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Compressed Natural Gas Short Line Locomotive Study

Final Report

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Final Report

Prepared for:

New York State Energy Research and Development Authority

Albany, NY

Joseph Tario
Senior Project Manager

and

New York State Department of Transportation

Albany, NY

Mark Grainer
Project Manager

Prepared by:

Genesee Valley Transportation Company

Batavia, NY

Greg Cheshier
President

and

Energetics Incorporated

Clinton, NY

Bryan Roy
Principal Engineer

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Abstract

Energetics Incorporated collaborated with Genesee Valley Transportation Company, Adirondack Scenic Railroad, and Finger Lakes Railway to evaluate natural gas technology for locomotives. This study identified the best technology for each application and evaluated the operational, economic, and environmental impacts of compressed natural gas (CNG) use in locomotives and the required supporting infrastructure for fueling and maintenance. Short line railroads in New York State have characteristics that are often favorable for CNG use such as relatively short hauls, fixed base locations, and consistent routes. While CNG locomotive technology is not currently widespread, a few retrofit solutions are available for models used by these short lines. This includes dedicated (entirely natural gas) spark-ignited engines or dual fuel technology added to a compression-ignited engine, which blends natural gas with diesel. The currently low cost of diesel fuel and considerable investment for converting a locomotive to use CNG with all supporting infrastructure challenges the economic viability of this solution. However, several observations and lessons learned from this evaluation can help guide the decision for short lines to consider CNG in the future when there is a favorable cost differential between natural gas and off-road diesel fuel.

Keywords

Natural Gas, CNG, Short Line Railroad, Locomotive, Dual Fuel

Acknowledgements

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Summary

This study identified natural gas fuel options for short line railroads, then evaluated the operational, economic, and environmental impacts in five operations with Genesee Valley Transportation Company, the Adirondack Scenic Railroad, and the Finger Lakes Railway. Several larger railroads have begun testing natural gas as an alternative fuel to diesel. Canadian National Railway has deployed two dual fuel (blending natural gas and diesel) locomotives on a 480 kilometer stretch between the Edmonton and Fort McMurray in Alberta. Others currently evaluating and testing natural gas technology include CSX, Norfolk Southern, and Burlington Northern Santa Fe railroads. Short line railroads in New York State have relatively consistent short hauls and a fixed base location that may prove beneficial for the deployment of natural gas technology. Long haul, Class I railroads are anticipating a fuel changeover from diesel to natural gas, similar to the transition from steam to diesel in the 1950s, and short line railroads may also find cost and emissions benefits from deploying this technology.

Natural gas for transportation is either in the form of compressed natural gas (CNG) or liquid natural gas (LNG). Similar engine technology is used for both forms since it is combusted in a gaseous state, but the fueling equipment, tanks, pumps/injectors, and overall system costs differ. CNG, which is the primary focus of this study, is compressed and stored in tanks at approximately 3,600 pounds per square inch (psi). LNG, in a liquid state, has a fueling process similar to petroleum fuels, but requires more energy to compress and cool to this state. There are also more logistical challenges to find a steady supply and use it enough to prevent it from “boiling off.”

While CNG is not currently widely used in locomotive applications, a few companies offer CNG solutions. Natural gas technology options for large locomotives are a dedicated (natural gas only) spark-ignited engine or a dual-fuel (blends natural gas and diesel) compression-ignited engine. GFS Corp. and Energy Conversions Incorporated offer retrofit conversions for existing engines, while VeRail Technologies, Inc., General Electric, and Motive Power & Equipment are developing fully integrated dedicated natural gas powered locomotives.

Dedicated natural gas systems operate very similar to a gasoline engine, requiring a throttle and spark ignition to combust the natural gas and air mixture in the cylinder. Natural gas will offset all diesel fuel use with this solution, but it is more expensive because additional components are required. Also, the

inherent power loss and decreased efficiency from a spark-ignited engine becomes more apparent in larger locomotives engines. Engine manufacturers are further advancing this technology so it can become a more viable option in heavy-duty truck, railroad, and marine applications.

Dual fuel technology uses the existing diesel engine and injects natural gas at the intake or with the diesel in the cylinder. The diesel fuel in the cylinder acts as a pilot to combust first, before igniting the natural gas mixture. Dual fuel technology eliminates the need for a throttle or spark ignition system and maintains the efficiency benefits of compression ignition combustion. While this system does not allow 100 percent natural gas operation, diesel fuel offset can be as high as 80 percent during medium power operation. This type of technology can be retrofitted on both two- and four-stroke diesel engines, but has different requirements for each. This technology is relatively inexpensive compared to a dedicated natural gas system because it is retrofitted on existing engines and will allow full diesel operation if natural gas is not available.

Short line railroads would require new fueling infrastructure for a CNG locomotive that compresses the gas from line pressure (30-100 psi) to the tank pressure at 3,600 psi. Time-fill fueling infrastructure fills tanks more slowly (typically overnight), while fast-fill is similar to diesel fueling rates. Fueling could also be done using a portable trailer system that fills at a nearby CNG station before being driven onsite to dispense CNG fuel to the locomotive. Any facility used to perform maintenance or store a natural gas locomotive would be required to adhere to numerous safety codes.

A number of important factors pertaining to natural gas locomotives for NYS short line railroads emerged throughout the study.

- Locomotive types and age vary among the short lines and can significantly impact the feasibility and cost to retrofit for CNG.
- Locomotive CNG retrofits are specialized and unique to each application increasing system complexity and costs.
- Many short lines operate on limited schedules and rotate use among several locomotives (which are old and not always reliable requiring them to keep multiple options available) resulting in lower fuel consumption per locomotive. Some operations have adopted more of a cargo/railcar storage or transload business model than transportation only operations.
- CNG fueling infrastructure and maintenance facility upgrade costs are high and challenge the business case for use by a single CNG locomotive. Fueling with a CNG trailer filled at an existing nearby station and defueling the locomotive prior to entering the maintenance facility are options to reduce costs (but, can inconvenience staff).

There is currently no cost benefit for locomotives to use CNG due to low off-road diesel fuel costs that are less than natural gas. Petroleum costs will likely increase in the future, which will help provide some economic justification for a few of the examined operations. Because railroads do not pay road tax on their fuel, cost savings will always be slightly lower than for on-road applications. Based on this evaluation, CNG fuel prices will have to be around $2 per diesel gallon equivalent (DGE) less than diesel fuel prices to result in payback periods under 10 years. Several observations and lessons learned from this evaluation can help guide the decision for short lines to consider CNG in the future when this favorable cost differential between natural gas and off-road diesel fuel occurs. For any railroad that is creating a new operation for which they would be acquiring locomotives and building a facility, the incremental costs to operate on CNG would only be a small percentage increase and have a quicker return on investment.

Besides economics, using natural gas instead of diesel fuel in locomotives will result in emission and noise reductions. These environmental savings (primarily lower carbon dioxide, particulate matter, and nitrogen oxides emissions) improve air quality for the operators, as well as any residents where they operate. This is particularly important in EPA non-attainment areas where pollution levels are already higher than desired for maintaining good health.

1 Introduction

Several larger railroads have begun testing natural gas locomotives as an alternative to diesel fuel with potential cost and emissions savings. Short line railroads, with relatively short hauls, fixed base locations, and consistent routes, may also find benefits from natural gas technology. NYS has several short line railroad operations that play a vital role in freight transportation. However, many of these short lines struggle financially and welcome innovative opportunities to reduce operating costs when it is feasible. This study's goal was to identify the best natural gas technology and evaluate the operational, economic, and environmental impact from natural gas locomotive use. A few companies offer retrofit natural gas technology for locomotives and others are developing fully integrated natural gas powered solutions for the railroad industry. Energetics Incorporated and AET Energy Solutions conducted this study in collaboration with Genesee Valley Transportation Company (GVT), Finger Lakes Railway (FGLK), and Adirondack Scenic Railroad (ADIX).

1.1 Participating New York State Short Line Operations

Five NYS short line railroad operations were evaluated for incorporating natural gas locomotives into their current equipment fleet:

- Mohawk, Adirondack, and Northern Railroad (MHWA) operated out of Utica.
- Scenic Adirondack Railroad (ADIX) operated out of Utica.
- Finger Lakes Railway (FGLK) operated out of Geneva.
- Depew, Lancaster & Western Railroad (DLWR) operated out of Batavia.
- Falls Road Railroad (FRR) operated out of Lockport.

MHWA, DLWR, and FRR are owned by GVT, while the others are independently owned. ADIX is a passenger/tourist service and the other short lines transport freight. Each operation is quite different (e.g., length of track, cargo, locomotives) based on their location and customers.

Locomotives used by these railroads are quite old (typically models from the 1960s and 1970s) and were purchased used from larger, Class 1 railroads. The only exception is FGLK, who lease several newer EMD locomotives for their main line operations. Some locomotives are used only for switching duties or as a backup if another has a critical issue. Those were not heavily used and would not be a good choice for a natural gas retrofit. The study focused on the short lines' primarily operated, line haul locomotives shown in Table 1. All of the four-stroke diesels listed use a similar engine design, configured slightly different depending on application, and could use similar natural gas technology. The two-stroke engines on the EMDs would require more specialized equipment to utilize natural gas.

Table 1. Locomotives Included in this Study

Make	Model	Engine	Power (hp)	Locations
Alco	C425	V-16 (four-stroke)	2,500	MHWA
Alco	S-6	I-6 (four-stroke)	900	DLWR
Alco/MLW	RS	V-12 (four-stroke)	1,750-2,000	ADIX, FRR, DLWR
EMD	F7	V-16 (two-stroke)	1,500	ADIX
EMD	SD38	V-16 (two-stroke)	2,000	FGLK
GE	B23	V-12 (four-stroke)	2,300	FGLK
MLW	420	V-12 (four-stroke)	2,000	MHWA

1.2 Natural Gas Locomotive System Manufacturers

There are several natural gas locomotive system manufacturers for conversions, but most do not have a commercial system for the older engines operated by these short lines (their focus is on the newer Class 1 locomotives). Energy Conversions Inc. is the only manufacturer that has developed a compatible system for some of the locomotive engines used by these short lines. Other manufacturers offered to develop a custom system for these locomotives if there was sufficient interest.

Natural gas technologies for transportation use CNG or LNG. The difference between these are primarily associated with the storage of the fuel and use similar engine technology. CNG, the primary focus of this study, is compressed and stored in tanks at approximately 3,600 psi. CNG has a significantly lower energy density than diesel and requires larger storage cylinders. LNG is cryogenically cooled to -260^0 F to become a liquid and increase its energy density. It is stored in cooled, insulated cylinders to maintain its state. Liquefaction occurs offsite at large facilities and must be delivered to the locomotives in tankers, similar to diesel fueling practices. LNG has a much higher energy density than CNG and allows more fuel per unit volume. However, this density comes at a cost premium as well as added system complexity.

1.2.1 VeRail Technologies, Inc. (VeRail)

VcRail Technologies, Inc. offers a dedicated natural gas power module solution for repowering locomotives natural gas. The power modules are an electrical generator powered by a natural gas spark-ignited engine. VeRail is expecting to put a 1,200 horsepower (hp) power module on the market by late 2016 or early 2017 and was in the final testing stages for their 800 hp module in early 2016. Multiple natural gas power modules can be integrated into one locomotive to reach higher power levels. The natural gas power modules can also be combined with a downsized conventional diesel powered engine. Combining the 800 hp natural gas power module with a 1,500 hp diesel power module, VeRail claims that this 2,300 hp locomotive solution has emission levels 80 percent lower than Environmental Protection Agency (EPA) Tier 4 standard. In simulations, VeRail has demonstrated natural gas substitution rates of 92 percent on typical duty cycle by using the natural gas power module for idle and low power requirements, and only bringing the diesel power module online when more than 800 hp is needed. The natural gas power module is estimated to cost around $900,000, including onboard fuel storage. The solution combining a 1,500 hp diesel unit with the 800 hp natural gas module is estimated to cost between $1.5 and $1.8 million.

VeRail is also currently working with another company to develop a dual fuel retrofit solution for Alco C425 locomotives in an overseas operation. This technology incorporates port timed injection of natural gas with the diesel fuel to avoid flow through due to valve overlap.

1.2.2 GFS Corp

GFS Corp offers their EVO-LT™ system for a dual fuel LNG and diesel solution on locomotive engines. The system allows the operator to select whether the locomotive uses a mix of LNG and diesel or only diesel. The system will automatically revert to full diesel operation if there is a system fault or the onboard LNG is depleted. The original diesel propulsion system is retained, with the EVO-LT™ system only connecting to the coolant plumbing and intake system. The installation of the EVO-LT™ system should be completed within eight hours using conventional shop tools and equipment. This system has been designed primarily for 4,000 hp or larger locomotives.

1.2.3 General Electric (GE)

General Electric offers their NextFuel natural gas retrofit kit for locomotives. This system is a dual fuel solution that is reported to provide up to 50 percent of fuel cost savings. The kit's flexibility allows 100 percent diesel operation when required or up to 80 percent natural gas substitution when available, resulting in Tier 2+/Tier 3 EPA emissions level. GE partnered with CSX to test the technology; however, no large scale deployment has been undertaken to date. This technology is developed primarily for GE locomotives and high output diesel engines (4,400 hp).

