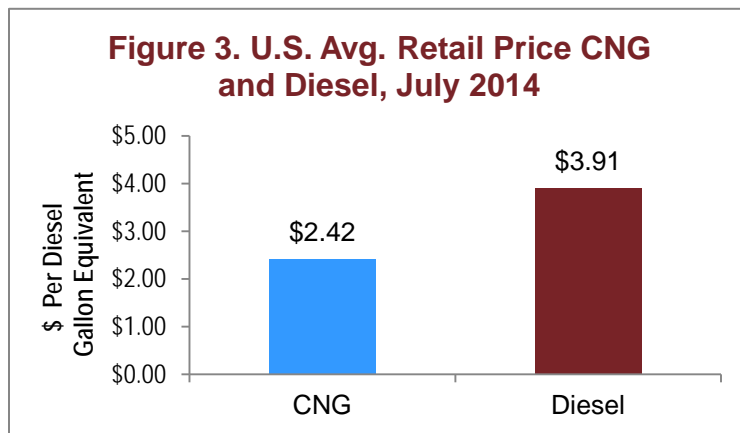
³ Source Figure 1: American Public Transportation Association, *2014 Public Transportation Fact Book*, <http://www.apta.com/resources/statistics/Documents/FactBook/2014-APTA-Fact-Book-Appendix-A.pdf>.

⁴ Federal Transit Administration, *National Transit Data Base*, <http://www.ntdprogram.gov/ntdprogram/data.htm>.

year service life or run at least 500,000 miles before they are eligible to be replaced with funding from the Federal Transit Administration.⁵ High mileage means that fuel procurement decisions have considerable local and regional – and in a time of climate change – global emissions implications.⁶ Bus purchasing decisions made today determine a transit agency’s cost structure and environmental footprint for years. For a growing number of transit providers, getting a sustainable future right means investing in buses fueled by compressed natural gas (CNG).

Why CNG Bus Deployments by Transit Agencies are Growing

Between 2006 and 2012, the percentage of the nation’s transit bus fleet accounted for by buses fueled by natural gas rose from 15.2 percent to 20 percent (Figure 2).⁷ The year 2008 is particularly notable in helping to explain growth in deployments of buses fueled by natural gas, as



that year saw a historic divergence in the price of diesel and natural gas fuels. The dramatic change was a result of the large-scale production of natural gas from unconventional sources in the United States.⁸ As a result, when measured on a diesel gallon equivalency basis, the average retail price today of purchasing CNG transportation fuel is about 40 percent less than the retail price of purchasing diesel (Figure 3), and most transit agencies pay far less than the retail price.⁹ With the U.S.

⁵ Federal Transit Administration, *Useful Life of Transit Buses and Vans, April 2007* (Report No. FTA VA-26-7229-07.1), http://www.fta.dot.gov/documents/Useful_Life_of_Buses_Final_Report_4-26-07_rv1.pdf

⁶ See Federal Transit Administration, *Transit Greenhouse Gas Emission Management Compendium*, Jan.2011, p. 9, Washington D.C., <http://www.fta.dot.gov/documents/GHGCompendGTv2.pdf>

⁷ American Public Transportation Association, *2014 Public Transportation Fact Book*, <http://www.apta.com/resources/statistics/Documents/FactBook/2014-APTA-Fact-Book-Appendix-A.pdf>.

⁸ Conventional natural gas is typically “free gas” trapped in multiple, relatively small, porous zones in naturally occurring rock formations. With technological breakthroughs, most of the growth in North America’s natural gas supply is recovered from unconventional reservoirs, including shale gas. Chemically, gas from both sources is identical, and comprised of mostly methane (CH₄).

⁹ U.S. Department of Energy, *Clean Cities Alternative Fuels Price Report, July, 2014*, http://www.afdc.energy.gov/uploads/publication/alternative_fuel_price_report_july_2014.pdf.

having at least a 100-year domestic supply of natural gas, U.S. Energy Information Administration projections point to natural gas remaining a significantly less expensive fuel with lower price volatility than diesel for decades to come.

Ten years ago, deployments of natural gas buses were driven primarily by the goal of reducing tailpipe emissions of regulated pollutants. Natural gas remains a cleaner burning low emissions fuel. But sound financial management is as much a part of a transit agency's mission as sound environmental practice. With fuel accounting for a large share of a bus system's operating expense, sustained low natural gas prices and muted price volatility in future projections have created a compelling and renewed impetus for the deployment of CNG buses.

Turning Point

CNG is an optimal fuel solution for transit agencies seeking to deploy bus fleets that are both environmentally and fiscally sustainable. The clearest evidence can be seen in deployments by large, mid-size, and smaller transit agencies (Table 1). A recent survey of North American transit agencies provides additional evidence of rising CNG bus deployments. Whereas natural gas fuels 20 percent of the transit buses operating in the U.S. today, 104 of 252 transit properties surveyed, or 41 percent, reported they are considering purchasing CNG buses in their upcoming procurement cycles over the next three years.¹⁰

The intrinsically beneficial environmental properties of CNG buses coupled with historically low natural gas prices now and in the future present a turning point for transit agencies seeking to modernize their fleets. Transit leaders pursuing a transportation future that maximizes both economic and environmental sustainability can consider the information presented in this handbook on the benefits to be accrued by deploying CNG buses as they assess their best path forward.

The clearest evidence of the renewed impetus for CNG as a bus fuel is found across North America in deployments by large, mid-size, and smaller transit agencies. Table 1 summarizes recent and announced CNG bus rollouts

Because transit agencies do not pay fuel taxes, for example, most transit agencies pay less for their fuel than national average retail prices. However this does not change the underlying nature of the price spread advantage offered by purchasing CNG compared to diesel fuel.

¹⁰ AFV Intelligence, *2014 Transit Bus Census and Alternative Fuels Digest*, <http://www.afvintelligence.com/>.

Table 1. Recent and Announced Deployments of CNG Buses¹¹	
Transit Agency	Deployment
Birmingham-Jeff. County Transit	Deployed 30 x 40' CNG buses with option for 20 more
CamTran (Penn)	Plans to convert most of 66 bus fleet to CNG with first CNG bus deployed in 2015
Central Arkansas Transit	Ordered 15 CNG buses in first ever deployment of CNG buses
Central Ohio Transit (COTA)	Deploying 72 x 29', 35' and 40' CNG buses this year
City of Phoenix (Valley Transit)	Ordered 120 x 40' CNG buses as agency converts 360 LNG bus fleet to CNG buses
DART (Dallas Area Rapid Transit)	Completing conversion of entire fleet of 580 buses to CNG from diesel by 2015
Foothill Transit	Exercised option for 30 x 40' CNG buses; Entire fleet is alternative fueled with more than 290 CNG buses
GCRTA (Cleveland)	Executed order for up to 240 40' CNG buses in 2014; Returning to CNG buses as diesel buses retired
GRTC (Richmond)	In process of deploying first 39 CNG buses; Plan to convert entire 155 bus fleet to CNG
HART (Tampa Metro)	Converting entire 194 bus fleet to CNG with first deliveries in 2014
Houston Metro	Option for 180 x 40' CNG buses for 2015 and 2016 as part of a 265-bus order
Jacksonville Transit (JATA)	Plans underway to purchase 100 CNG buses
Kansas City Transit (KCATA)	Recently deployed first 25 CNG buses as part of plan to convert entire 260 bus fleet to CNG
Los Angeles Metro	Entire 2,300 bus fleet CNG; Ordered 550 40' CNG buses for 2015 delivery; Option for up to 350 more
MARTA (Atlanta)	Ordered 88 x 30' and 40' CNG buses with option for up to 177 40' CNG or hybrids
Miami-Dade Transit	Issued RFP for full conversion of 817 bus fleet to CNG over 10 years; First CNG bus deployment
MTA of New York	Ordered 29 x 40' CNG buses. Operates fleet of 730 CNG buses
New Jersey Transit	Ordered 147 CNG Cruiser commuter buses over past year; Will have 159 deployed in 2015
Orange County Transit	Ordered 20 CNG buses; Operates 546 CNG buses, 90+ percent of fleet CNG
Roaring Fork TA (Aspen, CO)	Deployed 22 CNG buses in 2013; First CNG bus deployment
San Diego Metro Transit System	Ordered 250 x 40' and 85 x 60' Artic CNG buses; Options for up to 180 more through 2017
San Diego MTS	Ordered 335 x 40' and 60' Artic CNG buses with options for 180 more through 2017

¹¹ Source: AFV Intelligence, *2014 Transit Bus Census and Alternative Fuels Digest*, <http://www.afvintelligence.com/>. Data as self-reported by transit agencies.

Southern Nevada RTA (Las Vegas)	Converting entire 343 route and 59 BRT bus fleet to CNG by 2022 with 25 CNG buses delivered per year
StarTran (Lincoln, NE)	First CNG deployment with 5 CNG buses and 11 CNG handi-vans in 2014; 8 more CNG buses next year
Sun Metro (El Paso)	Executed contract in 2013 for up to 180 CNG buses; Entire fleet is CNG
TriMet (Portland, OR)	Option to purchase 120 x 30' and 40' CNG buses in 2016-2017
Utah Transit Authority	Deployed 24 CNG buses in 2013; Plans full 200 bus fleet conversion to CNG within 5 years
WMATA (Wash. D.C. Metro)	Option for up to 164 x 42' CNG buses for 2016-2017; Operates 460 CNG buses

Top 40 Transit Operators of CNG Buses in U.S.

Transit Agency	# CNG Buses	Transit Agency	# CNG Buses
Los Angeles Metro	2300	Blue Water Area Transit (Michigan)	79
MTA of New York	730	FAX - Fresno Area Express	77
Orange County TA	546	NJ Transit	76
DART – Dallas Area Rapid Transit	493	SunLine (Riverside)	66
WMATA (Washington D.C. Metro Area)	459	Long Beach Transit	64
San Diego MTS	450	Birmingham Jefferson CTA	59
MARTA (Atlanta)	369	City of Santa Clarita	56
Nassau Inter-County Express	315	Gold Coast Transit (Oxnard, Ventura)	54
Foothill Transit (Cal)	311	METRO Regional Transit Authority	52
Sacramento Regional Transit	220	Arlington Transit (Virginia)	46
City of Santa Monica - Big Blue Bus	187	SunTran (Tucson)	45
Omnitrans (San Bernardino)	163	Victor Valley Transit Authority	44
Sun Metro (El Paso)	156	Unitrans (UC Davis)	43
Fort Worth Transportation Authority	139	Valley Regional Transit (Boise)	41
North County Transit District (San Diego County)	120	Santa Fe Trails	37
Central New York RTA (Syracuse)	102	Stark Area RTA (Canton OH)	35
RTC of Southern Nevada (Las Vegas)	90	Salem-Keizer Transit (Oregon)	34
Golden Empire Transit District (Bakersfield)	88	Visalia Transit	33
Ride On (Montgomery County MD)	87	Central Ohio Transit Authority (Columbus, OH)	30
Santa Cruz MTD	80	Utah Transit Authority	30

2. Economic and Environmental Properties of CNG Buses

CNG buses are fueled by the same natural gas that is used to heat homes and businesses, a gas composed principally of methane (Table 2). Natural gas is a clear, odorless, and tasteless fuel.¹² The distinct scent noticed when in the presence of natural gas is due to an odorant injected into the gas to make it detectible. Processing of raw natural gas removes impurities resulting in the CNG that is injected into the bus engine being comprised of 97 percent methane.