1.2.4 Energy Conversions Inc. (ECI)

Energy Conversions Inc. offers a variety of natural gas solutions designed for locomotive and other large diesel engine applications. ECI has dual fuel engine kits ranging from full engine rebuild systems for GE and EMD engines to simple natural gas fogger systems. The natural gas fogger systems are their most simplistic design and introduces natural gas into the air stream before the intake. The diesel engine's governor automatically reduces diesel flow to maintain requested power levels. Their full engine kits allow a natural gas offset of approximately 95 percent, but require new fuel injectors, pistons, cylinder heads, engine control and monitoring systems, and cooling equipment, which increases cost. Their natural gas fogger system is more economical and much less intrusive to the original engine, but only allows a peak diesel fuel offset of approximately 70 percent.

ECI has several systems available for EMD locomotives. Their dual fuel solution for the Alco 251 engine would use a simple fogger system. One challenge with a system for Alco locomotives is the excessive valve overlap, which results in natural gas blowing throughout the cylinder without combusting when simple intake port injection is used. Possible solutions include custom cam shafts, timed injection, or direct injection into the combustion chamber. These options add cost and complexity to the system, but are necessary to avoid excessive fuel use and emissions.

1.3 Natural Gas Railroad Projects

Many Class I railroads are investigating natural gas to offset or replace diesel fuel to reduce their carbon footprint and maintain competitive transportation costs. To date, no railroad has fully committed to natural gas. They are waiting for proof of savings, fuel cost stability, and technology verification before committing to such a large operational change and investment.

1.3.1 Canadian National Railway (CN)

Canadian National Railway (CN) is currently undertaking a pilot project with LNG-fueled locomotives using Westport prototype fuel tenders. These fuel tenders hold over 10,000 gallons of LNG, which allows longer distances between fueling and decreases infrastructure requirements. These 3,000 hp locomotives operate on a diesel and natural gas mix (dual fuel) resulting in a 90 percent reduction in diesel consumption for their duty cycle. It is estimated that these LNG-fueled engines release 30 percent less carbon dioxide and 70 percent less nitrogen oxide than similar diesel powered locomotives. Overall, CN sees this technology as a viable alternative to diesel in the future, but there are barriers to overcome. A full conversion of the entire fleet would create significant logistical challenges for the railroad. CN's test locomotives and fuel tender are shown in Figure 1.[1]

Figure 1. CN Railroad's Test LNG Locomotives and Fuel Tender

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[1] The Globe and Mail. CN tries out liquefied natural gas to power locomotives. http://www.theglobeandmail.com/report-on-business/industry-news/energy-and-resources/cn-tries-out-liquefied-natural-gas-to-power-locomotives/article11901916/

1.3.2 CSX

CSX partnered with GE to develop dual fuel locomotive solutions. GE's dual fuel technology could allow CSX to transfer the majority of their operations to natural gas use while still retaining diesel operational ability if required (while the fueling infrastructure is rolled out).[2] Railroad personnel view this fuel shift from diesel to natural gas as a continued evolution of the shift from steam to diesel in the 1950s. An example of a natural gas powered GE locomotive is shown in Figure 2.[3]

Figure 2. A CSE Operated GE Locomotive being fueled

1.3.3 Norfolk Southern

Norfolk Southern is testing the feasibility of a prototype GP38-2 switcher locomotive engine modified to run entirely on CNG. The yard switcher will store fuel in a pared locomotive slug outfitted with eight CNG cylinders to have a total capacity of 1,000 DGEs. The locomotive is expected to significantly educe the amount of nitrogen oxide, particular matter, and hydrocarbons emitted compared to a similar diesel operation. Additional future efforts by Norfolk Southern may include converting EMD SD70ACe locomotives to a dual fuel configuration, including tender fuel storage cars for long haul CNG use. However, Norfolk Southern believes the lack of infrastructure will prove challenging for long-range CNG use and the development will require approval from the Federal Railroad Administration.[4]

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[2] Finance & Commerce. Natural gas locomotives may prove cheaper, cleaner. http://finance-commerce.com/2014/01/natural-gas-locomotives-may-prove-cheaper-cleaner/

[3] HHP Insight. GE: Low Pressure for Locomotive LNG. http://hhpinsight.com/rail/2013/12/csx-to-test-lng-locomotives-with-ge/

[4] Norfolk Southern. 2015 Sustainability Report. http://nssustainability.com/conservation/alternative.php

1.3.4 Russian Railways

Russian Railways recently ordered 50 LNG-powered locomotives for their Moscow operations. They have been testing a CNG locomotive, built by Transmashholding, since 2013 as a yard switcher near Yekaterinburg in central Russia (shown in Figure 3) and have already logged more than 300 hours. They developed the locomotive as a modular system including a driver's cab, cooling system, natural gas feeder systems, motor-generator set, equipment chamber, compressor unit, and electro-dynamic braking equipment. The forward mounted LNG tanks are based on conventional shipping container dimensions to create a cartridge system effect, which would allow for the speedy replacement of empty tanks from a depot. They are predicting a 20 percent fuel cost savings from this technology and significantly reduced warm up time in the cold climate.[5] Russian Railways also has 40 twin gas-turbine powered electric locomotives, powered by LNG, on order from the Russian locomotive builder Sinara. Heavy, long-haul freight trains such as coal and iron will use these to replace their aging diesel locomotives.[6]

Figure 3. LNG Locomotive Built by Transmashholding for Russian Railways

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[5] HHP Insight. Report on Russia's LNG Locomotive. http://hhpinsight.com/rail/2015/02/report-on-russias-lng-locomotive/

[6] Trains. Russia Orders Natural-Gas Locomotives. http://trn.trains.com/news/news-wire/2015/06/russia-orders-natural-gas-locomotives

1.3.5 BNSF Railway

BNSF Railway had several successful natural gas test locomotives, using LNG tenders for fuel storage, in the early 1990s. Current efforts focus on dual fuel technology, which has the added benefit of increasing the locomotives range between fill-ups when a tender fuel storage car is used. BNSF is working with their two domestic locomotive suppliers, GE and EMD, to test and develop natural gas solutions for widespread deployment. A BNSF natural gas locomotive with a fuel storage tender is shown in Figure 4. BNSF is working to address natural gas regulatory issues such as siting and operating a natural gas fuel infrastructure, as well as locomotive and tender-specific restrictions.

Figure 4. BNSF Test Locomotives and LNG Fuel Tender

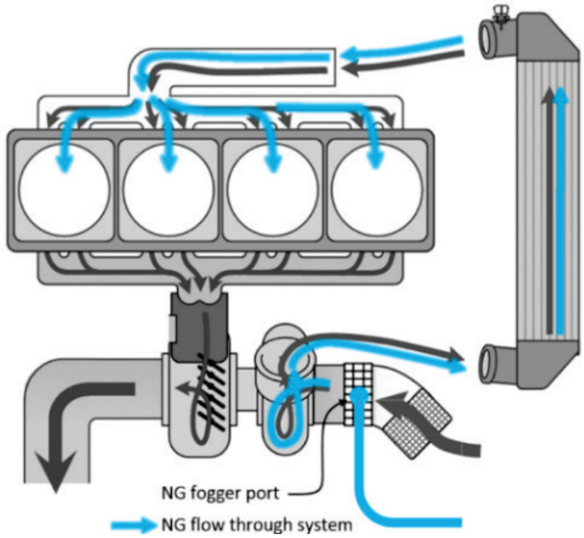
2 Locomotive Natural Gas Technology

Natural gas locomotives gained popularity in the 1980s and 1990s before interest declined due to technological complications. However, there is a recent resurgence due to an increased supply (and lower price) of natural gas from advanced extraction techniques. A handful of manufacturers are currently offering natural gas technology or developing new systems. Natural gas technology for heavy duty applications is available as a dedicated (only natural gas) system in a spark-ignited engine or as dual fuel, which blends natural gas and diesel in a compression-ignited engine.

2.1 Compression-Ignition (Dual Fuel) Natural Gas Engines

Dual fuel technology relies on the existing compression-ignited diesel engine system, but injects natural gas to offset diesel. Natural gas is injected in the intake or with diesel into the cylinder. The diesel fuel in the cylinder ignites first, which then combusts the natural gas mixture. This configuration eliminates the need for a throttle or spark ignition system. It also maintains the compression-ignition combustion of the diesel engine, which has torque and efficiency benefits. While this system does not allow 100 percent natural gas operation, diesel fuel offset can be as high as 80 percent during medium power operation. Figure 5 shows the injection point, system layout, and flow of natural gas throughout the engine of a dual fuel system for a four-cylinder application (a much smaller version than a 12 or 16 cylinder locomotive engine). Dual fuel systems also allow full diesel operation when natural gas is not available, and it is relatively inexpensive compared to a dedicated natural gas system because it retrofits on existing engines.

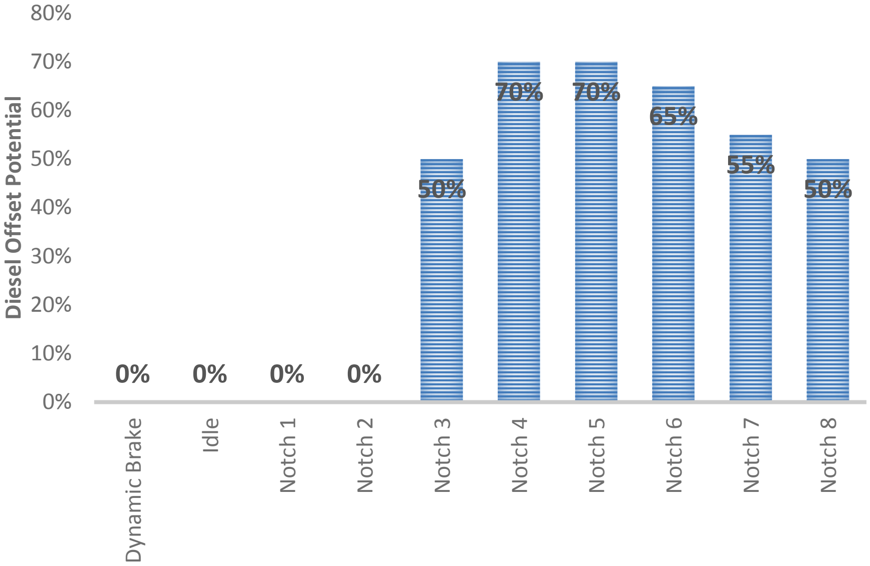
Figure 5. Dual Fuel, Compression Ignition (diesel Pilot) Natural Gas Engine Fuel System



2.1.1 Four-stroke Diesel Natural Gas Solution

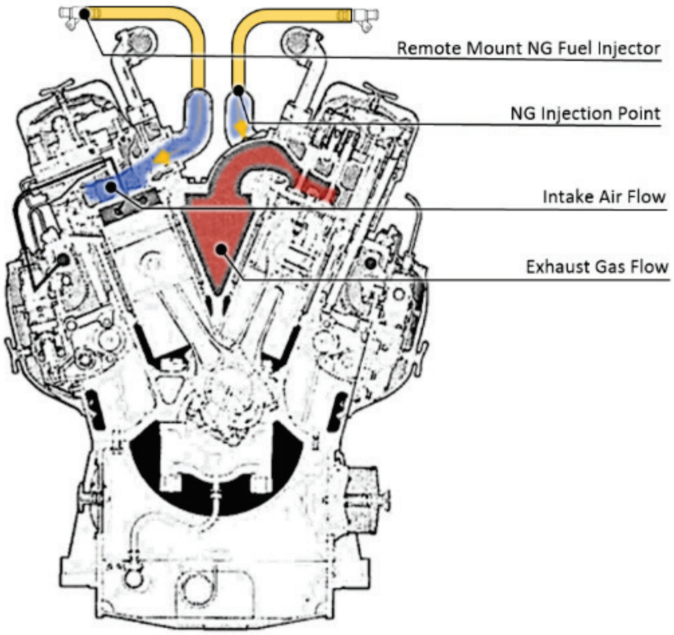
Energy Conversions Incorporated (ECI) offers a dual fuel solution for four-stroke diesels, including the Alco/MLW and GE locomotives used by some NYS short lines. ECI's solution uses similar engine designs for both of these locomotive types, which includes an electronic control box, sensors, wiring, and gas control hardware. The system is fully automated when displacing diesel with natural gas with no noticeable difference to the operator. ECI's dual fuel technology detects the necessary operational variables with sensors to determine when to use natural gas. The system has a diesel only mode and is fully fail safe; in the event of natural gas or electric power loss, it switches the engine to diesel only while continuing to generate electrical power. The amount of diesel fuel offset by natural gas is monitored and controlled to ensure ideal engine performance and safety while maximizing natural gas substitution. The typical natural gas offset rates for each throttle notch are shown in Figure 6.

Figure 6. Estimated Natural Gas Offset Rates



Dual fuel operation starts by opening the automated natural gas cutoff valve and then controlling natural gas fuel rate through the flow control valve. Natural gas is delivered to each cylinder after the turbocharger and near the intake valve. Due to the proximity of the intake ports to the exhaust ports and the associated thermal issues, natural gas injectors are mounted away from the intake manifold to maintain sufficiently low temperatures. A cross sectional view of the Alco 251 engine (virtually identical to the GE diesel engine) in Figure 7[7] shows the layout of the intake, exhaust, and proposed natural gas injection hardware. Natural gas injection timing is configured to minimize unburned natural gas being exhausted before combustion ("blow-through") due to valve overlap. The locomotive's governor automatically compensates for the injected natural gas by reducing the amount of diesel fuel while still achieving the selected throttle notch power level.

Figure 7. Alco 251 Cross Sectional View Showing Proposed Natural Gas Injection System



2.1.2 Two-stroke Diesel Natural Gas Solution

ECI also offers dual fuel natural gas technology for EMD locomotives. The control strategy for two-stroke dual fuel combustion is similar to their four-stroke application. However, it requires reconfigured cylinder heads with high pressure gas injectors, pistons, and manifolds due to the two-stroke engine configuration. This solution injects natural gas with the pilot diesel directly into the combustion chamber to limit blow-through and maintain consistent fuel ratios. Natural gas is injected into the cylinder near the bottom of the piston's stroke when cylinder pressures are low using an electro-hydraulic valve incorporated into the head. This requires far less injection pressure than late-cycle injection, and allows the fuel and air to mix thoroughly during compression. The system achieves full rated engine horsepower with only 120-150 psi of injection supply pressure. Extending

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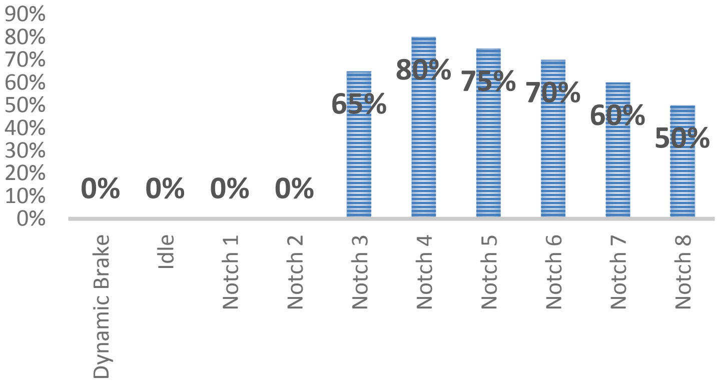
[7] Developed from http://www.workboatequipment.com/images/bombardieralco-diesel-manufacturing-202995.jpg

the performance of the aftercooling circuit is required for rated power performance, as less than optimum aftercooling will result in a reduction of maximum power output. The ECI conversion kits include ECI pistons and cylinder heads, ECI gas injectors, pilot fuel (diesel) control system, electronic control unit and corresponding electronic components and software, gas supply piping and necessary flow controls, pneumatic controls, fittings and hoses, wiring cabinets, harnesses, switches and diagrams, water system aftercooling tanks, pumps and valves, and a complete reference guide including installation, maintenance, and parts documentation.

The natural gas substitution rates for ECI's two-stroke dual fuel system (as shown in Figure 8) are higher than the four-stroke system. The diesel fuel is used primarily for ignition and most of the energy comes from the combustion of the natural gas. This is enabled through the use of specifically designed pistons, manifolds, and injectors, which result in better combustion control and reduced knock.

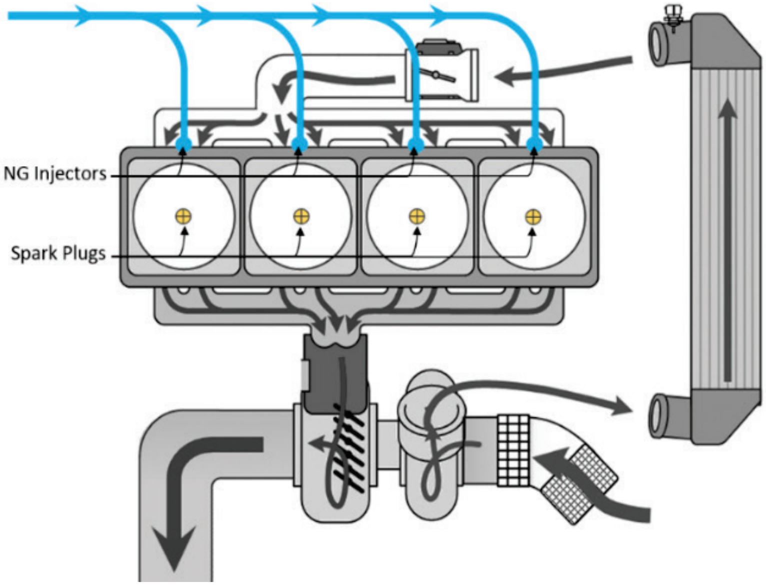
Figure 8. EMD Dual Fuel CNG Offset Potential



2.2 Spark-Ignited Natural Gas Engines

Dedicated natural gas systems operate similar to a gasoline engine, requiring a throttle and spark ignition to combust the natural gas/air mixture in the cylinder. This technology has proven successful for smaller engines, such as light- and medium-duty trucks. However, the inherent power loss and decreased efficiency in a spark-ignited engine design becomes more apparent in larger engines found in heavy-duty trucks, locomotives, and marine vessels. Engine manufacturers are further advancing this technology to be an equally viable option on par with a compression-ignition engine. The flow of natural gas and the design of a dedicated spark-ignited engine is shown in Figure 9 for a four-cylinder application (a much smaller version than a 12 or 16 cylinder locomotive engine). Dedicated natural gas systems will use similar technology for a two- or four-stroke engine.

Figure 9. Dedicated, Spark-ignited natural gas Engine Fuel System



ECI's dedicated, spark-ignited solution is configured similarly to their dual fuel system on two-stroke engines. It requires reconfigured cylinder heads with high pressure gas injectors, pistons, and manifolds. By means of an electro-hydraulic valve incorporated into the head, natural gas is injected into the cylinder near the bottom of the piston's stroke when cylinder pressures are low (requiring less injection pressure than late-cycle injection) and allows fuel and air to mix thoroughly during compression. This system includes redesigned pistons and a prechamber spark ignition system. The ECI spark-ignited prechamber replaces the diesel injector and, at the top of the piston's stroke, provides enough ignition energy to light the lean mixture of natural gas and air in the main combustion chamber. This oil-cooled prechamber is supplied with natural gas separately from the main chamber, and the engine controller continuously adjusts the prechamber air-fuel ratio for ideal ignition. Some of these components, including the control box (top left), high pressure injectors (bottom left and top right), and the engine block layout are shown in Figure 10.

Figure 10. ECI CNG System Components for EMD Locomotives

ECI's dedicated natural gas system and dual fuel system for two-stroke locomotive engines are very similar and both systems have similar costs. In many cases, it would likely make sense to convert a two-stroke locomotive engine to a dedicated system for the additional diesel offset, including natural gas use at notch 2 and below which is not possible with the dual fuel systems. For four-stroke locomotive engines, the dual fuel solution is much simpler and costs significantly less than the dedicated natural gas solution. VeRail Technologies also offers a dedicated natural gas option that completely replaces the engine and generator with a power module. This system, described in the previous section, can be used in almost any locomotive since it does not use any of the original engine components. It provides a very high-efficiency and clean operation, but is very expensive.

2.3 Environmental Factors

Natural gas is a clean burning fuel with the potential to significantly reduce emissions. Emission reduction is dependent on the optimization of the engine for natural gas combustion. Unfortunately, the existing locomotive diesel engines, which a dual fuel solution would still use, were not designed or optimized for natural gas. However, there are meaningful environmental benefits from using natural gas technology in this application.

Natural gas can have a significant impact on the production of **carbon dioxide (CO_2)** when used in an internal combustion engine because it contains less carbon than other fossil fuels. CO_2 plays a large part in smog formation and contributes to global warming. The reduction of CO_2 is primarily based on the offset of diesel fuel.

Particulate matter (PM) is a combustion byproduct that occurs under very rich operating conditions. A properly configured natural gas engine will not emit PM. Reductions are significant with the dual fuel technology because much of the high notch position diesel fuel use (which produces the most PM) is offset with natural gas. PM emissions are almost completely eliminated in dedicated natural gas engines.

The formation of **nitrogen oxides (NO_X)** in an internal combustion engine is due to high combustion temperatures and available oxygen (lean burn). Natural gas has a much lower flame temperature, which reduces the overall NO_X formation rate. The relatively low stressed configuration of a large, dual fuel natural gas and diesel engine lends itself well to NO_X reduction as compared to light duty engines where higher compression ratios and spark advance (to compensate for lower energy densities) increases flame temperature. Dedicated natural gas engines further reduce NO_X to extremely low values.

The proposed dual fuel systems retrofit on older diesel engines, so unfortunately there are some downsides to the overall emission profile. One of the major sources of increased emissions from a dual fuel system on a large, four-stroke diesel engine is valve overlap and the potential for the unburned natural gas fuel and air mixture to exit through the open valves between combustion strokes ("blow-through"). The valve overlap helps with cylinder evacuation and does not waste diesel fuel because that is directly injected into the cylinder. However, when the natural gas mixes with air prior to the combustion chamber, the potential for some loss (due to boost pressure on the back side) is inevitable. Timed natural gas injection (to only inject fuel when the exhaust valves are closed) and custom cam shafts (to reduce valve overlap) are two possible solutions to this issue. Blow-through is not an issue on two-stroke diesel engines since they inject gas directly into the combustion chamber with the timing and volume precisely controlled.

The blow-through issue increases **total hydrocarbon (THC)** emissions due to the release of unburnt fuel. However, natural gas thoroughly mixed with air before combustion reduces hydrocarbons by 50-80 percent and the resulting non-methane hydrocarbons (NMHC) are much less. Blow-through is less of an issue with dedicated natural gas systems, but THC emissions are still higher because the fuel mixes with the intake air.

Incomplete combustion produces **Carbon monoxide (CO)**. While natural gas thoroughly mixes with air as it injects into the cylinder, there may be issues with complete combustion due to the diesel's slower ignition reaction time. Dual fuel engines produce more CO because they are not optimized for natural gas.[8] Dedicated natural gas engines perform better at controlling CO than dual fuel systems and result in Tier 0+ levels for CO.

Figure 11[9] shows the comparative emission factors for diesel and natural gas in locomotive systems. These emission factors and the potential fuel offset for each technology determines the overall emission reduction potential.

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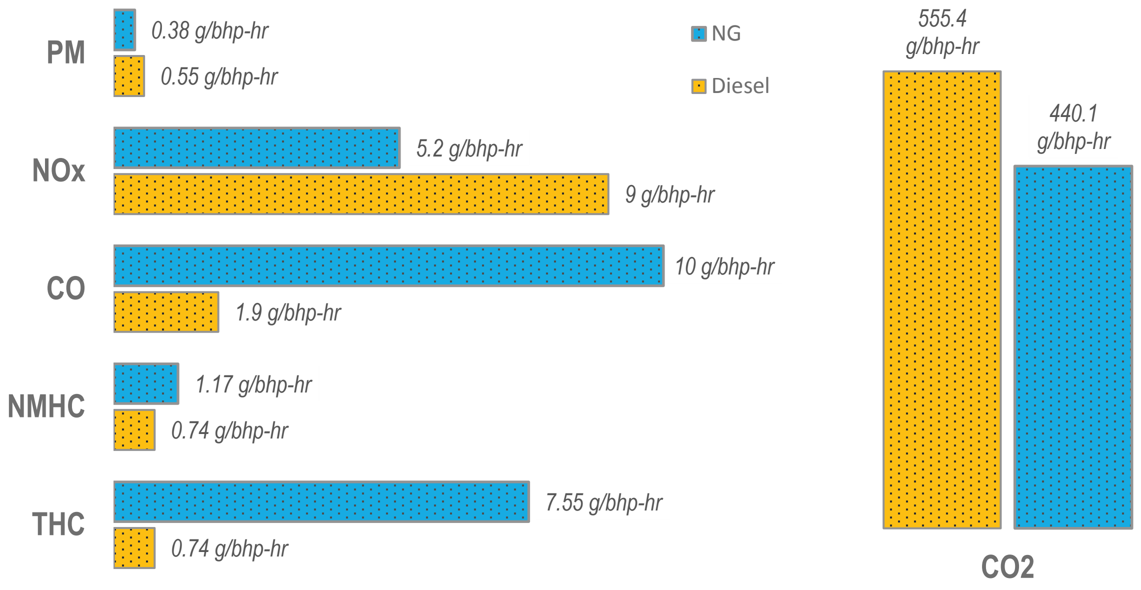
[8] Bruce Chehroudi (1993) Use of Natural Gas in Internal Combustion Engines. https://www.researchgate.net/publication/266374105_USE_OF_NATURAL_GAS_IN_INTERNAL_COMBUSTION_ENGINEs

[9] BNSF Railway Company. An Evaluation of Natural Gas-Fueled Locomotives. http://www.arb.ca.gov/railyard/ryagreement/112807lngqa.pdf