Composition	≈ 97% methane = CH ₄
State	Colorless, odorless, tasteless gas compressed and stored under pressure. An odorant is added for detection
Energy Density	20,160.551 Btu/lb. at lower heating value ¹³
Diesel Gallon Equivalent (DGE)	1 DGE = 128,700 Btu = 6.38 lbs. (140 cu. ft.) of CNG ¹
Ignition Temp.	842° – 1,004° F

Large Supply, Low Price and Low Price Volatility Make CNG the Fuel of Choice

Natural gas prices today are significantly lower than diesel prices and projected to remain so for the foreseeable future. At a time when many transit agencies are facing fiscal pressures, CNG bus deployments are enabling transit agencies to reduce the amount of money they need to spend on bus fuel, and these cost savings are a key driver behind growing deployments of CNG buses.¹⁴

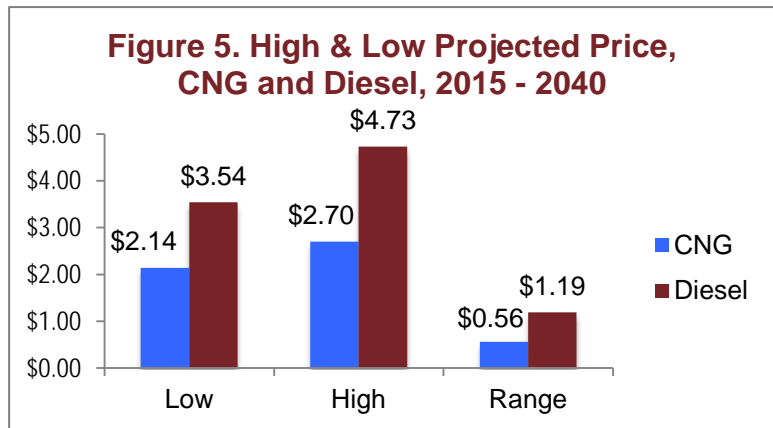
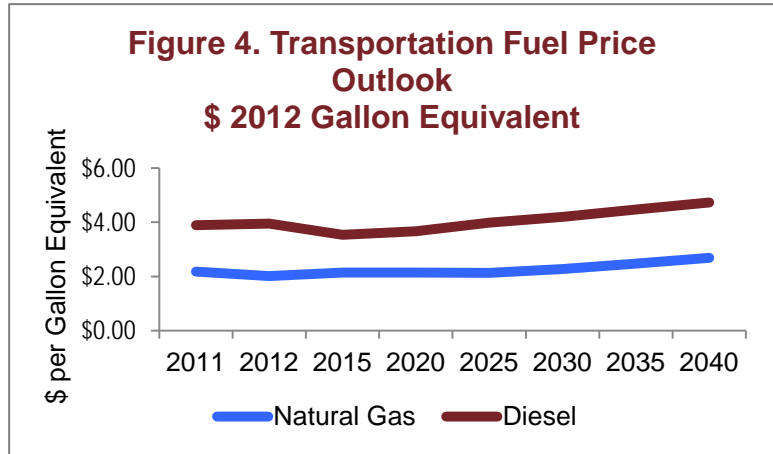
¹² When dispensed as a transportation fuel after raw gas has been processed, CNG is about 97 percent methane. Other major constituents of natural gas are Ethane (C₂H₆: 0-20%) and Propane (C₃H₈: 1.7%) with trace elements not exceeding 4.3 percent of the gas composition of Butane (C₄H₁₀), Hexane (C₆H₁₄), Carbon Dioxide (CO₂), Oxygen (O₂), Nitrogen (N₂), Hydrogen (H₂), and Carbon Monoxide (CO).

¹³ Heating value is the energy released per unit mass or per unit volume of fuel when the fuel is burned. Lower heating value refers to the condition in which water in the final combustion products remains as vapor; the steam is not condensed into liquid water and thus the latent heat is not accounted for. Higher heating value accounts for all of the energy generated during the combustion process, including waste energy.

¹⁴ In addition to its low cost and low emissions benefits, using CNG as a transportation fuel reduces U.S. dependence on imported oil from unstable regions of the world while bolstering U.S. economic competitiveness. In 2010, the cost to the U.S. economy of dependence on imported oil totaled about \$300 billion measured in 2008 dollars. See Oak Ridge National Laboratory Memorandum, 2011, *OPEC and the Costs to the U.S. Economy of Oil Dependence: 1970-2010*,.

Revolutions in horizontal drilling technologies now allow recovery of previously inaccessible deposits of natural gas found in tight rock formations in the United States. With these technologies, it is now estimated that the U.S. possesses 3,000 trillion cubic feet (Tcf) of recoverable natural gas reserves with current technology. This is enough domestically supplied natural gas to last at least 100 years.

Increased domestic natural gas resources have lowered natural gas prices to a range where the price of CNG is significantly lower than the price of diesel, measured on a gallon equivalent basis.¹⁵ The U.S. energy Information Administration (EIA) projects that natural gas prices will remain significantly lower than diesel prices for decades (Figure 4).¹⁶



Unlike in the past, when natural gas markets often experienced periods of high price volatility, abundant U.S. natural gas reserves will ensure that natural gas supplies can easily respond to changes in demand. Natural gas prices are projected to be significantly less volatile than diesel prices in coming years (Figure 5). Predictable pricing allows transit agencies using CNG as a fuel to more accurately anticipate and plan for what their fleet fuel costs will look like over the longer term. This is in contrast to diesel, which

¹⁵ See Figure 3 regarding the low price of CNG when purchased as a transportation fuel. Compression of natural gas into CNG allows natural gas to be stored on board buses in quantities that provide a comparable driving range to that afforded by diesel. Converting CNG to diesel gallon equivalents (DGE) allows for CNG to be measured on an energy equivalency basis with diesel when used for transportation fueling. One DGE of CNG is equal to 128,700 Btu.

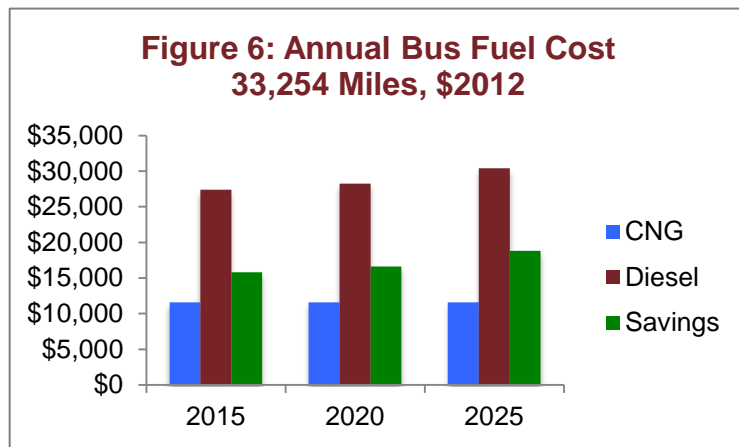
¹⁶ Source Figure 4: *Energy Prices by Sector and Source*, U.S. Energy Information Administration, 2014, <http://www.eia.gov/oiaf/aeo/tablebrowser/?release=AEO2014&subject=0-AEO2014&table=3-AEO2014®ion=1-0&cases=lowmacro-d112913a,highmacro-d112913a,ref2014-d102413a>. Figure 4 prices reflect the EIA's reference case and higher heating values of natural gas and diesel, and a 7.298 gallon equivalent conversion factor per 1 million Btu.

is subject to much greater price volatility than natural gas due to so much of the world’s petroleum being supplied from unstable regions of the globe.

Fuel Cost Savings of CNG Buses

The approximately 69,000 transit buses operating in the U.S. in 2012 ran a cumulative 2.045 billion miles, averaging 33,254 revenue miles per bus.¹⁷ High mileage makes transit bus economies highly sensitive to fuel prices, making low cost CNG an attractive fuel option. Buses return to their operations centers at the end of their daily runs to fuel. The “return to base” aspect of bus operations facilitates fueling fleets with CNG at centrally located operations centers.

Forward-looking scenarios allow for calculation of the prospective fuel savings to be obtained from operating CNG buses in lieu of diesel buses (Figure 6). Measured in constant 2012 dollars and using fuel pricing escalation projections, operating a bus running the 2012 U.S. transit bus fleet average of 33,254 miles on CNG instead of diesel would produce an annual fuel savings of \$15,818 in 2015, rising to \$18,834 in 2025.¹⁸ CNG fuel cost is expected to grow at less than the rate of consumer inflation. For a single bus entering service in 2015, over a 12-year operating period, fuel savings resulting from running the bus on CNG instead of diesel would exceed \$206,000 measured in 2012 dollars.



Agencies that go “all in” – that convert the most rolling stock possible to CNG – will recognize the greatest savings from using CNG as a fuel.

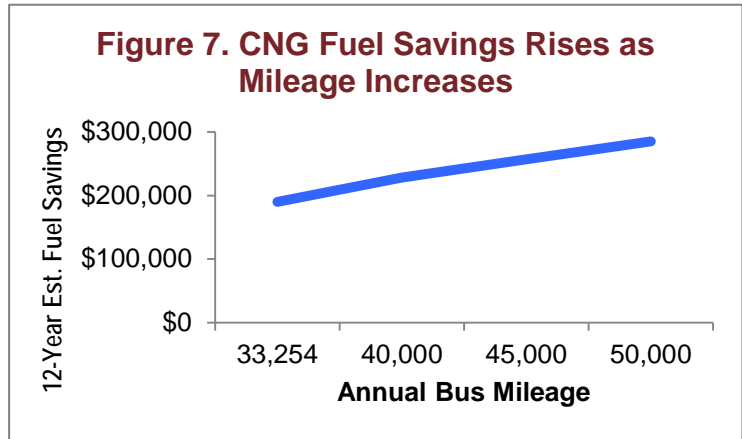
It is critically important to understand that fuel savings derived from using CNG as a fuel improve as the number of CNG buses a transit agency deploys increases, the number of miles the buses run increases, and the volume of fuel

¹⁷ Oak Ridge National Laboratory, for the Vehicle Technologies Office, Office of Energy Efficiency and Renewable Energy, U.S. Department of Energy, July 2013, *Transportation Energy Data Book Edition 32*, http://cta.ornl.gov/data/tedb32/Edition32_Full_Doc.pdf.

¹⁸ Figure 6 assumes composite fuel economy of 3.47 MPDGE for CNG buses and composite 4.1 for diesel buses using 2012 CNG and diesel fuel prices. See Table 4.

consumed by the buses increases (Figure 7).¹⁹ Transit agencies that convert their entire rolling stock to CNG will recognize the greatest savings from using CNG as a fuel.

Fuel price of fuel is not the only cost to take into account when comparing different bus propulsion technologies. Rolling stock unit purchase price and maintenance and the infrastructure costs are also critical variables. Section 5 of this handbook provides a formula that can be used to calculate comparative CNG bus deployment costs, taking into account fuel prices as well as bus purchasing and maintenance costs, which are discussed in greater detail in the following sections of this handbook.



Fuel Economy of CNG Buses

When used as a transportation fuel, natural gas is compressed into CNG and stored on board buses in cylinders (see next section of handbook). The amount of energy stored in one diesel gallon equivalent of CNG is equal to the amount of energy stored in one liquid gallon of diesel (Table 2). Measuring CNG in DGE’s allows for the ease in comparing the pricing and fuel economy of CNG and diesel fuels in terms of energy equivalency.

Altoona Test Equivalency			
	Manhattan	Orange County	Composite
CNG	2.8	4.13	3.47
Diesel	3.53	4.67	4.1
Hybrid	4.83	6.28	5.6

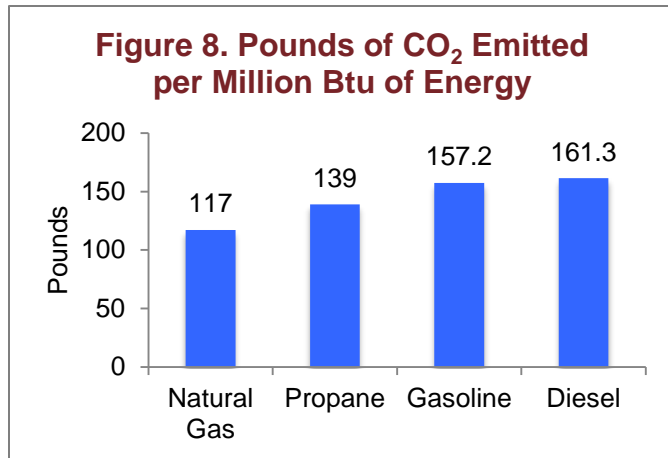
Engines fueled by CNG are spark ignited, and spark ignition engines generally produce a lower fuel economy than diesel engines (Table 3).²⁰ Despite CNG buses having a lower fuel economy than diesel, the lower price of CNG compared to diesel more than offsets that, to produce net savings.²¹

¹⁹ Figure 7 assumes composite fuel economy of 3.47 MPDGE for CNG buses and composite 4.1 for diesel buses using 2012 CNG and diesel fuel prices. See Table 4.

²⁰ Hybrid buses have a higher fuel economy than both CNG and diesel buses. However, hybrid buses also have a significantly higher upfront rolling stock purchase price than both CNG and diesel buses,

Clean Air Benefits of CNG as a Transportation Fuel

Reducing greenhouse gas emissions is a key concern of transit agencies, and the concern is well founded. Carbon dioxide makes up 95 percent of all transportation-related greenhouse gas emissions. As the FTA has noted, "Switching to riding public transportation is one of the most effective actions individuals can take to reduce their carbon footprint."²²



The principle component of CNG, methane is the cleanest burning fossil fuel. As measured on an energy per unit basis, the burning of methane produces about 72 percent of the amount of carbon dioxide (CO₂) produced by burning diesel, as well as low emissions of other pollutants and no diesel particulate emissions (Figure 8).

Table 4. Greenhouse Gas Emissions EPA Testing 8.9 Liter Engines Grams per Brake Horsepower-Hour (g/bhp-hr)				
Engine	GHG	GHG Reduction CNG	CO ₂	CO ₂ Reduction CNG
CNG 8.9 L	4.75	12.5%	408.05	17.9%
Diesel 8.9 L	5.43		497	

Federal regulations tightened permissible levels of engine exhaust emissions for diesel bus engines manufactured after 2010 ("new diesel"). Emissions testing results of 2010-compliant CNG and diesel engines used in transit buses highlight the lower emitting greenhouse gas benefits of bus engines that combust CNG (Table 4).²³ The data shows CNG bus engines emit 17.9 percent less CO₂ than a comparable diesel engine and 12.5 percent fewer greenhouse gases including CO₂, nitrous oxides (N₂O) and methane.

which diminishes the higher fuel economy benefits of hybrid buses when viewed over the full lifecycle cost of the bus. See section 5 of the handbook for more detailed discussion.

²¹ The different fuel economies of CNG and diesel buses are accounted for in Figures 6 and 7.

²² Federal Transit Administration, *Public Transportation's Role in Responding to Climate Change*, <http://www.fta.dot.gov/documents/PublicTransportationsRoleInRespondingToClimateChange.pdf>.

²³ Source Table 6: U.S. Environmental Protection Agency, *Engine Certification Data, On Highway Heavy Duty – Diesel and Gasoline*, <http://epa.gov/otaq/certdata.htm> - oh. NM=Not measured.

The 2010 emission regulations have required that diesel buses be equipped with after-treatment emission systems utilizing selective catalytic reduction (SCR) and diesel particulate filter (DPF) systems. With SCR and DPF systems installed – and because CNG buses have a lower fuel economy than diesel buses and therefore consume more fuel per mile than diesel buses – in road testing, tailpipe exhaust emissions of CO₂, NO_x and unburned hydrocarbons (NMHC) from new diesel engines are roughly on par with emissions from CNG engines (Table 5)²⁴ and hybrid propulsion systems when measured on a mileage equivalency basis. However SCR and DPF after-treatment systems have increased the complexity and cost of maintaining new diesel engines.

Table 5. Measured Emissions: CNG, Diesel and Hybrid Bus Road Testing ²⁴ (Grams per Mile)				
	NO _x	PM	NHMC	CO ₂
Manhattan Cycle				
CNG	.58	NM	.025	2,826
Diesel	1.675	.0065	.0225	2,856
Hybrid	1.755	.003	.01	2,162
Orange County Cycle				
CNG	.28	NM	.025	1,682
Diesel	.955	.011	.0225	2,017
Hybrid	1.5	.0045	.0055	1,632

Transit maintenance directors say they expect more rigorous emissions regulations to be enacted in the future. New regulations could require more complex and costly emissions after treatment control technologies on diesel engines. The U.S. Department of Energy says that while the federal government now requires “all fuels and vehicle types to meet the same thresholds for tailpipe emissions of air pollutants,” vehicles fueled by natural gas “continue to provide emissions benefits – especially when replacing older conventional vehicles or when considering life cycle emissions.”²⁵

Vehicles fueled by natural gas “continue to provide emissions benefits – especially when replacing older conventional vehicles or when considering life cycle emissions.”

– U.S. Department of Energy

²⁴ Source for Table 7: Altoona Bus Research and Testing Center, Thomas D. Larson Pennsylvania Transportation Institute. The figures presented in the table are averaged for 2010-2012 model year 40-41 foot CNG, diesel, and hybrid buses. Altoona report numbers are PTI-BT-R1205, PTI-BT-R1211, PTI-BT-R1015, PTI-BT-R1117, PTI-BT-R1202-P, and PTI-BT-R1007. Emissions testing results for CNG and diesel buses differ from results for heavy-duty trucks due to difference in duty-cycle (slower driving speeds, more idling time for buses) and differences in propulsion technologies (e.g. transmissions).

²⁵ U.S. Department of Energy Alternative Fuels Data Center, http://www.afdc.energy.gov/vehicles/natural_gas_emissions.html.

3. CNG Bus Propulsion, Reliability, Maintenance and Safety

The heavy duty CNG buses sold in the U.S. transit market today are assembled by one of three companies: Winnipeg, Manitoba-based New Flyer Industries Inc., Hayward, California-headquartered Gillig LLC, and NABI Bus LLC (formerly North American Bus Industries), headquartered in Anniston, Alabama.²⁶ These companies also assemble diesel buses and hybrid buses.²⁷ Bus bodies and interiors are the same regardless of whether a bus is powered by CNG, diesel, or uses hybrid propulsion technology. It is the propulsion system that distinguishes the bus – whether fueled by CNG, diesel, or a hybrid diesel-electric system.

CNG Engine Mechanics, Performance and Maintenance

Regardless of which company assembles the bus body, all heavy-duty CNG buses available for sale in the U.S. market use engines manufactured by Indianapolis-based Cummins Inc. Cummins manufactures the ISL G 8.9 liter CNG engine, developed by Cummins through a joint venture with Chilliwack, British Columbia-based Westport (Figure 9).²⁸

The six-cylinder 8.9 liter ISL G natural gas engine is a mature technology, derived from the Cummins 8.9 liter ISL diesel bus engine, first introduced in 1998. The ISL G CNG version of the engine uses the same engine block as the diesel model and shares nearly 80 percent of the same parts with the diesel version.²⁹ The engines share the same block, crankshaft, rods, and bearings. They differ

Figure 9. Cummins Westport ISL G 8.9 Liter Engine



²⁶ New Flyer Industries purchased NABI Bus in 2013. NABI continues to manufacture and market buses under the NABI brand, although it is uncertain if those options will continue to be available. The CNG bus offerings from these companies can be viewed under the products tab at New Flyer, <http://www.newflyer.com/>; Gillig, <http://www.gillig.com/>, and NABI, <http://www.nabusind.com/>.

²⁷ Buses with hybrid CNG-electric propulsion have also been deployed by at least two transit agencies: Arlington Transit, which serves Arlington County, Virginia, and the San Diego Metropolitan Transit System. Hybrid CNG-electric buses are a very small part of the market and lack significant performance data, so they are not discussed in detail in this report.

²⁸ Detroit Diesel, a wholly owned subsidiary of Daimler Trucks North America LLC produced CNG engines for buses through 2009, when the company exited this market segment, leaving Cummins as the only North American manufacturer of CNG engines for heavy-duty buses.