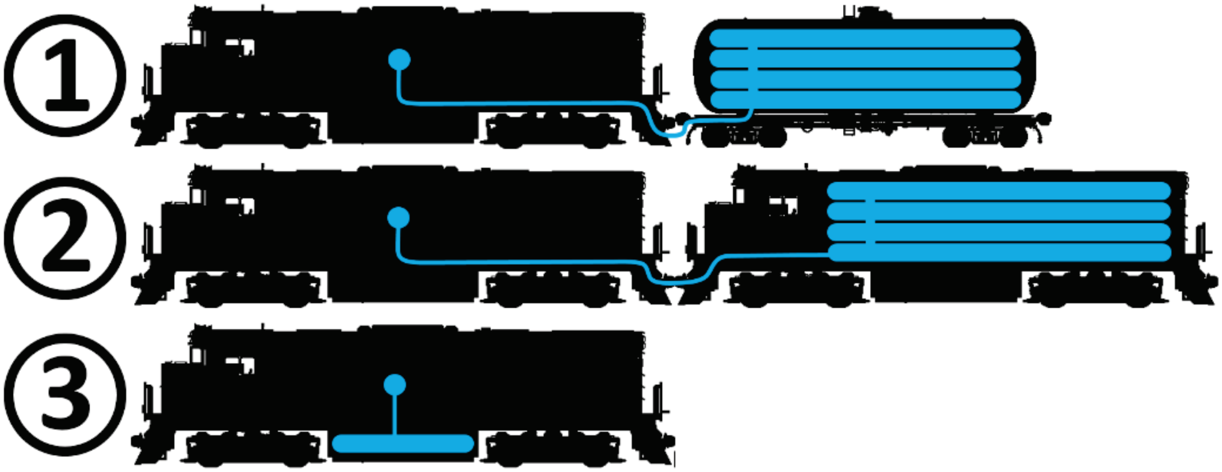
Figure 11. Natural Gas Locomotive Emission Factor Comparison



2.4 Fuel Storage Technologies

There are various configurations for fuel storage for natural gas powered locomotives with options for CNG and LNG. The fuel tender configuration (option 1 in Figure 12) is designed for long haul because of its large fuel storage capacity and is sufficient for LNG or CNG. “Mother-slug” locomotive configurations are optimal when a single locomotive can generate the power required but needs a larger tractive force. For these configurations, the “slug” locomotive is completely gutted except for the drive trucks and control system. It is then connected behind a similar locomotive (with its power system intact) and shares the electrical energy generated by the first locomotive. This provides an excellent opportunity for natural gas storage since the shell of the “slug” can house the fuel tanks and the weight of the cylinders provides ballast for increased traction (option 2 in Figure 12). An option for switcher and short haul locomotives is belly tank storage for CNG or LNG (option 3 in Figure 12). These tanks are submerged in the diesel tanks to optimize fuel storage density and meet tight packaging requirements. This design can store up to 500 gallons of CNG within conventional sized diesel fuel tanks to fully optimize space and reduce the footprint of retrofit tanks. However, the cost and complexity of a belly tank for NYS short line applications would likely be prohibitive. Additional custom arrangement options are also available and configurations for frame mounted and roof mounted fuel storage solutions are further discussed. CNG storage cylinders would take the place of the large diesel tank in the belly of the locomotive for dedicated CNG configurations as it requires no diesel fuel.

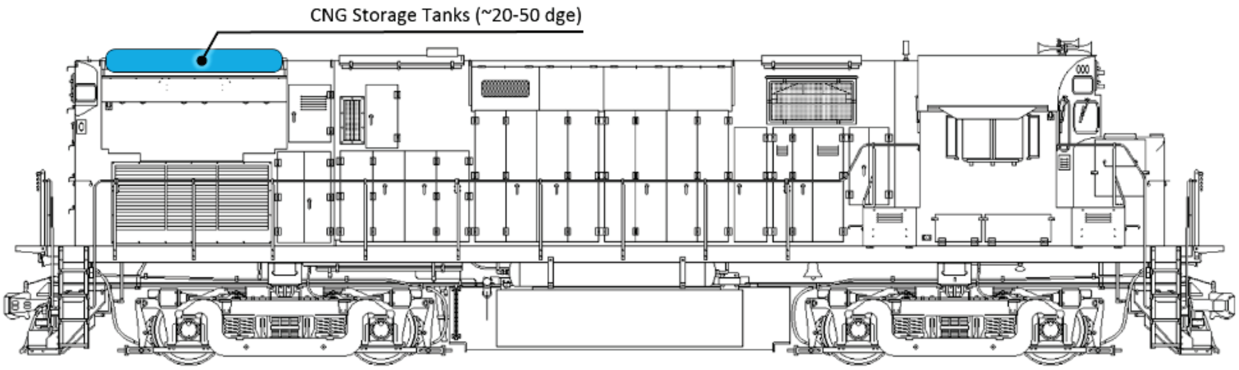
Figure 12. Natural Gas Fuel Storage Layout Options



Type 1 steel CNG fuel storage cylinders are appropriate for this application where weight is not a concern and are available in a variety of sizes. They can be installed in various configurations and plumbed together to result in a modular fuel storage solution. The required volume of CNG fuel storage is dependent on fueling schedules/types, daily operations, and operator preferences. While dual fuel systems can revert to full diesel operation if onboard CNG is depleted, there should be a sufficient amount of CNG to optimize the investment and provide as much diesel offset as possible. Dedicated CNG systems must include sufficient storage to complete all current tasks efficiently and in a similar manner to the diesel locomotives.

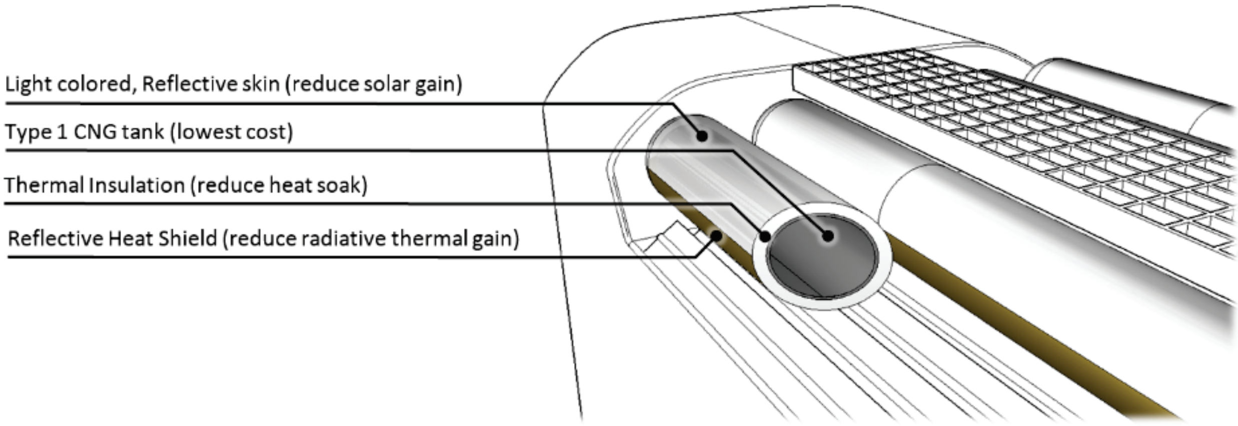
The Alco and MLW locomotives have limited available space onboard, so adding CNG storage may be a challenge. Low overpasses restricts locomotive height and placing tanks along the sides of the locomotive is potentially hazardous if struck by debris (e.g., trees or branches). It is possible to place the CNG tanks above the radiator at the rear of the locomotive, in eight inch diameter cylinders, as shown in Figure 13.

Figure 13. CNG Storage Tank Configuration



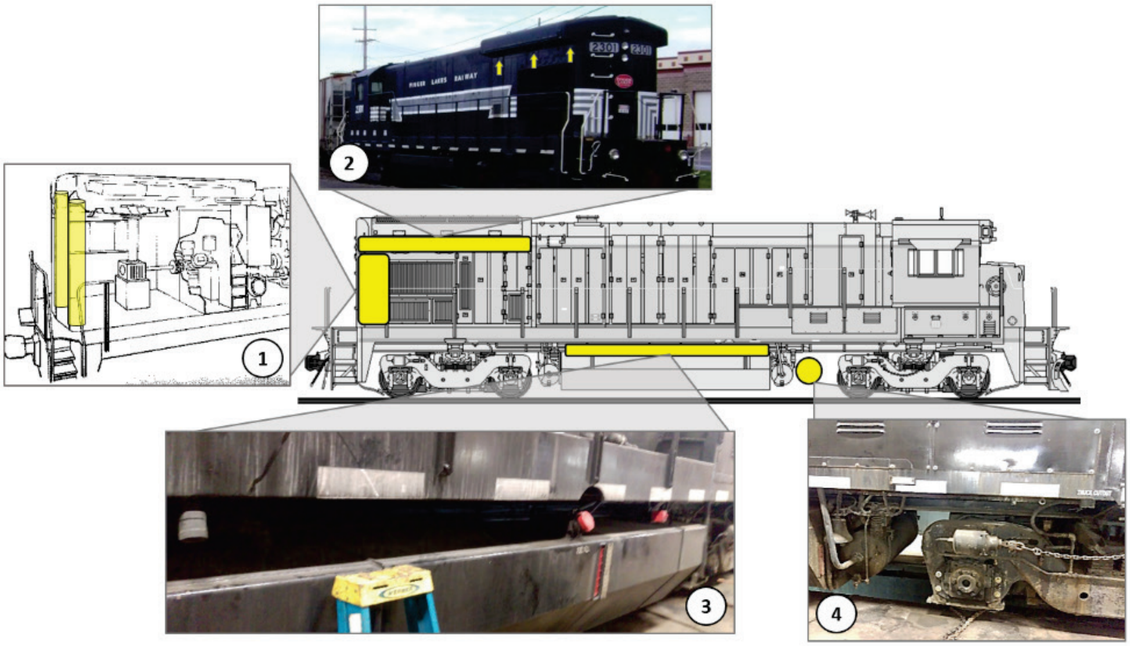
However, this location may present some thermal issues due to radiator exhaust air and solar radiation during high ambient temperatures. Tank insulation and reflective materials (as outlined in Figure 14) may alleviate these issues and enable tank placement in this radiator cavity.

Figure 14. Potential CNG storage Tank and Insulation Details



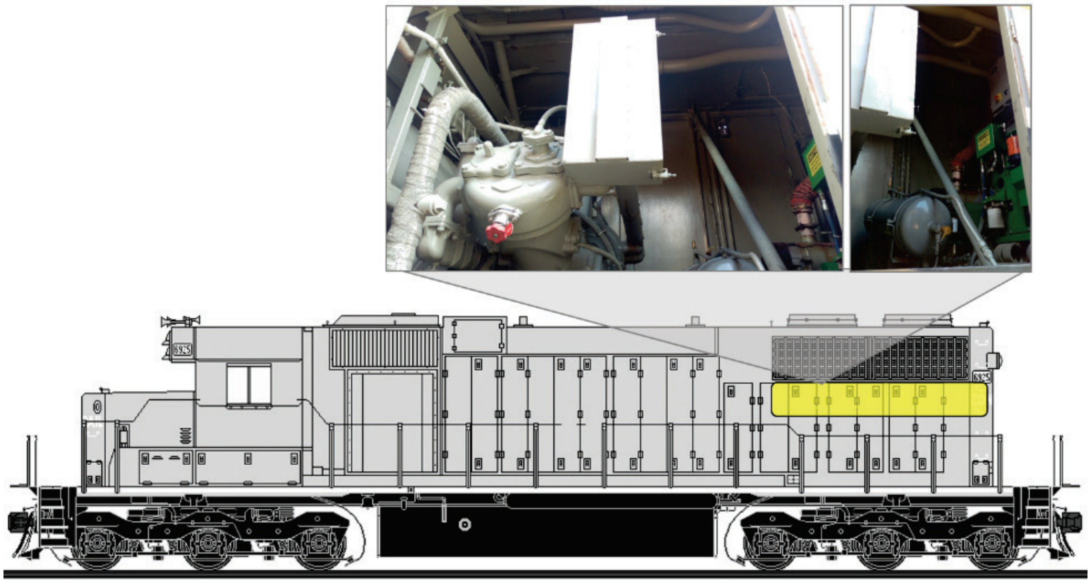
There are a number of available spaces on the GE B23 locomotive for CNG fuel storage that do not interfere with operations or obstruct the use of onboard equipment. Figure 15 depicts the possible locations for CNG tanks on the GE B23 locomotive including: 1) the “sand boxes” at the rear of the locomotive; 2) under the overhang of the radiators; 3) along the side of the fuel tank; and, 4) just behind the front trucks. Depending on the specific volume of fuel required, one or more of these locations is an option.

Figure 15. GE B23 CNG Fuel Storage Options



EMD locomotives have significant free space in the rear with their radiator configuration. The area below the radiator is mostly free with the exception of the air compressor (to power onboard equipment) and an idle reduction module (which could be reconfigured to free up even more space). CNG cylinders could mount to the ceiling of the rear compartment for dual fuel configurations requiring less fuel, as shown in Figure 16.

Figure 16. EMD SD38 CNG Fuel Storage Options



3 Natural Gas Infrastructure

Short line railroads using natural gas locomotives would need fueling infrastructure as well as potential modifications to locomotive maintenance or storage facilities. The use, fueling, and safety aspects of CNG are significantly different than current diesel operations and would require several onsite infrastructure additions and alterations for optimal operational performance and safety.

3.1 Fueling Technologies

U.S. automotive applications have used CNG fueling stations since the early 1930s. CNG station technology has greatly evolved and improved since that time so that CNG can now dispense as quickly and efficiently as its liquid fuel counterparts. CNG stations are a fast-fill infrastructure, where fueling the vehicle is similar to gasoline or diesel, and time-fill infrastructure, where the vehicle connects and automatically fuels unattended for an extended period (usually overnight). A portable trailer system filled at a nearby CNG station can also serve as an onsite fueling option. CNG stations typically include some level of redundancy to ensure continued operation, for example, installing more than one compressor in case one fails. Since there are often no nearby CNG stations to rely on as a back-up, redundancy improves system reliability. There are several companies that supply compression equipment or fueling trailers.