²⁹ As with their diesel counterparts, CNG engines are rated by horsepower. ISL G 8.9 liter engines are installed in buses in two horsepower ratings – 280 horsepower engines, installed in buses 29 to

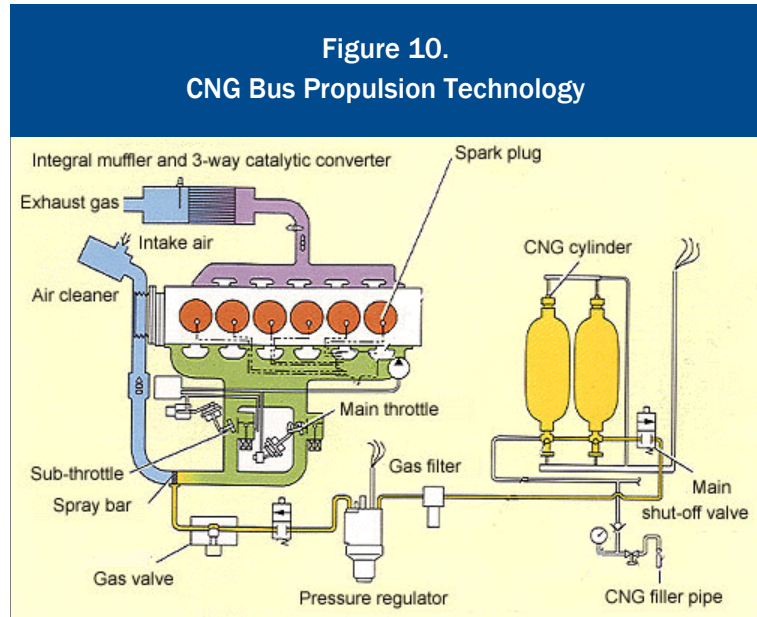
primarily in that CNG engines lack fuel injectors and unlike diesel engines, CNG engines incorporate spark plugs. CNG buses have their fuel stored in high strength compressed gas cylinders, as opposed to the liquid fuel storage tanks installed on diesel buses.

Although CNG engines use the same engine blocks as diesel engines, they are more technically similar to gasoline engines in that CNG engines use spark-ignition as opposed to compression ignition. CNG is released from the gas storage cylinders and flows through tubing to the engine where the gas is combusted (Figure 10). In contrast to diesel engines that require fuel injectors to spray fuel into the engine cylinders, in a CNG engine, a fuel regulator and fuel control valve control the flow of natural gas into the engine, with the fuel regulator reducing the pressure at which the gas enters the engine to about 150 psi from the 3,600 psi cylinder storage pressure.

The ISL G CNG engines are stoichiometric and use cooled exhaust gas circulation with a three-way catalyst (TWC), making CNG buses on the market today the cleanest burning CNG bus engines ever to be operated in North America.³⁰

CNG Fuel Storage Cylinders

In the heavy-duty low floor model buses that are the norm in today's North American bus market, CNG is stored on-board in heavy-duty cylinders mounted on top of the roof



45 feet in length; and 330 horsepower engines, installed in 60-foot articulated buses. Manufacturer specifications require that ISL G bus engines be fueled with CNG with a minimum methane number of 75. Methane number is a standardized measure of natural gas's ability to resist auto-ignition, detonation or knock. It is analogous to octane number as used for gasoline. ISL G engines operate at a lower compression ratio than diesel engines: 12:1 for an ISL G engine compared to a 16.6:1 for the Cummins ISL9 diesel engine the ISL G is based upon.

³⁰ Stoichiometric combustion utilizes a one to one oxygen/fuel ratio. TWC reduces tailpipe emissions of oxides of NO_x and NMHC by 87 to 98 percent compared to the lean combustion technologies that were employed in prior generations of CNG engines, For emissions of stoichiometric combustion using three-way catalyst, see Yoon, S., Collins J., Thiruvengadam A., Gautam, M., Herner, J. & Ayala, A. *Criteria pollutant and greenhouse gas emissions from CNG transit buses equipped with three-way catalysts compared to lean-burn engines and oxidation catalyst technologies*, *Journal of the Air Waste Management Assoc.*, 2013 Aug., 63(8): 926-33, <http://www.ncbi.nlm.nih.gov/pubmed/24010373>.

of the bus (Figure 11). In high floor “cruiser” CNG buses, the CNG tanks are mounted under the bus body on the bus chassis.

The cylinders store CNG at an industry standard fill pressure of 3,600 psi but are designed to store CNG at 125 percent of their fill pressure. Therefore, a 3,600-psi tank can be filled to 4,500 psi capacity. As a gas is compressed, it heats up and increases the pressure inside the storage vessel. The added pressure allowance allows an industry standard 3,600 psi cylinder to fill to its needed volumetric capacity, while compensating for ambient temperature and heating during compressing.³¹

Four types of CNG cylinders are currently available on the market. Each type is comprised of different materials, which determines their weight, volumetric storage capacity, and cost. In general, the lighter weight the cylinder, the higher its cost.

Type I cylinders are typically of all carbon steel construction. Type II cylinders are made of a thinner steel or aluminum liner partially wrapped in reinforcing fiberglass. Lighter type III cylinders are constructed of thin aluminum liners fully wrapped with a carbon fiber and/or glass composite material. Type IV cylinders are the lightest in weight, being made of a polymer liner fully wrapped in a reinforcing composite.

In a Type III cylinder the metal liner and composite wrap each absorb about half of the stress generated by internal gas pressurization. The lightweight polymer and composite cylinder walls absorb all of the pressurization in Type IV cylinders. Type III liners weigh as much as 60 percent less than Type I cylinders and Type IV cylinders of comparable size and volumetric capacity weigh, weigh even less. A cylinder’s weight impacts bus performance, CNG buses purchased today in the North American market are outfitted with lighter Type III or Type IV cylinders.



³¹ A rule of thumb is that for every $\pm 10^{\circ}\text{F}$ change around 70°F , CNG pressure will expand or contract 100 psi.

CNG Engine Maintenance Protocols

There are several notable features of CNG engines in terms engine maintenance protocols (Table 6). Because they do not require fuel injectors, CNG engines eliminate the need for fuel injector adjustments. CNG engines utilize spark ignition, and therefore require that ignition system spark plugs and coils be replaced at intervals provided for in vehicle manufacturer maintenance manuals. Because gaseous fuels do not act as engine lubricants, the valves in CNG engines must be adjusted more frequently than for diesel engines, and the motor oil in CNG engines must be changed more often than their diesel engine equivalents. The spark ignition used in CNG engines requires that these engines utilize a specially formulated, low ash content motor oil to prevent the formation of ash and deposits in the engine.

Table 6. ISL G Bus Engine Maintenance Snapshot³²

Maintenance Intervals			
	Hours	Miles	Months
Oil & Filter*	500	7,500	6
Spin On Fuel Filter	1,000	15,000	12
Spark Plugs	1,500	22,500	18
Standard Coolant	2,000	30,000	24
Valve Adjustment	2,000	30,000	24
<ul style="list-style-type: none"> • No fuel injector adjustment • No SCR or DPF maintenance • Spark plugs and coils must be replaced • Low ash content motor oil needed 			

Cost of Maintaining CNG Engines

According to the Transit Cooperative Research Program (TCRP), CNG buses incur a propulsion system maintenance cost of about 18 cents per mile, two cents more per mile than diesel buses (Table 7).³³ The incremental costs for maintaining CNG bus propulsion systems are primarily attributable to CNG engines requiring spark plug and coil changes, overhead valve adjustments and more frequent oil changes than diesel engines.

³² Source: Cummins Westport, http://www.cumminswestport.com/content/430/4971373_0413.pdf. Assumes normal duty cycle based on 30 mph average speed. Default interval is the hours stated. Interval is whichever comes first – hours, miles or time. Oil and filter change interval depends on average operating speed and ranges between 1,500 and 7,500 miles.

³³ Source Table 10: Transit Cooperative Research Program, Transportation Research Board, 2011, Guidebook for Evaluating Fuel Choices for Post-2010 Transit Bus Procurements, http://onlinepubs.trb.org/onlinepubs/tcrp/tcrp_rpt_146.pdf

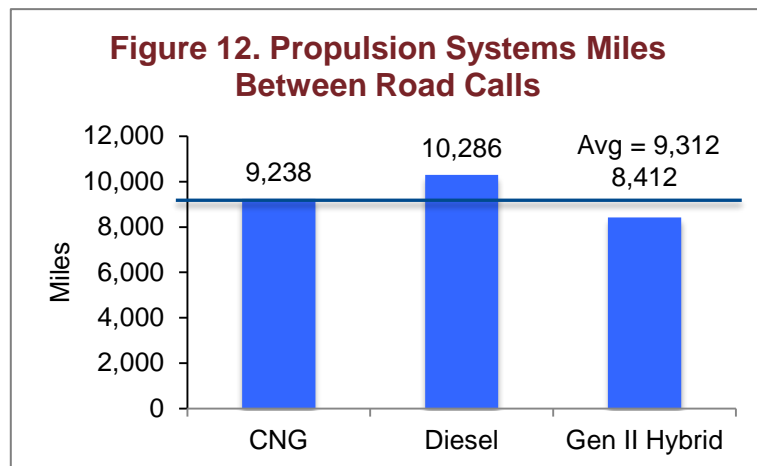
The TCRP maintenance cost data is based on older generation bus models. Comprehensive maintenance cost data on newer generation bus models is less available and difficult to systematically correlate.³⁴ Many transit agency maintenance directors say that they expect the long term incremental cost of maintaining CNG buses to be lower than those for new diesel buses as the costs of maintaining the emissions after-treatment systems required on diesel buses to comply with 2010 federal standards is better quantified.³⁵

Table 7. Propulsion System Maintenance Costs	
Propulsion	Cost Per Mile
CNG	\$0.18
Diesel	\$0.16
Hybrid	\$0.13

CNG Bus Reliability

Mile between road calls (MBRC) is the primary metric used to assess transit bus reliability. MBRC measures the number of miles a bus operates before it has a malfunction that requires the bus driver to call for assistance.

Survey data points to current generation CNG buses having a propulsion system mean (average) MBRC of 9,238 miles, which is about the average propulsion system MBRC for later generation CNG, new diesel, and hybrid buses considered as a group (Figure 12).³⁶ The



³⁴ Comparing data on the propulsion system maintenance costs of transit buses is challenging. Agencies report their maintenance costs in different ways. Some include personnel costs in their reports that others do not, and personnel costs can vary widely by locality. Rolling stock age also leads to significant variations in bus maintenance cost and makes comparisons difficult. In surveys, some agency maintenance directors report that their maintenance costs for CNG buses are lower than those for diesel buses, others report higher maintenance costs for CNG buses.

³⁵ AFV Intelligence, 2014 *Transit Bus Census and Alternative Fuels Digest*, AFV Intelligence, 2014 *Transit Bus Census and Alternative Fuels Digest*, <http://www.afvintelligence.com/>.

³⁶ AFV Intelligence, 2014 *Transit Bus Census and Alternative Fuels Digest*, AFV Intelligence, 2014 *Transit Bus Census and Alternative Fuels Digest*, <http://www.afvintelligence.com/>. The data was collected as part of a survey to which more than 250 transit providers responded and reflects post model year 2008 buses. A number of factors influence the propulsion system MBRC of transit buses. These include age of the bus and engine, how well the bus is maintained by properly trained personnel, the duty cycle a bus runs, terrain, and weather. Accordingly, the MBRC averages presented in Figure 12 may not be indicative of every transit agency's fleet. The propulsion MBRC typically declines as a bus fleet ages, so fleets composed of older buses may have MBRC metrics that are lower than those reported here, while more recent bus models may achieve higher MBRCs. The MBRC figures presented in the table have been cross-checked against and are reasonably

MBRC for 2010 and later model year hybrid buses is about 9 percent less than that of comparable CNG buses, while comparable diesel buses have propulsion MBRC of 10,286 miles.

Some transit system maintenance directors hold a perception that CNG buses have a significantly lower propulsion system MBRC than diesel buses. This may be due to past analyses that have compared the reliability of CNG buses and older diesel buses that used technology that was less prone to failure. The propulsion systems of current generation diesel buses incorporate engine sensors and more complex exhaust after-treatment systems that are more prone to failure. Transit maintenance directors say that they expect this to narrow the MBRC between the current generation of CNG and diesel buses as additional data becomes available. MBRC data show hybrid buses to perform more poorly than both CNG and diesel buses when measured in terms of MBRC.

Many transit maintenance directors say they expect CNG buses to have lower long-term maintenance costs and increased MBRC compared to diesel buses as more current data on the performance of diesel bus after-treatment systems becomes available

Safety Record of CNG Buses

CNG is a safe fuel. According to the Federal Transit Administration, "There are no significant environmental hazards associated with the accidental discharge of CNG."³⁷ CNG is composed primarily of methane with minor constituents including ethane and propane. All three of these molecules are considered to be nontoxic.³⁸ The National

consistent with propulsion system MBRC figures reported by the Department of Energy's Office of Energy Efficiency and Renewable Energy, http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/fceb_status_2012.pdf; The American Public Transit Association, <http://www.apta.com/mc/bus/previous/2011/Presentations/Electric-Buses-L-Eudy.pdf>; and the National Renewable Energy Lab, http://www.actransit.org/wp-content/uploads/NREL_rept_JUN2010.pdf.

Transit directors interviewed do report that the 3 Way Catalyst EGR system installed in CNG buses with the ISL G engine is prone to malfunction. However this same EGR system is installed in comparable diesel bus engines and the same malfunctions arise with similar frequency in the diesel buses, so the EGR problem is not specific and exclusive to the CNG propulsion system.

³⁷ U.S. Department of Transportation, Federal Transit Administration, August 1995, *Summary of Assessment of the Safety, Health, Environmental and System Risks of Alternative Fuels*, Report FTA-MA-90-7007-95-1, http://ntl.bts.gov/lib/000/400/422/20021101_alt_fuel.pdf. Natural gas is an asphyxiant, and the only known direct health risk associated with CNG is the possibility that in a highly confined space, a release of natural gas could potentially displace oxygen, leading to suffocation. There are no known instances of use of CNG for transportation fueling resulting in suffocation in the United States.

³⁸ *Report on Carcinogens, 12th Edition, 2011*, U.S. Department of Health and Human Services Public Health Service National Toxicology Program, <http://ntp.niehs.nih.gov/ntp/roc/twelfth/roc12.pdf>. The nontoxicity of natural gas contrasts with diesel, which is "reasonably anticipated to be a human

Renewable Energy Laboratory examined the fire risk of CNG buses and concluded that the incidence of fires on CNG buses is rare and equivalent to the fire risk of operating a diesel bus. In the rare instances where CNG buses have been involved in fire incidents, transit agency officials did not attribute the fire to the buses being fueled by CNG.³⁹

“There are no significant environmental hazards associated with the accidental discharge of CNG.”

– Federal Transit Administration

Unlike diesel, which pools on the ground when released, CNG is a gas that rises, eliminating the risk of costly cleanups and the potential for groundwater and stream pollution. Because they contain natural gas under pressure, CNG cylinder construction is much more durable and robust than diesel tanks. The cylinders are stress tested for resistance to heat, ballistic gunfire, collision impacts, fire, flame and ambient heat, and resistance to corrosion from salt and other hazards. Only after a CNG tank design has passed these tests is it available for installation on transit buses and other vehicles. CNG cylinders are also fitted with pressure relief valves that release gas stored in the cylinder into the atmosphere in the event that the pressure inside the cylinder exceeds its design capacity.

The inherent non-toxicity of natural gas, the narrow concentrations in which natural gas must be present in air to ignite, and certified, risk-tested cylinders make CNG a fuel no more dangerous and in a number of respects safer than diesel as a transit bus fuel.

Federal regulations require that all CNG cylinders mounted on buses and other motor vehicles in the U.S. be labeled with a “do not use after” date. Cylinders installed on CNG buses are certified for a useful life of at least 15 years. Some manufacturers certify their cylinders for a 20-year life.⁴⁰ CNG cylinders should be

carcinogen,” with long term exposure to diesel exhaust posing the risk of lung cancer and other lung damage. In addition to tiny particles, diesel exhaust gases contain carbon dioxide, carbon monoxide, nitrogen oxides, sulfur compounds, formaldehyde, benzene, volatile organic compounds, persistent organic pollutants (POPs), and methanol.

³⁹ National Renewable Energy Laboratory, September 2010, *Compressed Natural Gas (CNG) Transit Bus Experience Survey April 2009 – April 2010*, Subcontract Report NREL/SR - 7A2-48 814, September 2010, <http://www.nrel.gov/docs/fy10osti/48814.pdf>

⁴⁰ See Federal Motor Vehicle Safety Standard (FMVSS) 304 Compressed Natural Gas Fuel Container Integrity,” 49 CFR 571.304 - Standard No. 304; Compressed natural gas fuel container integrity, <http://www.law.cornell.edu/cfr/text/49/571.304>. The minimum 15-year CNG cylinder life and inspection labeling standard are stipulated by the American National Standards Institute(ANSI)/Canadian Standards Association (CSA), NGV2 – Basic Requirements for Compressed Natural Gas Vehicle Fuel Containers, <http://webstore.ansi.org/RecordDetail.aspx?sku=ANSI+NGV2-2007>. This is a voluntary industry standard that is more comprehensive than that mandated under federal law. While ANSI NGV2 is not generally a legal requirement, all cylinders outfitted on CNG buses sold in North America comply with the ANSI NGV2 standard.

inspected periodically, and each cylinder installed on a transit bus is labeled with the statement “This container should be visually inspected after a motor vehicle accident or fire and at least every 36 months or 36,000 miles, whichever comes first, for damage and deterioration.” In practice, few transit buses are operated for a period exceeding a 15-year cylinder service life, so unless a CNG bus or cylinder is damaged, a CNG cylinder installed on a newly purchased bus will likely not need replacement or retirement during the service life of the bus.

	CNG	Diesel	Gasoline
Flammability Limits (Volume % in air)	5-15	0.6-5.5	1.4-7.6
Auto ignition (°F)	842-1,004	446	572
Min. Ignition Energy (10-6 Btu)	.27	.23	.23
Peak Flame Temperature (°F)	3,423	3,729	3,591

Source: Murphy, Michael J., *Properties of Alternative Fuels*, Federal Transit Administration, Office of Technical Assistance and Safety, March 1994

Auto ignition temperature is the lowest temperature at which a substance will ignite absent a spark or flame. The auto ignition temperature for natural gas is 842 degrees F at its lower heating value; almost 400 degrees higher than the 446 degrees F at which diesel will auto ignite (Table 8). The ignition of natural gas outside the combustion chamber requires a very narrow range of conditions. Natural gas will not ignite unless air is present in a narrow concentration between 5 percent and 15 percent by volume. Outside of this narrow range, natural gas will not ignite in air, making the accidental ignition of CNG highly unlikely. Further, natural gas rises when released, away from the release point, and dissipates safely into the atmosphere

When idling, CNG buses can be as much as 10 decibels quieter than diesel buses

The inherent non-toxicity of natural gas, the narrow concentrations in which natural gas must be present in air to ignite, and certified, risk-tested cylinders make CNG a fuel no more dangerous and in a number of respects safer than diesel as a transit bus fuel.

Rider and Transit Agency Staff Satisfaction with CNG Buses

To the transit customer, there are no significant differences in ridership experience that arise due to a bus propulsion system. In urban areas where noise pollution is a nuisance, CNG buses may offer a benefit in that when idling, CNG engines can be as much as 10 decibels quieter than diesel engines.

From the perspective of a bus driver, there is likewise little difference in the level of satisfaction between driving a CNG, diesel, or hybrid bus. Transit maintenance directors often point to a marked difference in terms of the satisfaction levels among bus technicians and mechanics that maintain CNG and diesel buses. They note that because CNG buses are cleaner than diesel buses, the uniforms of mechanics servicing CNG buses do not accumulate the grime and odors that accumulate when servicing diesel engines. This leads to quality of life improvements for mechanics servicing CNG bus engines in comparison to those servicing diesel engines.

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4. Infrastructure for Fueling and Maintaining CNG Buses

Fueling and maintaining buses quickly, efficiently, and safely is a priority for transit agencies. To paraphrase transit directors, *“Our buses need to be ready to roll and be on the road every day, and we cannot afford delays and disruptions in the fueling process.”*

Fueling and maintenance for CNG buses is broadly similar to other buses. The differences largely pertain to the high-pressure equipment needed to compress natural gas for onboard storage in cylinders and for improvement features specific to working with high-pressure natural gas at facilities where CNG buses are maintained.

Transit agencies operating CNG buses typically have CNG fueling infrastructure installed at their bus operations centers, although some smaller CNG bus fleets fuel their vehicles at third party locations where CNG fueling is available. An example would be a gasoline station where CNG fueling has been installed or fueling buses at a CNG fueling facility operated by an affiliated government entity such as a municipal fleet.

Having CNG fueling infrastructure installed at an agency’s operations center provides several benefits. These include being able to fuel the vehicles at any time of the day or night, being able to perform bus cleaning and servicing of liquids as part of the fueling process, and avoiding delays from congestion at the point of fueling that could occur due to queuing for fueling by non-transit fleet vehicles at a third party fueling location. On-site CNG fueling also improves fueling reliability, as the transit agency can monitor and control the quality of maintenance on the fueling system to minimize fueling system downtime.