3.1.1 Fast-fill Stations

Fast-fill stations are available in either buffer or cascade configurations. These stations, designed to serve many vehicles, are typically built for a large fleet and may also provide access to other fleets or privately-owned CNG vehicles. For short line railroads that only have a few locomotives, a fast-fill station would be under-utilized and not economically feasible unless built in collaboration with another large fleet that would also use it.

Buffer fast-fill stations are ideal for high fuel use vehicles that require immediate fueling, one after another. Transit buses frequently utilize this configuration so they can sequentially fuel multiple buses (each with significant fuel demand) at the end of their shift. Buffer systems primarily fuel directly from larger compressors into the vehicle and require a smaller quantity of CNG storage. These stations typically serve a captive fleet and dispense large quantities of fuel in a relatively short period of time.

Cascade configured fast-fill systems primarily dispense CNG from storage tanks and are typically used for retail applications or for fleets of smaller vehicles that require fueling at varying times. Some fleet operations and most public CNG stations are cascade fast-fill configurations. Fast-fill systems include (also shown in Figure 17):[10]

- **Dryer –** removes water or water vapor from the natural gas supply prior to compression using desiccant material. Some dryers require the desiccant to be periodically replaced, while others will regenerate the desiccant.
- **Compressor –** compresses natural gas to the appropriate pressure required. Compressors come in multiple sizes and are often “ganged” to provide redundancy and consistent pressurized operation.
- **Priority-sequential panels –** determines the priority and sequence of CNG flow from the compressor into storage or directly to the dispenser. These valve systems are often custom built to station requirements.
- **Storage –** American Society of Mechanical Engineers-certified storage tanks are used to store CNG and can be cylinders or spheres.
- **Dispenser –** dispenses CNG into vehicles. There are many types of dispensers with similar metering and charging features of conventional fuel dispensers.
- **Temperature compensation system –** uses an algorithm to adjust for ambient temperature and temperature of compression to ensure that vehicles receive a complete fill.

Figure 17. Fast-fill CNG Station Equipment (shown for a Cascade Configuration)

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[10] Photos courtesy of AET Energy Solutions © 2013

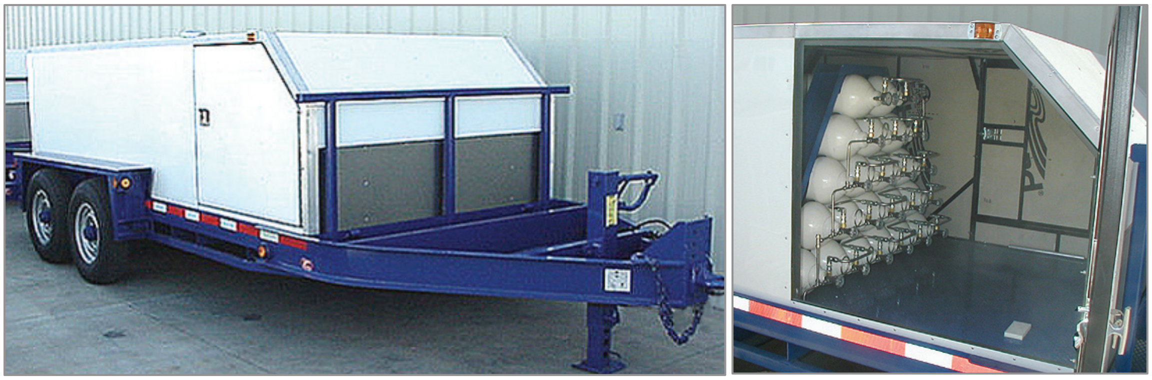
3.1.2 Time-fill Stations

Compressors provide fuel to the vehicle directly in a time-fill station with no storage and are ideal for fleets that return to a central location for an extended period of time. Time-fill stations have significantly lower equipment and installation costs because they do not require storage, priority, or sequential fueling components. The size of the compressors is directly dependent on the volume and timing requirements of the vehicles. Time-fill stations are specifically designed to fuel parked vehicles over an extended period of time while unattended. The vehicles connect to a fill post at the end of the work day and filled for six to 10 hours between shifts.

3.1.3 CNG trailers

A CNG fueling trailer may be an option for a location with minimal CNG demand (few vehicles) and an existing nearby CNG station. This is the best, or perhaps only, option if a site lacks sufficient electric or gas supply and requires significant investment to provide this. It might also be considered if the limited volume of fuel consumed make the economics of building a full CNG fueling facility challenging. Figure 18[11] shows examples of trailer options.

Figure 18. Examples of Fueling Trailer Options



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[11] Photos courtesy of Tulsa Gas Technologies.

3.1.4 LNG options

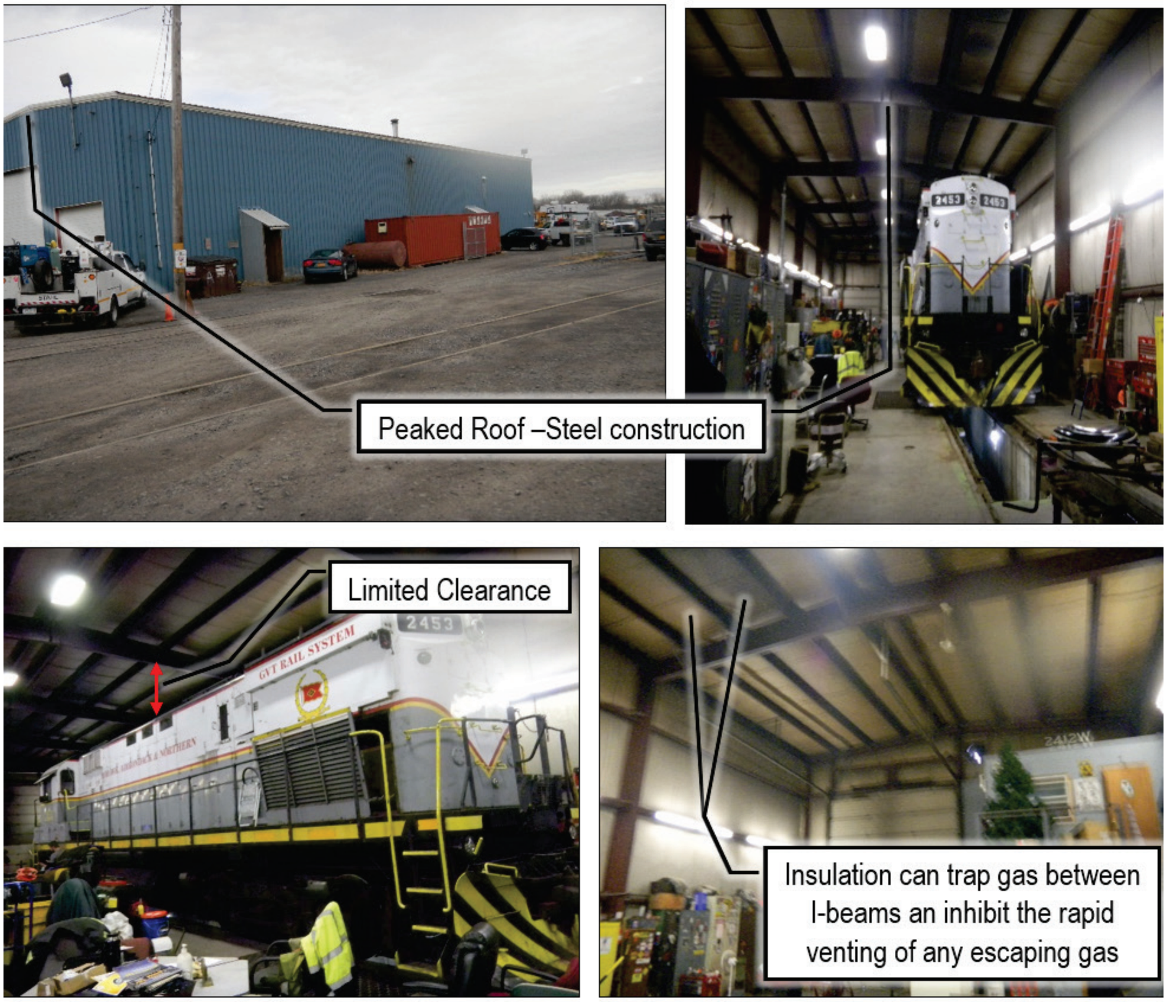
LNG fueling stations operate similarly to conventional gasoline or diesel stations and are not typically connected to a gas/fuel supply line. LNG is delivered from a large production facility and stored in cooled, insulated tanks onsite. The liquefied natural gas dispenses through pumps into vehicles that store it in heavily insulated tanks. While LNG infrastructure is relatively simple and low cost, the fuel has a cost premium and must be used quickly enough so new LNG is added to maintain low temperatures.

3.2 Maintenance Facility Retrofits and Requirements

Any facility used to perform maintenance or store a natural gas locomotive must adhere to code and regulation requirements, intended to prevent gas accumulation and ignition. These include building configurations that won't trap gas at peaks, ventilation systems that provide sufficient air exchanges, heating systems, lights, and other electrical systems that are not potential ignition sources, and gas detection equipment. Most of the short line maintenance facilities in this study are newer steel construction with high ceilings, which is typically good for upgrading to support CNG activities. However, further review of the facilities revealed a number of items that would necessitate significant retrofitting of the building for CNG code compliance.

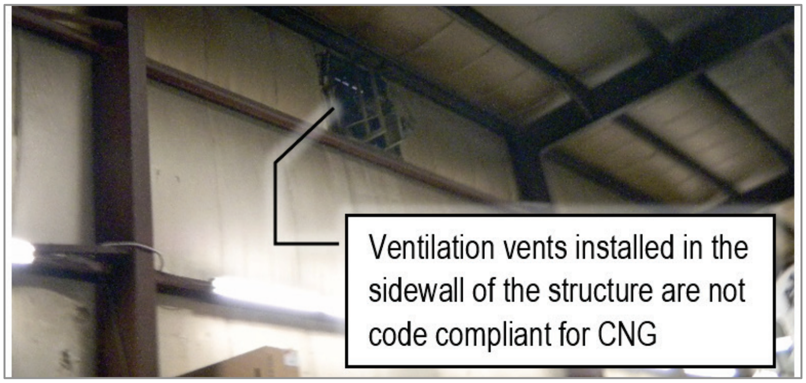
Almost all locomotive maintenance is performed in the garages, which also serve as heated storage during cold winter months. One major issue with these buildings for CNG maintenance is the ceiling design with support beams running parallel to the outside walls. The pockets created between each beam due to the roof pitch could trap escaping gas. Another issue is the minimal space between the top of the locomotive and the garage ceiling, which most likely does not provide sufficient clearance for proper ventilation (typically at least 16 feet). Therefore, it may be necessary to increase the ventilation system to provide the required air exchanges that ensures escaping gas exhausts quickly. Example pictures from the MHWA garage, which has similar characteristics to many of the others examined, shown in Figure 19 highlight the issues for CNG compliance.

Figure 19. Utica MHWA Maintenance Facility Considerations for CNG



SiThe National Fire Protection Association (NFPA) and NYS Fire code require any structure repairing or maintaining a CNG or LNG vehicle to provide continuous mechanical ventilation of at least five air exchanges per hour (ACH). The current ventilation systems would not likely meet this requirement (shown in Figure 20). The continuous ventilation requirement does not have to be followed if a continuously monitoring gas detection system is installed and interlocked with the ventilation, heating and other critical electrical systems, and the local fire department. However, the ventilation system still must meet the five ACH requirement when activated. The short line garages would need a major ventilation system upgrade to be code compliant.