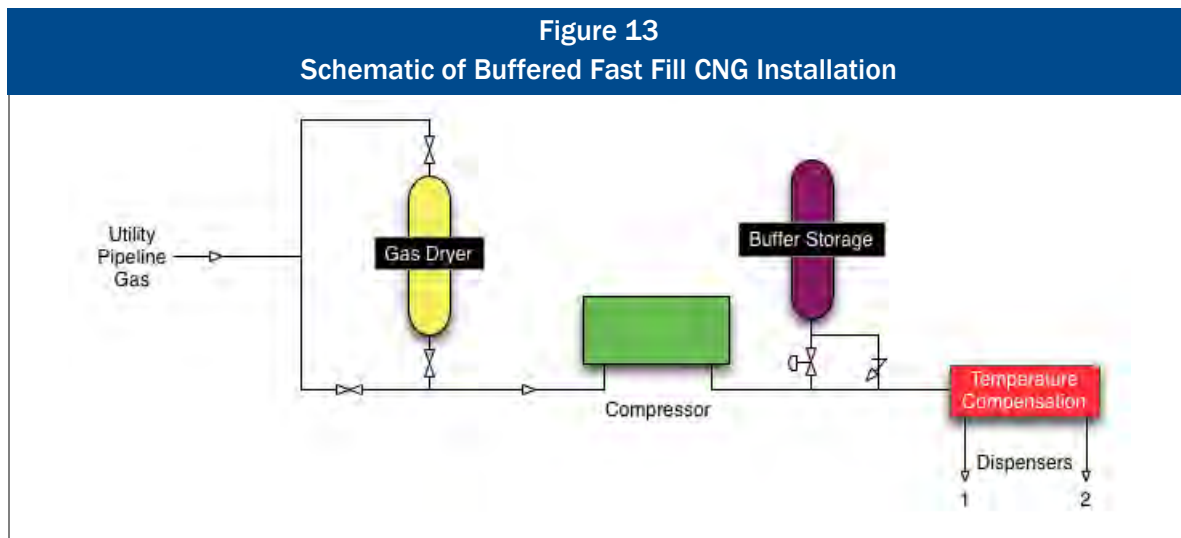
Buffered Fast-Fill Fueling Technology

Most transit fleets that operate CNG buses fuel their buses using buffered fast-fill fueling systems (Figure 13).⁴¹ These systems allow CNG buses to be fueled in sequence in a comparable amount of time to diesel buses. Buffered fast-fill systems use a compressor to mechanically pressurize and compress natural gas from a local utility gas pipeline. Most of the CNG fuel flows directly from the compressor through a dispenser and through a high-pressure hose and nozzle into the bus for storage in the bus’s CNG cylinders. These fast-fill systems also contain buffered storage – high pressure CNG

⁴¹ Some smaller transit systems fuel CNG buses with time-fill fueling infrastructure. Time-fill fueling comprises essentially the same fueling process as the buffered fast-fill fueling described in detail in this report, with the exception that time-fill fueling infrastructure does not include buffer storage vessels. The fuel flow is directly from the compressor to the dispenser and through the nozzle into the bus’s onboard cylinders. Because the buffer is not included, a time-fill fueling infrastructure array costs less than buffered fast-fill fueling. However, time-fill fueling takes longer than buffered fast fill-fueling. It can take between 4 and 8 hours to time-fill a CNG bus. Most transit agencies have shorter time constraints to fuel a bus and so opt for buffered fast-fill fueling.

storage vessels co-located with compressing equipment that ensure consistent CNG flow into the fueling dispenser during intermittent periods when the rate of gas dispensed for sequenced buses exceeds the compressor output rate. When the dispensing flow exceeds the compressing rate, stored CNG is released from the buffer storage vessel to maintain fuel pressure and flow rate. Buffered fast-fill CNG fueling systems can fuel a large CNG bus in as few as four minutes.⁴² Fast-fill fueling is a must to ensure that buses are fueled quickly and can be on the road for their next shift.

The major components of a typical buffered fast fill CNG fueling system are one or more compressors and buffer storage vessels, a gas dryer, control panels and a temperature compensation system, CNG dispensers, and a backup generator. The components of a buffered fast fill system are described in greater detail in Table 9.



⁴² Several large transit agencies report that they can complete fueling of a large CNG bus, check the fluids, and clean the bus interior in seven minutes.

Table 9. CNG Fueling Infrastructure Components

Compressors	Dispensers
<p>Compressors are the heart of a CNG bus fueling system. They mechanically compress inlet natural gas delivered by a local utility pipeline for pressurized storage in onboard CNG cylinders that fuel the CNG bus engine. See the discussion of compressors.</p>	<p>Dispensers are flow control devices that interface between the compressor and buffer storage and bus on-board fueling cylinders. A dispensing unit includes temperature compensation flow control valves, a high-pressure hose outfitted with a break-away coupling and a nozzle that ensures an airtight seal between the hose and the bus fueling port. Dispensers either contain meters for measuring the amount of CNG dispensed or are “fueling posts” that lack meters but can electronically communicate with a centralized control and measurement system for metering. Dispensers incorporate cutoff valves. In the event the hose connection to the bus is ruptured or severed during fueling, the cutoff valve engages, stopping the flow of CNG.</p>
<p>Inlet Dryer and Filters</p> <p>Pipeline gas can contain water vapor depending on location, the source of the gas and its processing, and pipeline quality. Moisture and corrosive constituents in the water vapor can impair engine, compressor, and storage cylinder performance and longevity. Inlet dryers reduce the moisture content to standards provided for by Society of Automotive Engineers fuel spec J1616, while filters trap potentially harmful impurities.</p>	
<p>Standby Generator</p> <p>The reliability of an area’s electrical generation, transmission, and distribution system is beyond the control of a transit agency. A backup diesel fired electrical generator is strongly recommended for redundancy in the event that there is an electrical failure due to a blackout or other disruption to the electrical supply to ensure uninterrupted operation of compressing and other fueling equipment.</p>	<p>Controls, Priority Panels, and Temperature Compensation</p> <p>Because CNG is a gas, its volume varies with ambient temperature. Computerized priority panels control valves that manage the rate and temperature at which CNG flows from the compressor to buffer storage and the dispenser for unloading to bus CNG cylinders. Temperature compensation uses an algorithm to ensure unloading of a full fill into the bus’s onboard CNG cylinders given surrounding ambient temperature.</p>

Keys to Compressors

Compressors are the heart of a CNG fueling system. The compressors used to fuel CNG buses use the action of pistons driven by a crankshaft to compress natural gas at high pressure (Figure 14). The compressed gas is then delivered directly into bus mounted CNG storage cylinders or stored in the buffer storage vessel. The gas is delivered to the compressor via a gas pipeline operated by a local gas distribution utility. The typical compressor mechanically pressurizes gas to 4,500 psi for dispensing or storage in buffer vessels.

Compressors are rated in horsepower and the volume of gas they can compress per minute, measured as standard cubic feet per minute (scf). Compressor sizing is critical to the efficient

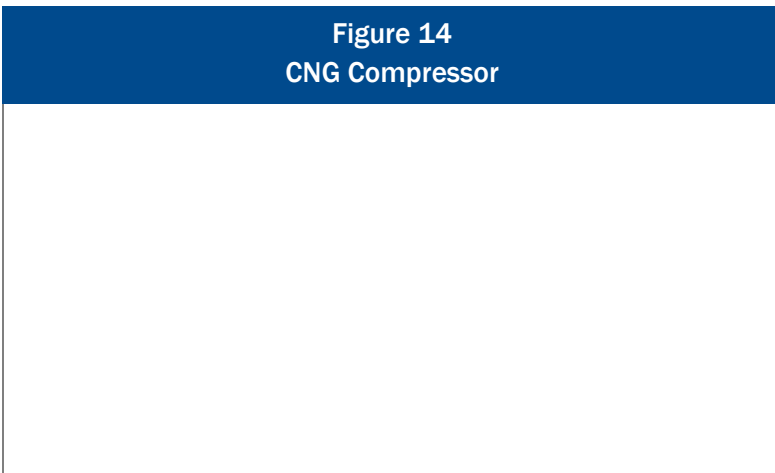
and effective fueling of a CNG bus. Several variables determine how much compression is needed to fuel a bus fleet. These include the number of buses that need to be fueled, how much fuel is needed for each vehicle, when fueling opportunities will arise given the bus's

duty cycle and the amount of time available to fuel the buses, and the pressure at which pipeline gas is delivered to the compressors. Generally speaking, the more buses that need to be fueled, the shorter the turnaround time allocated to fuel each bus, and the lower the input gas pipeline pressure, the greater is the amount of compression needed to fuel the buses efficiently. Anticipating and sizing compressors, dispensers, and associated equipment to account for additional future deployments of CNG buses to a fleet can significantly reduce future infrastructure improvement and expansion costs.

While older CNG fueling systems sometimes utilize gas powered compressors, modern CNG fueling compressors are electrically powered, making electrical supply an important cost to consider when operating a CNG fueling system. Most transit fleets fuel their CNG buses in the evenings and overnight when the majority of buses are not in route service. This fueling schedule has the advantage of benefiting from less expensive off-peak per-kilowatt electric rates and avoiding high demand charges.

Both lubricated and non-lubricated compressors are available on the market. Lubricated compressors inject oil into compressors moving parts during the

Figure 14
CNG Compressor



compressing process, including the compressor's crankshaft and piston rings. Because oil can contaminate CNG engines and storage cylinders, lubricating compressor packages incorporate built in filtration systems at several points to remove "carry over" oil from the CNG before it is dispensed into a bus's onboard storage cylinders. Non-lubricating compressors use oil to lubricate the compressor crankshaft but use low-friction Teflon polytetrafluoroethylene (PTFE) and polyetheretherketone (PEEK) materials to line the piston and compressor rings to reduce the amount of carry over oil. Still, some residual oil is carried with the CNG even when non-lubricating compressors are used. Both mineral oil and synthetic oils can be used as compressor lubricants. Synthetic oils cost more than mineral oil. But synthetic oils resist vaporization much more than mineral oils. So using synthetic oils for compressor lubrication instead of mineral oils helps prevent oil carryover.

The hydraulic intensifier (Hy-C) is a unique compressor technology that improves compressor efficiency (Figure 15). A technology developed by Trillium CNG, Hy-C technology compresses gas in two stages and can operate at slower speeds than conventional compressor technologies and over a wider range of pressure. The units compress gas more efficiently using less horsepower than a traditional CNG system, and require less maintenance. This results in faster fill rates with reduced wear and tear on the compressor components, and a longer compressor service life. The Hy-C alternative to a compressor is more energy efficient at supplying high flow rates at the filling pressures required, but not when dealing with the low suction pressures typical from the pipeline. For this, reason, the Hy-C works best in concert with traditional compressors and storage vessels. It allows for smaller and fewer traditional compressors, thus lowering the total equipment cost and electrical usage while supplying higher peak fueling rates.

Figure 15. Trillium Hydraulic Intensifier



Several issues should be considered when evaluating compressor technologies. These include the initial cost of the compressor, compressor maintenance, and service life (Table 10). Because they require oil circulation systems and are thus more complex, lubricated compressors are generally more costly to purchase than non-lubricated compressors. Also, because lubricated compressors require periodic oil changes, they will have somewhat higher maintenance costs than non-lubricated compressors. However lubricated compressors typically have longer service life spans than non-lubricated compressors. Friction is the number one cause of wear and tear

on compressors and lacking oil, non-lubricated compressors incur higher friction. Once the compressor’s non-lubricated piston lining has been worn out, it will typically require that the entire compressor be replaced.

Table 10: Key Compressor Considerations
Lubricating or Non-Lubricating
Compressor Sizing and Cost
Compressor Maintenance Intervals
Service Life
Compressor Redundancy
Hydraulic Intensifier Technology

While the CNG fueling equipment on the market today is highly reliable, as with any technology, unexpected disruptions are unavoidable. Ensuring that the fueling infrastructure is designed and built with adequate backup compression is highly recommended. Standby electrical generation is also highly recommended for a transit CNG fueling station. Traditional diesel fueling also typically involves the installation of a backup generator, so redundancy in electric supply does not generally constitute a significant additional cost for installing CNG fueling above and beyond the costs involved in fueling buses with diesel. Redundancy in backup compression and electrical supply should not be overlooked as simply an extraneous cost if a transit agency wants to ensure that it meets its service obligations to the public.

Given the multiple variables and technologies that effect compressing efficiency and cost, a transit agency should consult professionals expert in designing, building, operating and maintaining CNG bus fueling infrastructure early in any CNG bus deployment program.

It is critical to understand the gas supply situation when installing CNG fueling. Local gas pipelines typically deliver gas at pressures of between 25 psi and 100 psi, although inlet gas pipeline pressure can vary considerably above or below these pressures depending on location. It is important to know the available inlet pipeline gas pressure at the outset of designing a CNG fueling system, and therefore vitally important that a pipeline assessment be undertaken at the outset of CNG fueling infrastructure planning.

Local gas distribution pipeline networks are owned and operated by municipal or investor owned gas distribution utilities. In some cases, these utilities also sell the natural gas commodity to consumers. In other cases, the utility only transports the gas to the end user location and the end user purchases the gas commodity from a third-party gas marketing company. In states that have deregulated their natural gas markets, the gas commodity is likely to be sold by a third-party natural gas marketing company while the local gas distribution utility will sell the gas commodity in states that have not deregulated their natural gas markets. The capacity and age of the pipeline system plays an important role in determining the inlet pressure at which natural gas is delivered to the end user location. Depending on the extent of the pipeline network, a pipeline extension may be needed to deliver gas to the bus

operations center where CNG buses are to be fueled. The particulars of local gas pipeline capacity and pressure may make investing in pipeline upgrades to raise input gas pressure economically advantageous. Pipeline upgrades can reduce the amount of compressing needed and the amount of electricity needed to run compressors, and can result in net overall CNG fueling infrastructure cost savings.

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Given the multiple variables and technologies that effect compressing efficiency and cost, a transit agency should consult professionals expert and experienced in designing, building, operating and maintaining CNG bus fueling infrastructure early in the process for any CNG bus conversion and deployment program.

CNG Bus Maintenance Facilities

Most transit agencies fuel their buses out of doors – although where harsh winter conditions prevail, some may fuel indoors. Agencies operating in warmer climates may perform their maintenance out of doors, either under protective canopies or in partially enclosed maintenance outbuildings. However many agencies perform bus maintenance within the confines of a building.

Because natural gas rises when released, fully enclosed buildings in which CNG buses are maintained need to be outfitted with several potential hazard prevention measures that differ from the measures required for facilities where diesel buses are maintained (Table 11). In newly constructed facilities, these improvements can be incorporated into a building's initial design and construction. Depending on a facility's layout, only those parts of a facility where CNG buses are maintained will require the improvements, reducing construction costs. Existing facilities not originally designed to accommodate CNG bus maintenance and fueling can be retrofitted with the needed improvements, which can be installed by segregating portions of a facility, allowing retrofits to be made without interrupting ongoing bus maintenance operations. Where CNG bus maintenance is performed out of doors, these hazard prevention measures may not be needed or may be needed only in part.

Table 11. CNG Bus Maintenance Facility Safety Measures

Heating Systems	Ventilation Systems
<p>All open flame heaters and heating devices with exposed surfaces greater than 750 °F prohibited in vehicle repair areas. Forced hot air or radiant in-floor heating optimal.</p>	<p>Repair areas have either continuous ventilation or ventilation activated by gas detection systems with a recommended ventilation rate that turns over the air six times per hour. Emergency ventilation introduced with fans at higher elevations and exhausted in the lower 18 inches above the floor, ensuring that the airflow in the facility is from top to bottom.</p>
<p>Electrical Systems</p> <p>Electrical systems in CNG bus repair areas flame-proofed with potential sources of ignition (could create an arc or a spark in on or off position) eliminated or removed within at least 18 inches of the ceiling. This includes electrical outlets and conduits, appliances, switching, and motor devices. Sealed ceiling lighting should be installed, or if traditional lighting is used the fixtures should be mounted at least 18 inches below the ceiling. If electrical equipment cannot be relocated from the ceiling, the equipment must be explosion proofed.</p>	<p>Gas Detection Systems</p> <p>Self-testing natural gas detection systems optimized to detect gas leaks that exceed 25 percent of natural gas’s lower flammable limit and trigger the ventilation system to evacuate gas, trigger circuit breakers to selected equipment and heating systems and open overhead doors. Two types of gas detection systems are commonly used: Passive Catalytic Bead technology that detects heat from oxidized gas, and infrared sensors which measure active gas concentration. No smoking signage should be visibly displayed.</p>
<p>Defueling</p> <p>Buses should be defueled before repair work is performed on the CNG fuel system, either by using defueling posts that recycle CNG from the onboard bus cylinders back through the facility’s compressors or by venting the CNG through hoses into the atmosphere outside the building. Checks for leaks in the CNG fueling lines performed before beginning repairs.</p>	<p>Building Envelop, Garage Doors and Walls</p> <p>Sloped roofs with open supports to prevent gas pockets and segregation of repair and non-repair areas where possible. Because CNG cylinders mounted on the vehicle’s rooftop, vehicle entry door clearance needs to be higher than for diesel buses. To help release pressure in the event of an explosion, equip fueling areas with blowout panels in the roof and walls and install overhead doors made of heavy fabric instead of metal where feasible.</p>

5. Procurement, Contracting, and Financing Issues

CNG buses typically cost more to purchase than comparable diesel-fueled buses. Transit agencies also incur costs for building and maintaining the infrastructure needed to fuel and maintain CNG buses, costs offset by the significantly lower cost of using CNG as a fuel instead of diesel, resulting in a net savings over time for the transit agency. These cost savings increase as the number of CNG buses a transit agency deploys, the number of miles the buses run, and the volume of fuel consumed by the buses increases. Specific costs for purchasing natural gas commodity and installing the infrastructure needed to fuel and maintain CNG buses will vary by agency depending on local factors. A transit agency deploying CNG buses will typically be able to recover its incremental costs of CNG bus deployment within a two to six year payback period, meaning that the agency benefits from a net positive economic return from the deploying CNG buses.

In most cases, higher costs of purchasing and maintaining CNG buses and for CNG bus fueling and maintenance infrastructure will be offset by the significantly lower cost of using CNG as a fuel instead of diesel, resulting in a net savings over time for the transit agency. These cost savings increase as the number of CNG buses a transit agency deploys, the number of miles the buses run, and the volume of fuel consumed by the buses increases.

Most transit agencies seek funding from the Federal Transit Administration to help defer the cost of bus purchases. FTA rules generally call for assistance when buses have reached a threshold of 12 years in service or accumulated 500,000 service miles. FTA will generally pay up to 80 percent of the capital cost to replace a bus and may pay up to 80 percent of the cost of infrastructure needed for fuel and maintenance.

Purchase Price of CNG Buses

Because the propulsion systems used in CNG buses incorporate engines modified to run on CNG, on board CNG storage cylinders and other equipment, the purchase price of a CNG bus is higher than the cost of purchasing a comparable diesel bus. Based on recent bus pricing survey data, the price paid for buying a CNG bus averages between 10 and 13 percent more per unit of rolling stock than comparable diesel models (Table 12). Hybrid buses are even significantly more expensive to purchase.

Table 12. Recent Pricing for CNG, Diesel and Hybrid Buses⁴³

	CNG	Diesel	Hybrid
35 Foot	\$435,000	\$400,000	\$590,000
40 Foot	\$460,000	\$420,000	\$639,000
60 Foot Artic	\$720,000	\$637,000	\$846,000

Calculating the Feasibility of CNG Bus Deployment

A key step in any bus deployment plan is calculating feasibility. Major components of the feasibility cost calculation when deploying CNG buses include the incremental capital cost of purchasing buses fueled by CNG – how much more it costs to purchase a CNG bus than a comparable diesel or hybrid bus – the incremental cost of maintaining the CNG buses, the cost of installing fueling infrastructure and of building upgrades needed to maintain CNG buses, the cost of electricity to run CNG compressors, and the cost of purchasing gas

The prospective ROI to be derived from deploying CNG buses constitutes a compelling argument that a growing number of transit agencies are embracing as a reason to evaluate the cost effectiveness of deploying CNG buses as they look to meeting their future fleet modernization and bus procurement needs

commodity supply compared to the cost of purchasing diesel. Aside from the cost of purchasing the rolling stock units, which tends not to vary widely given a particular propulsion system and bus model, and the bottom line cost of purchasing fuel, for which CNG will enjoy a significant price spread advantage in all cases, other costs that weigh on the feasibility equation will vary, in particular based on how many buses will fuel and how many miles the buses travel and the cost of building fueling and maintenance infrastructure and electricity costs.