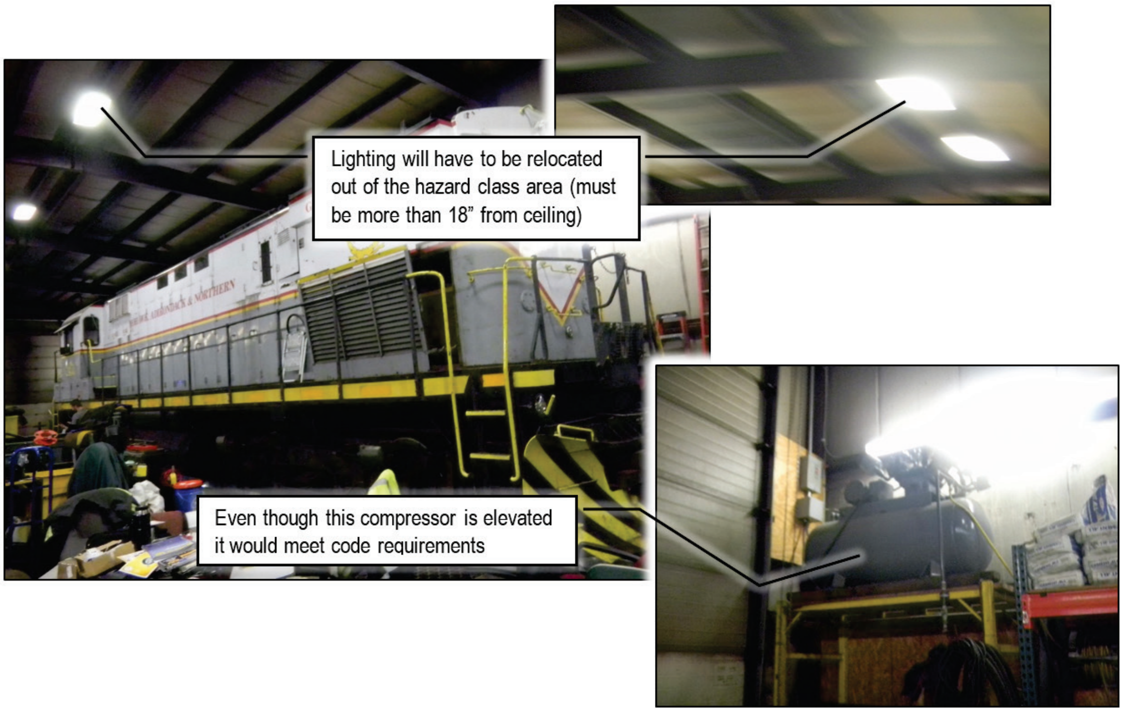
Figure 20. Existing Ventilation Fans



NFPA 30A section 7.6.6 prohibits the use of open flame heaters or heating equipment with exposed surface temperatures of 750° C or more in areas that might be exposed to ignitable concentrations of natural gas. All of these facilities have an open flame heater that is a possible source of ignition, example shown in Figure 21. Code calls for heating unit installation either outside the building or in a separate room with no connection to the repair area and sealed from the facility with a two-hour fire rated wall. NFPA 30A section 8.2.1 requires that all electrical equipment with 18 inches of the ceiling meet Class 1 Division 1 requirements for explosion proof devices. Many of the lights at the maintenance facilities will not meet this requirement and will have to relocate out of the hazard class area or meet the Class 1 Division 1 requirements. Figure 22 shows examples of noncompliant electrical equipment.

Figure 21. Existing Heating System

Figure 22. Electrical Equipment Details



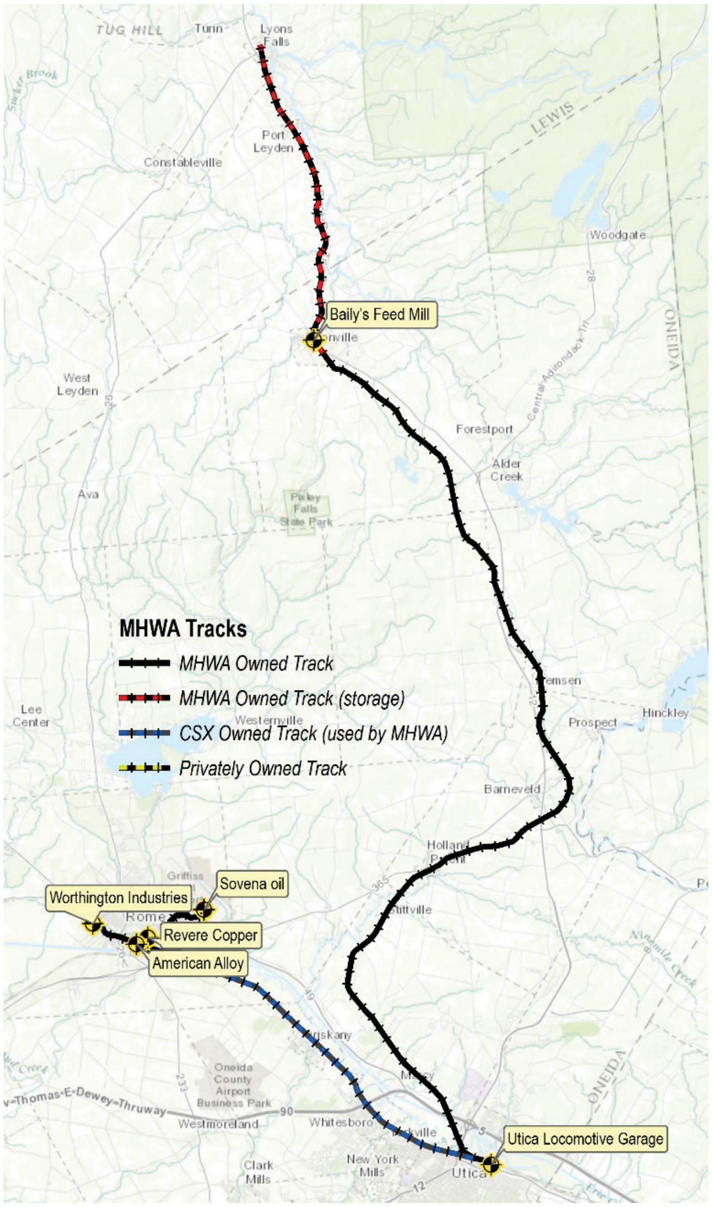
The cost to retrofit the maintenance garages for CNG code compliance is likely quite expensive. This would likely be cost prohibited for piloting a single dual fuel locomotive. One potential solution is to conduct routine maintenance outside. If major maintenance or storage is required, the CNG system could be completely defueled to move the locomotive inside.

4 Case Study: Mohawk, Adirondack & Northern Railroad

Mohawk, Adirondack & Northern Railroad (MHWA) is a Class III short line railroad based in Utica and owned by Genesee Valley Transportation (GVT). It provides switcher services, railcar storage, and local delivery for CSX, as well as providing other short moves for local customers. MHWA's track stretches north out of Utica to Lyon's Falls, with the final stretch between Boonville and Lyon's Falls used for railcar storage. MWHA utilizes the CSX mainline to transport railcars to various locations in the Rome area. MWHA also has a small operation out of Carthage with a single locomotive for local deliveries. Figure 23 shows the track layout (excluding Carthage).

Daily operations typically include a round trip from the Utica base to locations in Rome (approximately 30 miles). Customers in the Rome area include Sovena Oil, Revere Copper, American Alloy, and Worthington Industries. Weekly trips to Boonville serve Baily's Feed Mill by transporting several cars from the Utica CSX connection. Trips are conducted as needed to retrieve or deposit cars from the storage area north of Boonville. The Utica to Boonville route is approximately 90 miles round trip and often requires support crews to clear iced-over tracks during the winter months (particularly at road crossings). Carthage operations are minimal and typically only consist of local transport (less than two miles) on a weekly basis. CNG is not a good option for Carthage because of this limited use.

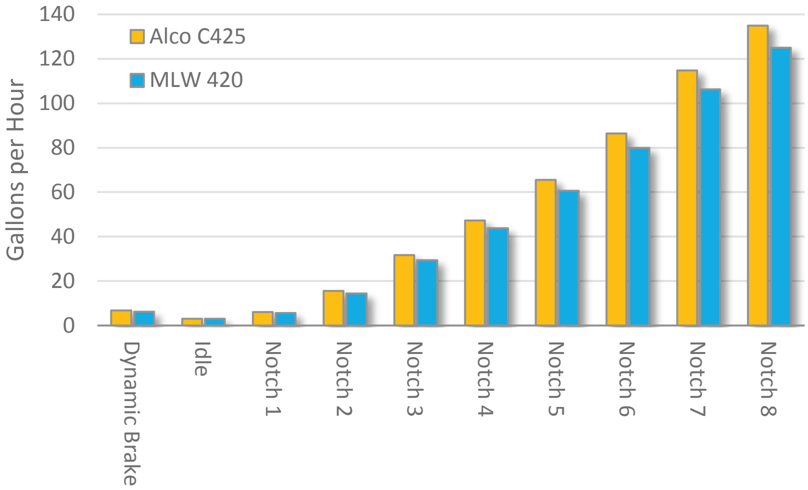
Figure 23. Mohawk, Adirondack & Northern Railroad Track Routes and Customers Served



Four locomotives typically operate out of Utica. Three of the four locomotives are Alco C425s built in 1964 and powered by Alco 251 16-cylinder, turbo-charged diesel engines rated at 2,500 hp. The fourth locomotive is a MLW 420 that is almost identical to the Alco C425s, but with a 12-cylinder engine rated at 2,000 hp. Of the four locomotives, numbers 2453 and 805 (both Alco C425s) see the heaviest use year round. Locomotive 2456 (also an Alco 425) is typically shut down during cold months to save on heating costs since there are fewer transport requirements in winter. Locomotive 2042 (the MLW 420) is in use throughout the year, but is typically not used for larger hauls due to its lower power level.

The Alco engine fuel system includes one primary feed line and three returns (one return from each bank's fuel galley and one from the pressure regulator). Due to this complexity, detailed fuel flow testing was not feasible. However, GVT Rail has extensive experience with Alco locomotives (a current employee worked for Alco to develop the C425) and provided actual fuel flow testing results, shown in Figure 24.[12]

Figure 24. Estimated Alco C425 and MLW 420 Fuel Flow Rate



Representative duty cycles for the MHWA locomotives were identified to fully evaluate the potential benefits of natural gas technology. The Federal Railroad Administration (FRA) requires locomotives to carry event recorders, which document operational data. Data monitored by the event recorders include traction motor current, brake pipe pressure, independent brake, throttle position, reverse, horn, and other parameters. This data was periodically downloaded in ~90 hour segments, and used to develop an overall average duty cycle profile for MHWA operations. This data, shown in Figure 25 as a percent of the total in each throttle notch, provides critical power and fuel flow distribution information.

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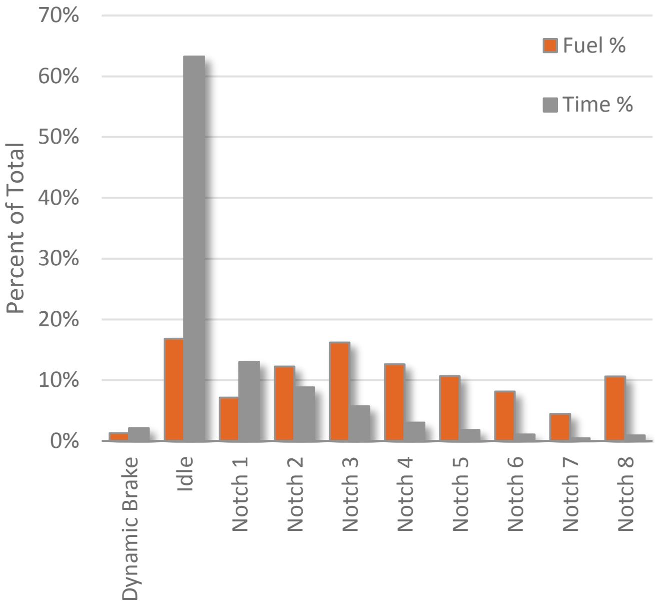
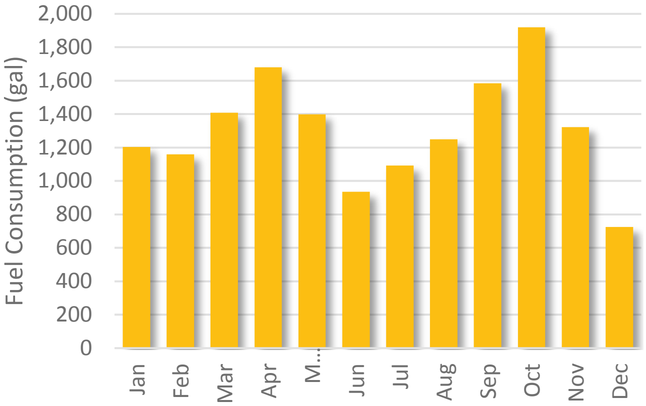
[12] Large hills near the Scranton rail yard allow locomotives to operate, under load and at fixed throttle positions, for several hours continuously. Fuel flow rates were previously estimated by GVT staff by comparing fuel levels before and after three+ hour, fixed throttle pulls.

Figure 25. Percent of Total Time and Fuel Use in Each Throttle Notch



GVT provided monthly fuel records to estimate yearly locomotive utilization. Due to a switch in fuel venders during 2015, fuel use per month for every individual locomotive was not available. Therefore, the monthly data provided an estimated average of the yearlong fuel consumption profile typical for each locomotive. This profile, shown in Figure 26, indicates an overall total annual fuel consumption of approximately 15,700 gallons for each of the two primarily operated locomotives.

Figure 26. MHWA Monthly Fuel Consumption



4.1 Natural Gas Feasibility

ECI offered a dual fuel retrofit system, identified as the best natural gas technology for MWHA locomotives due to the typical transport distances and power requirements. They quoted the overall system cost at $77,300 for each locomotive and $44,500 for tech support and commissioning. These costs do not include the installation done by MHWA employees.

Overall, MHWA has relatively modern maintenance facilities, although they would need modification for CNG maintenance work. MHWA should expect to have $150,000 to $250,000 in retrofit expenses for the facility at Utica. The facility site presents a number of unique problems in supplying adequate electric and natural gas for an onsite fueling station. The facility is between seven active rails, as shown in Figure 27. The majority of the rails are used for storage sidings, but two are main line transportation rails. The cost to get a natural gas pipeline to the locomotive facility would be extremely expensive. In addition, the facility does not have three-phase power and the existing electric service is an old 4800-volt system that would require an upgrade to support a station.

Figure 27. MHWA Utica Rail Yard

Due to the costly infrastructure upgrades for an onsite fueling station, the most viable fueling concept is a 100 DGE capacity trailer. There is a Clean Fuels CNG fueling station at a NYSDOT facility approximately two miles from the Utica rail yard that could easily provide the fuel needed for one or more dual fuel CNG locomotives. A 100 DGE trailer’s purchase price is approximately $40,000 or the lease option is $1,000 a month.

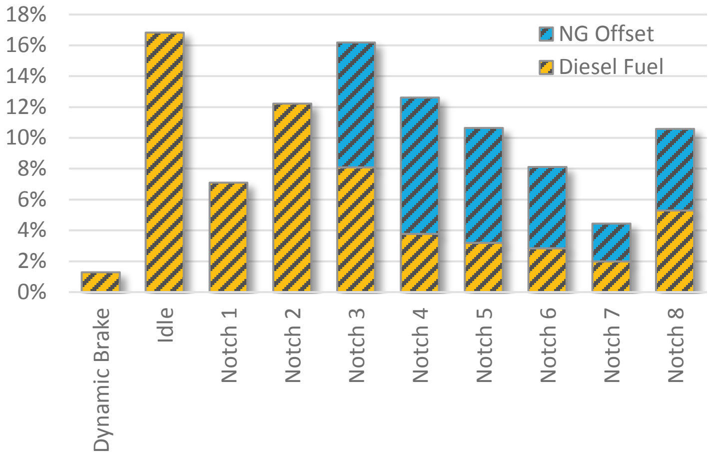
Dual fuel technology blends natural gas and diesel in varying ratios depending on conditions, so the dynamic operation of the locomotives impacts the overall fuel offset. Figure 28 shows the predicted natural gas fuel offset, based on duty cycle data (Figure 25), fuel consumption rates (Figure 24), and offset levels per notch predicted by the technology manufacturer (Figure 6). This analysis results in an overall annual average fuel offset of approximately 37 percent; a reduction of over 6,000 gallons of diesel fuel annually per locomotive.

4.2 Economic Analysis

Off-road diesel fuel costs have decreased significantly in recent years, going from a high of $3.22 per gallon at the end of 2014 to a low of $1.75 a gallon in October of 2016. These fuel prices do not include road taxes as all locomotives and associated equipment are off-road only. The current public fuel cost for CNG at the NYSDOT Clean Energy Station in Utica is $2.59 per gallon. Site managers and Clean Energy personnel determined an offering price of $2.49 to MHWA for the anticipated volume by dual fuel CNG locomotives.[13]

Figure 29 shows the overall upfront costs expected for MHWA to install a dual fuel system on one locomotive and use natural gas. For this application, it may be prudent to perform locomotive maintenance outside to avoid facility retrofit costs (at least temporarily).

Figure 28. Diesel Fuel Consumption Offset



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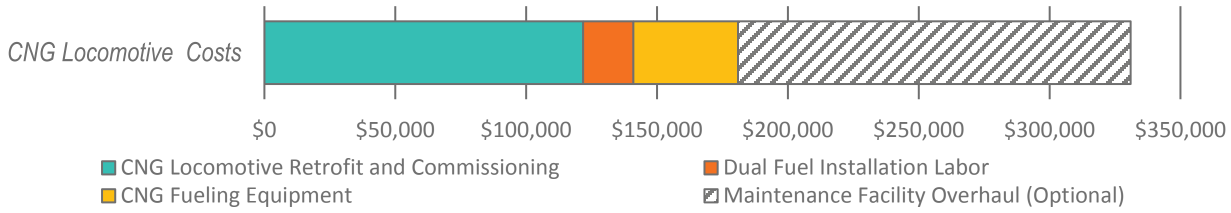
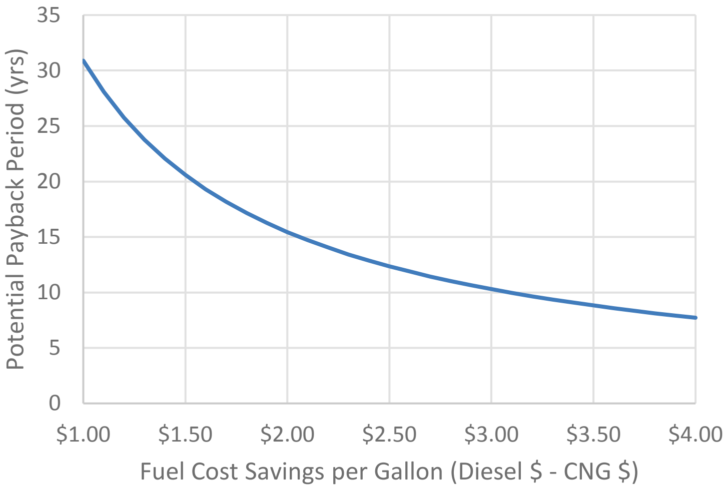
[13] Arrived at through conversations with Clean Energy – Leo Cortiza (917) 832-0643.

Figure 29. CNG Locomotive Startup Costs



Payback on the initial investment for all equipment to use CNG in an MHWA locomotive is not possible with a higher cost for natural gas than diesel. However, using natural gas has environmental benefits and may provide more stable fuel costs if diesel prices rise to previous levels or higher (~$4.00 per gallon). Exactly how long it could take for the price of diesel fuel to reach levels that make the locomotive dual fuel solution economically viable for MHWA is not clear.[14] Based on the upfront costs outlined in Figure 29 (excluding maintenance facility upgrades), Figure 30 shows the potential payback period for various fuel price differentials between diesel and natural gas per DGE (this assumes diesel fuel is *more expensive* than CNG fuel, which is not currently the case).

Figure 30. Potential System Payback Periods



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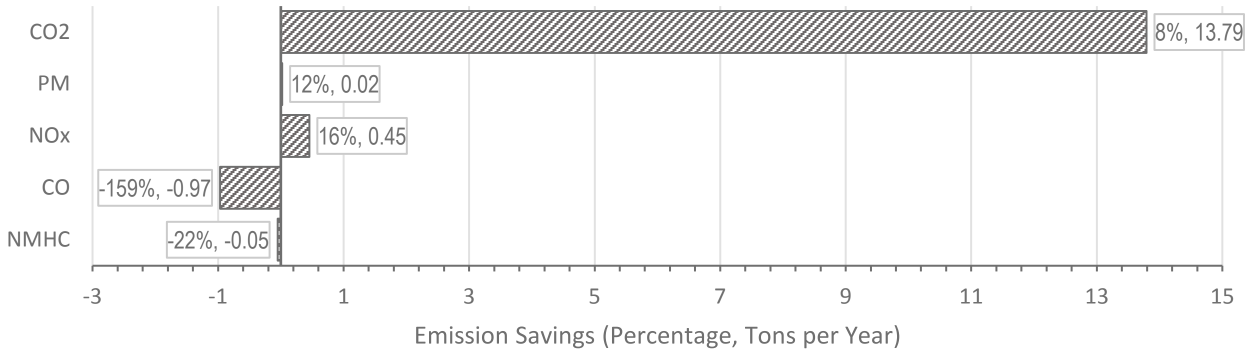
[14] Short-Term Energy and Summer Fuels Outlook. U.S. Energy Information Administration. https://www.eia.gov/forecasts/steo/report/prices.cfm

The environmental impacts of natural gas use by MHWA show some potential to reduce harmful emissions. The most significant savings are for NO_X and PM emissions with predicted reductions of 16 percent and 12 percent respectively compared to diesel. CO_2 emissions are also reduced by eight percent due to less diesel use. However, due to natural gas cylinder blow-through and incomplete combustion, CO and NMHC emissions are increased by 159 percent and 22 percent respectively. Figure 31 shows the actual emission reduction potential (shown in tons per year, negative values denoting an increase).

Figure 31. Annual Emission Reduction Potential by Percentage and Tons per Year

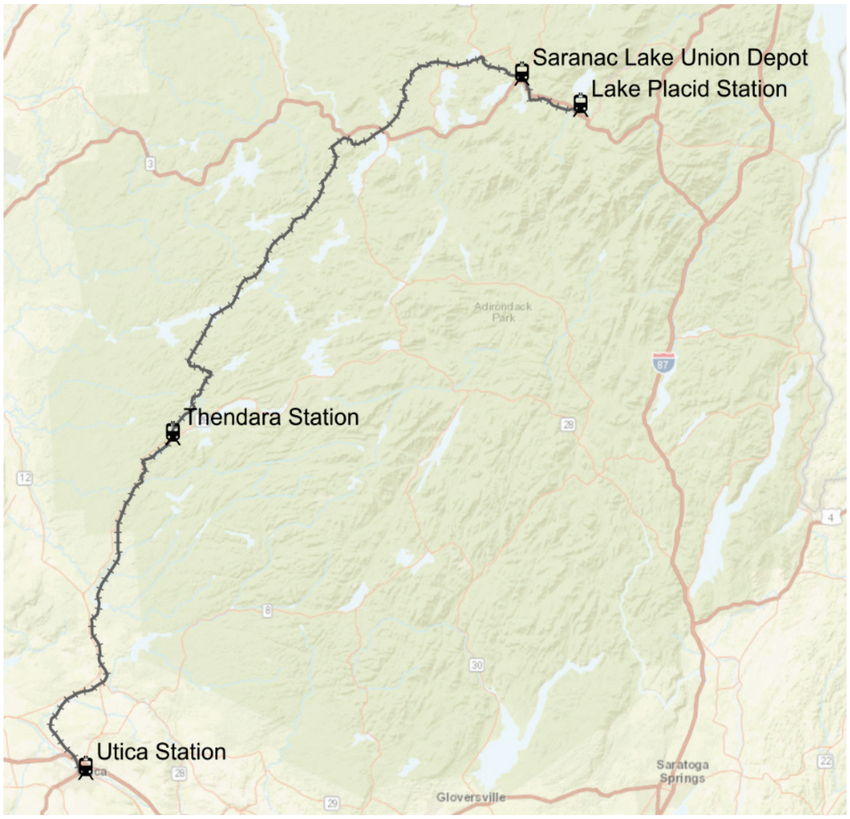


5 Case Study: Adirondack Scenic Railroad

In addition to the GVT freight operation (MHWA) operating out of Utica, the Adirondack Scenic Railroad (ADIX) is also based there. This operation was investigated as a possible collaborative partner to MHWA for CNG deployment as they could potentially share fueling infrastructure and maintenance facilities, which might improve the economic viability for CNG.

ADIX is a passenger rail service in the Mohawk Valley and Adirondack Park. Stations include Utica, Thendara (Old Forge), Saranac Lake Union Depot, and Lake Placid as shown in Figure 32. Operations are active between May and December with a total of 400-500 trips per year throughout the system, serving over 75,000 riders annually. From Utica to Remsen ADIX uses MHWA tracks. All tracks north of Remsen are State owned and operated.

Figure 32. Adirondack Scenic Railroad



ADIX locomotives examined for converting to natural gas are those based in Utica, which could leverage resources with MHWA. This rail operation conducts trips 68 miles north to Thendara and back during the warmer months. Other specialty trips throughout the year, such as the Polar Express, Beer & Wine, and holiday routes, are typically shorter. The Utica to Thendara route has an average speed of 30 mph and includes a six-mile long, steep grade uphill section that necessitates multiple locomotives to maintain speed. This route requires two or three locomotives, depending on the number of cars, for both power output and traction purposes. Due to the the hilly terrain, each locomotive consumes approximately 100 gallons of fuel over the course of one trip.

Most ADIX locomotives were donated after fulfilling duties for many years at other operations and are quite old. The majority of line work out of Utica (trips between Utica and Thendara) is completed by some combination of their four primary locomotives, two Alco RS-11s and two EMDs, all built in the 1950s.

The two Alco locomotives have four-stroke, diesel v-12 251 engines, almost identical to the MHWA locomotives other than fewer cylinders (12 vs. 16). These engines rate at 1,750 hp and have brake specific fuel consumption scalable to the power output and number of cylinders of the Alco's used by the MHWA.

The EMD F-series locomotives contain EMD 567 series two-stroke, supercharged, V-16 diesel engines rated at 1,500 hp. Designed for passenger trains, these locomotives have a more streamlined cab orientation but limited visibility. Because of the cab design and limited tractive force available from these locomotives, they are almost exclusively used together for line haul operations. An additional Alco may also be added for particularly heavy trains or damp conditions (to improve track adhesion).

The approximate fuel consumption rates per notch are shown in Figure 33 for both the Alco[15] and the EMD[16] locomotives.

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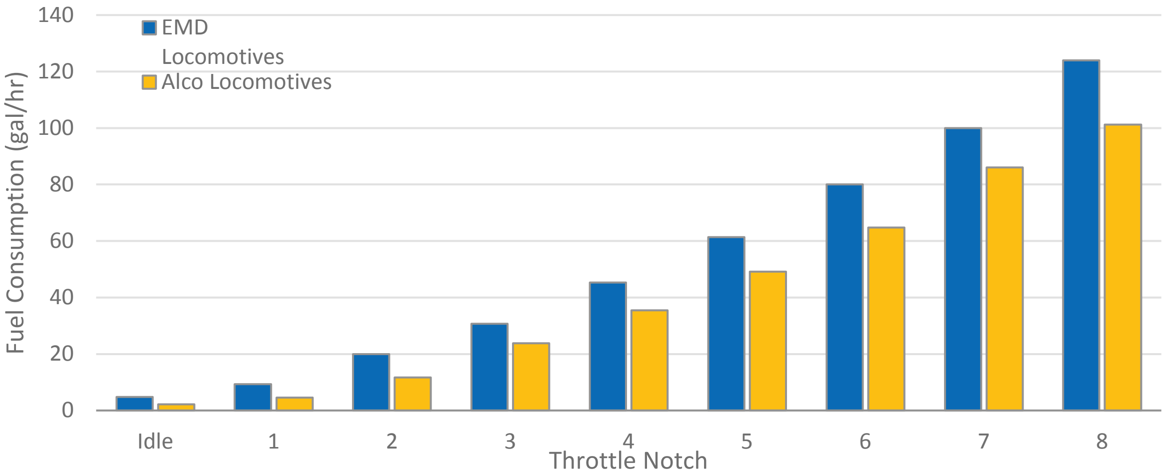
[15] Scaled data from data collected from the V16 Alco by GVT.