Table 13 provides an example of the calculation used to evaluate the feasibility of the cost effectiveness of deploying a fleet of CNG buses versus a comparable fleet of diesel buses.⁴⁴ As shown in the table, whether discussing deployment of a fleet of 50 buses or

⁴³ Source: AFV Intelligence, 2014 *Transit Bus Census and Alternative Fuels Digest*, <http://www.afvintelligence.com>. The exact price paid for a new bus can vary based on factors including the number of buses ordered, bus interior, delivery charges, and whether the bus price includes a training component and spare parts and tools.

⁴⁴ Table 14 assumes bus mileage of 33,254 miles annually. Fuel costs are an average of price escalated costs that transit agencies will actually pay over the 2015-202016 twelve year period based on U.S. EIA pricing projections (see page 7). For CNG, the cost is \$1.21 per DGE; for diesel, the cost is \$3.38 per gallon. Electrical costs are incorporated into the CNG fuel cost. CapEx for CNG fueling and maintenance infrastructure assumes CNG fueling and maintenance infrastructure costs at \$50,000 per bus for the first 50 buses and \$15,000 cost per bus for each additional bus above 50. Infrastructure cost could be lower if maintenance performed outdoors. Payback with Bus Grant = 80%

a larger deployment of 200 buses, the low cost of using CNG as a fuel instead of diesel produces net overall savings of a significant magnitude.

Furthermore, the magnitude of the cost savings increases as the number of CNG buses deployed and the mileage the buses run, and thus the amount of fuel each bus consumes, increases, with the result that the payback period associated with a CNG bus deployment shortens. This is what is known as the “all in” effect – the more CNG buses that are deployed, and the more miles they run and fuel they consume, the greater is the prospective return on investment that can be derived by a transit agency.⁴⁵ Due to the significantly lower cost of CNG versus diesel, payback periods of between two and six years are achievable, for buses that on average will run for a 12-year service life. Federal Transit Administration grants for purchasing CNG buses can significantly shorten the payback period.

The price spread advantages of using CNG as a transportation fuel and the magnitude of the operating cost savings produced will in most instances create compelling calculus to merit deploying CNG buses

The calculations in Table 13 are presented only as an example. The actual savings to be derived from deploying CNG buses will vary depending on the variables outlined above. But the price spread advantages of using CNG as a transportation fuel and the magnitude of the operating cost savings produced will in most instances create compelling calculus to merit deploying CNG buses.

FTA grant for bus purchase only, not for Infrastructure. Examples of CNG bus feasibility studies accessible online include CityBus Corporation of Lafayette, Indiana (2013), <http://onlinelibrary.wiley.com/doi/10.1002/ese3.14/pdf>; Kansas City Area Transportation Authority (2012), http://www.kcata.org/documents/uploads/CNGFeasibility_Study5.11_.2012_.pdf; Cape Fear Public Transportation Authority, *Compressed Natural Gas Fuel Evaluation (2012)*, http://www.wavetransit.com/Portals/0/documents/CNG_Fuel_Evaluation.pdf; and *Traverse City Natural Gas Vehicle Feasibility Study (2012)*, <http://tcchamber.org/wp-content/uploads/2012/08/feasibility.pdf>

⁴⁵ The calculations presented in Table 14 do not include a 50 cent per gallon of CNG federal alternative fuels excise tax credit. Congressional authorization for the excise tax credit expired on December 31, 2013. However bills are pending in both houses of congress that would retroactively renew the tax credit effective to January 1, 2014 through December 31, 2015. There is widespread bipartisan support for renewal of the tax credit, and a bill extending the tax credit is expected to be enacted into law. Tax exempt entities including state and local governments and public transit providers that dispense CNG from an on-site fueling station for use in transit buses qualify for the this excise fuel tax incentive even though transit agencies are not tax paying entities. The amount of the tax credit is based on the volume of CNG consumed and is in effect refunded as a rebate to a transit agency by the U.S. Internal Revenue Service. The effect of the excise tax credit is to further magnify the savings derived from using compressed natural gas as a transit bus fuel.

Table 13. Twelve Year Payback Calculations for CNG Bus Deployment				
CNG	DIESEL		CNG	DIESEL
50	50	Number Buses	200	200
1,662,700	1,662,700	Total Fleet Miles Year	6,650,800	6,650,800
3.47	4.1	MPG Diesel/MPDGE CNG	3.47	4.1
479,164	405,537	Annual Gallons/DGE Year	1,916,657	1,622,146
\$1.21	\$3.38	Fuel \$ Gallon/DGE	\$1.21	\$3.38
\$579,789	\$1,370,714	Fuel Cost Year	\$2,319,155	\$5,482,855
\$790,925		Annual Fuel Savings	\$3,163,700	
		Payback		
\$40,000		Incremental Cost Per Bus	\$40,000	
\$2,000,000		Total Incremental Capex Buses	\$8,000,000	
\$2,500,000		CapEx CNG Infrastructure	\$4,750,000	
\$4,500,000		Total CapEx	\$12,750,000	
5.7		Payback Years	4.0	
3.7		Payback with FTA Bus Grant	2.0	

Procurement Options for CNG Bus Fueling and Maintenance Infrastructure

Bus fueling and maintenance infrastructure must be designed, built, operated, and maintained (DBOM). Design and construction of fueling and maintenance facilities is always contracted out. Some transit agencies elect to operate and maintain their CNG fueling and maintenance facilities using their own staff. Other agencies contract operations and maintenance out to companies that deliver these services. In some cases, transit agencies contract out for a fully designed, engineered, constructed, and serviced turnkey solution to meeting their fueling and maintenance needs using a single master developer contracting vehicle. The approach a transit agency takes typically reflects state contracting laws and individual agency policies.

Companies that provide turnkey solutions often recover their costs through fueling contracts with the transit fleet – the cost of designing, building, operating and maintaining CNG bus facilities is fully amortized based on the amount of fuel the transit agency consumes.⁴⁶ For this approach to be viable, a transit agency must commit to consuming a certain minimum threshold of fueling volume, or throughput. This is directly related to the number of vehicles that will be fueled and the amount of fuel that is dispensed to each vehicle. The minimum throughput commitment is necessary to allow the company to offset not only the capital cost of facility design, construction, operations, and maintenance, but also to offset the cost of deploying dedicated technicians to a locality to provide the support needed for the facility's operations and maintenance.

Turnkey fueling solutions companies can generate economies of scale that allow the turnkey company to amortize its cost over higher throughput, with the net result of lowering the cost of building, operating and maintaining CNG fueling infrastructure, producing additional savings for the transit agency. The potential magnitude of these cost reductions can be significant.

Table 14 summarizes differences in the responsibilities for CNG infrastructure maintenance and operations between in-network turnkey and in house models.

Least Cost v Best Value for CNG Bus Infrastructure

Transit agencies generally use one of two models for soliciting proposals to meet their fleet fueling and maintenance facility DBOM needs. Some agencies use a traditional "Best Value" approach, while others use a "Lowest Cost, Technically Acceptable" model.

⁴⁶ Transit maintenance directors report the cost of contracting for maintenance and operation of CNG fueling infrastructure at between 15 cents and 20 cents per DGE of CNG dispensed.

Table 14. Turnkey and Agency In-House Facility Models

Turnkey	Transit Agency In House
Transit agency contracts with a vendor for full one stop shop turnkey DBOM solution	Transit agency separately contracts for components of DBOM process and/or manages in-house some or all functions/components including operations and maintenance
Having single DBOM contractor allows for efficiencies intrinsic to seamless engineering and operations under a unified and consistent set of management principles and best practices	Segmenting individual DBOM components can lead to disruptions, inefficiencies and unanticipated costs arising from incongruence in systems engineering and operations and maintenance
Turnkey contractor may be able to spread the costs associated with maintaining and operating CNG infrastructure over its wider network, reducing overall cost to the transit agency	Transit agency is responsible for the full cost of facility operations and maintenance in absence of wider network to spread costs
DBOM firms may operate centralized computerized control centers which allows for continual systems monitoring	Transit agency may incur higher costs for updating controls and monitoring systems
DBOM firms continually train their employees on up-to-date best practices with high pressure gas work	The transit agency must incur costs for initial training and training updates
Turnkey vendor may be able to finance installation on advantageous terms and amortize infrastructure capital cost through fueling contract, alleviating transit agency need to issue debt	Transit agency responsible for up-front capital cost of building infrastructure which may require debt issuance
Turnkey vendor responsible for these functions:	In house transit agency personnel responsible for these functions:
	Visual inspection of system; Monitor and maintain oil levels; Check for oil, gas, dispenser, nozzle and hose leaks, wear and tear; Monitor and record station operating parameters and equipment fault history; Drain and replace oil from compressors, air dryers, and dispensers; Schedule and perform preventive maintenance

Lowest cost solicitations involve setting forth minimum technical engineering specifications and inviting bids to meet these requirements. A best value model usually involves an agency specifying the overall performance goals it has identified for its fueling and maintenance infrastructure and deferring to the bidders to propose technical, engineering, and service performance solutions to meet these goals.

Lowest cost solicitations can be very effective contracting vehicles for the purchasing of routine services and materials. CNG bus fueling and maintenance facilities are complex installations, and a number of factors come into play

in determining how efficiently, cost effectively, and reliably these facilities succeed over time. These include, in addition to the immediate up front cost of purchasing and installing needed technology and equipment, options for trade-offs in arraying the technology and equipment in meeting performance requirements, management plans and quality control strategies, the qualifications and experience of the managers and technicians who oversee the facility, and options for accommodating future fleet growth and evolution in technology (Table 15).

Best value solicitations allow for the consideration of factors that can be highly instrumental in determining how efficiently, cost effectively, and reliably CNG bus infrastructure performs over time. Under a lowest cost solicitation model, there is typically no competitive ranking of proposals based on non-price factors and no higher value earned by proposals that exceed the minimum technical specifications stipulated in the solicitation. Best value solicitations not only allow for proposals to be weighted based on meeting minimum requirements, but also for proposals to be rated on the degree to which they exceed minimum requirements.

CNG fueling and maintenance facilities can be expected to last for a number of years. Failure to account for the full breadth and depth of the factors that determine the efficiency, cost effectiveness, and reliability of these facilities can undermine the longer-term value an agency derives from deploying a CNG bus fleet. Transit managers and agency governing boards should carefully consider which procurement model to choose when issuing proposals for CNG bus fueling and maintenance facilities and services.

Table 15. Key Considerations in CNG Bus Facility Solicitations	
•	Minimum performance requirements and if they can be exceeded
•	Short and long term costs
•	Management and Performance Plan
•	Future Expansion Options
•	Quality Control Protocols
•	Staffing Experience and Qualifications
•	Capacity to Finance
•	Experience with Codes
•	Options to accommodate future growth and evolving technologies

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