[16] Trainorders.com. http://www.trainorders.com/discussion/read.php?2,1304219

Figure 33. Locomotive Fuel Consumption Figures



Specific duty cycle data for ADIX was not available because most of the locomotives are not equipped with an event recorder, due to low operating speeds. Detailed fuel records were not provided, but operators estimated using 100 gallons of fuel per trip with approximately 400-500 trips per year. This annual fuel consumption of less than 5,000 gallons per year is low due to seasonal use and low operating speeds.

5.1 Natural Gas Feasibility

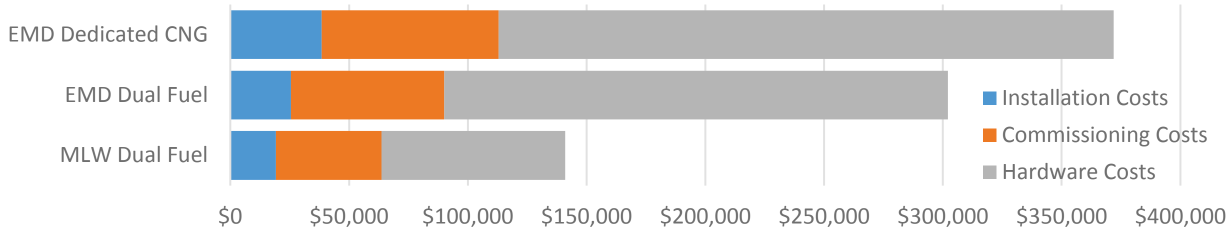
There are different CNG retrofit options for the two types of ADIX locomotives. The Alco locomotives could use a lower cost dual fuel system manufactured by ECI. The extended use periods under high power would increase CNG use as duel fuel technology offers significant diesel offsets in higher speed operations with throttle positions above notch three. The EMD locomotives have the option for a dedicated CNG conversion or dual fuel technology (since the dual fuel system for EMDs is more expensive and almost similar to the cost for a dedicated CNG conversion), both offered by ECI.

ADIX does not currently have a maintenance facility that houses the locomotives. Since they primarily operate during warmer weather, all maintenance and locomotive upkeep is performed outdoors with only minimal storage facilities for tools and equipment. The typical resting area for the locomotives is under the overpass for Genesee St., which does provide some cover from precipitation but would not cause any gas entrapment or issues for CNG use. They have received funding for the construction of a new maintenance facility on the property and are currently in the planning stages. This provides the ideal opportunity to design a CNG compatible facility because the incremental costs are almost negligible during a new build as compared to a retrofit.

5.2 Economic Analysis

Costs to retrofit the locomotives to operate on CNG are quite costly as shown in Figure 34. CNG technology for EMDs (two-stroke diesels) are significantly more costly than Alco systems (four-stroke diesels) due to more involved engine overhaul requirements. The incremental cost between dual fuel and dedicated systems for EMDs are relatively similar because both require many of the same components and modifications.

Figure 34. CNG Retrofit System Costs



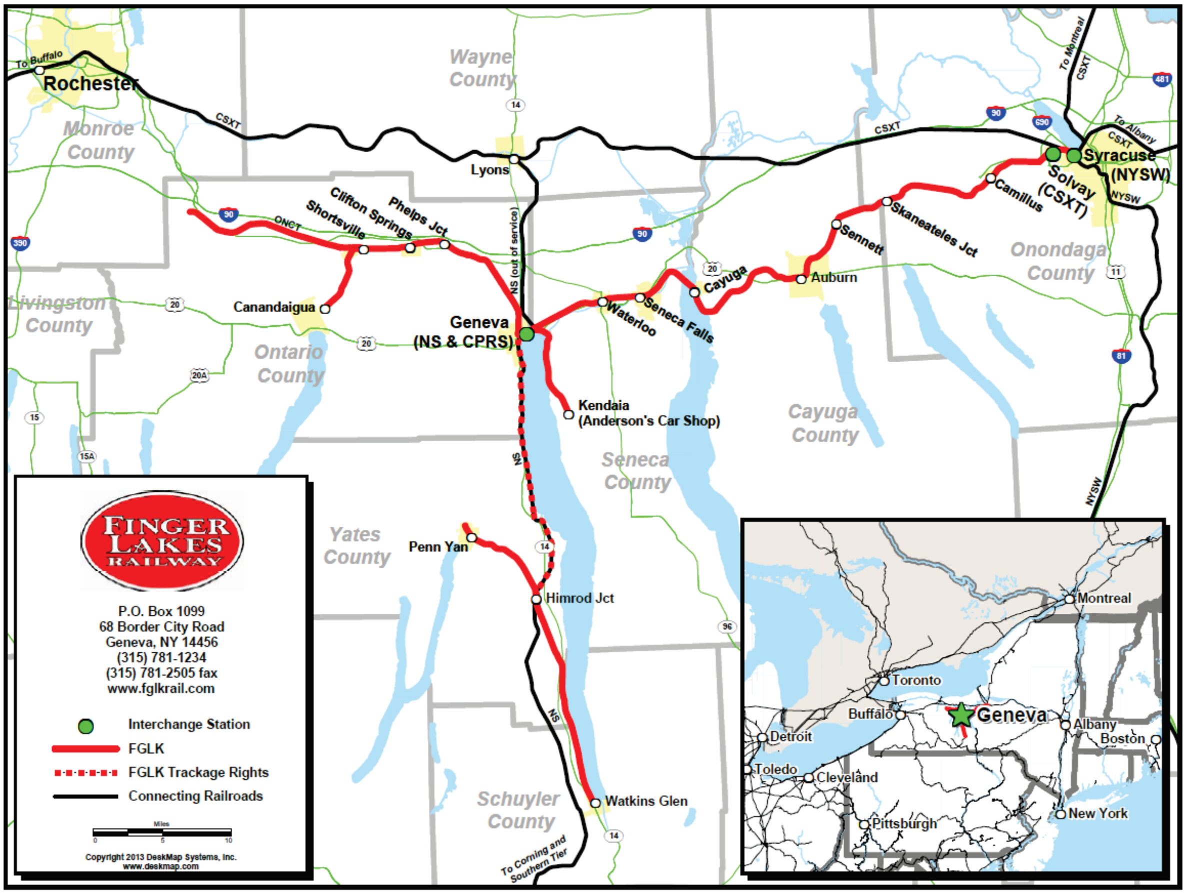
The estimated diesel offset potential for ADIX could not provide a meaningful return on investment because of the extremely low fuel consumption per locomotive based on how they operate. This economic analysis accounts for the sharing of a CNG fueling trailer with MHWA and no maintenance facility costs. The significant upfront costs required to retrofit multiple smaller locomotives, limited fuel use, fuel access challenges, and seasonal inactivity limit the potential for this application to use CNG. A potential justification for ADIX to use CNG is for the beneficial public image it may provide: a green transportation company operating in the Adirondack Park should be favorable to its customers. However, many of ADIX's most vocal supporters are historic locomotive fans and retrofitting original diesel technology with CNG may not endorse them.

6 Case Study: Finger Lakes Railway

Finger Lakes Railway (FGLK) is a Class III short line railroad that owns and operates 167 miles of track from its Geneva headquarters shown in Figure 35. Their current customer base has grown to 89 active shippers. FGLK connects with CSX, Norfolk Southern, Canadian Pacific, and New York Susquehanna & Western Railroads. Since they began operations in 1995, they have added 60 full time employees, have a fleet of 14 locomotives, and currently lease 581 railcars. FGLK has track in six counties in the Finger Lakes region, shown in Figure 36, including Ontario, Seneca, Cayuga, Onondaga, Yates, and Schuyler.

Figure 35. Batavia Headquarters Layout

Figure 36. Finger Lakes Railway Trackage

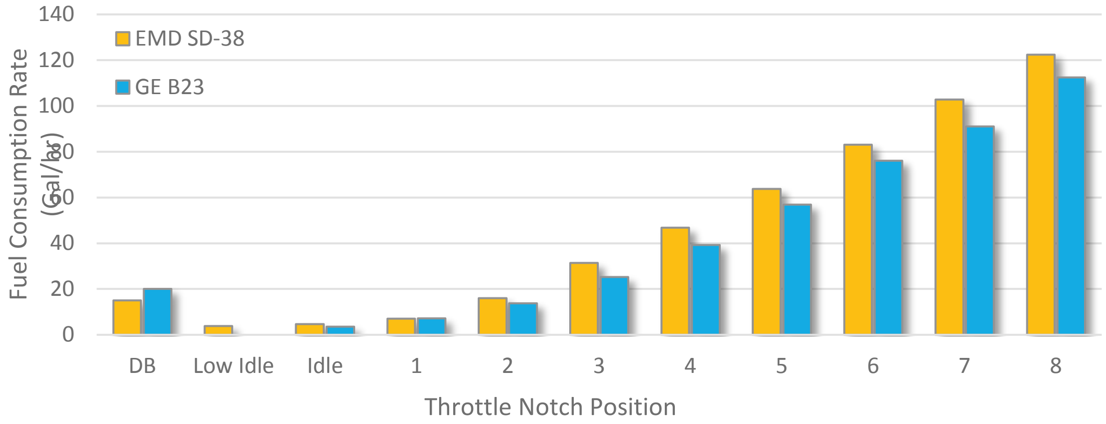


FGLK operates approximately 14 locomotives for line haul and several others for switcher applications. Many of the line haul locomotives based out of Batavia with switchers spread out depending on current operational locations. Some of the heaviest used equipment in their fleet are three EMD SD38s that FGLK leases for the line haul operations. These locomotives are relatively new (1980s) and use a 16-cylinder, 2,000 hp, supercharged two-stroke diesel engine. The remainder of the FGLK line haul fleet is GE B23 locomotives. These locomotives are slightly smaller than the EMDs and have a 12-cylinder, 2,300 hp, turbocharged four-stroke diesel engine. FGLK also operates leased and owned switchers currently stationed in Geneva, Solvay, and Auburn.

The primary candidate route for a CNG locomotive is the regular long distance trip between Geneva and Syracuse (Solvay) six times a week. Two leased EMD locomotives currently serve this route, supplemented by GE locomotives as needed. However, it is possible to shift locomotive types between various FGLK operations. There is another longer route operation that transports cargo between Geneva and Canandaigua, but it only runs twice each week

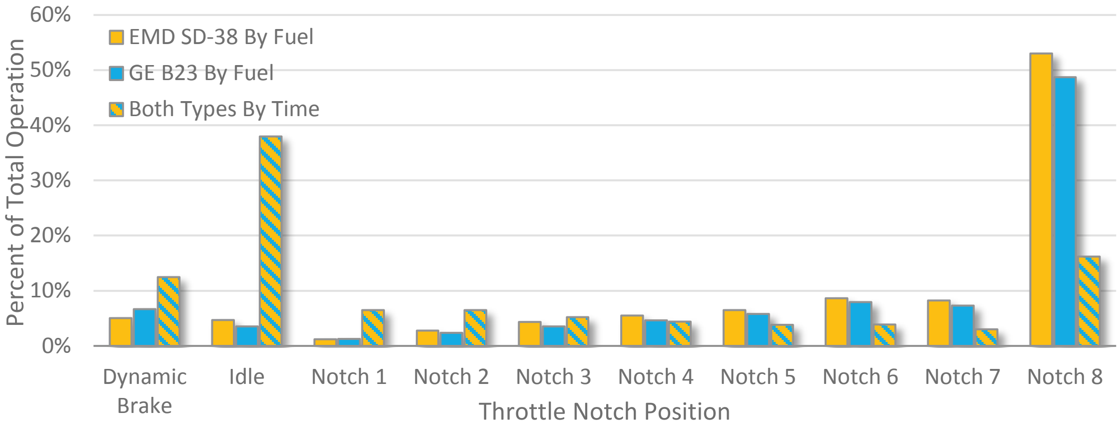
FGLK provided fuel consumption rates for the EMD and GE locomotives. This data, shown in Figure 37, demonstrates the increased efficiency of the four-stroke GE engine that makes more power and consumes less fuel than the two-stroke EMD locomotive. These fuel flow values vary based on ambient conditions and specific locomotive condition and specifications.

Figure 37. GE and EMD Locomotive Fuel Consumption Rates



FGLK locomotives do not operated at speeds over 25 mph, so they do not capture operational information with event recorders. Since no actual duty cycle information was available, typical line haul duty cycle data for emission testing shown in Figure 38 was used.[17]

Figure 38. Line Haul Locomotive Duty Cycle Information



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[17] 40 CFR 1033.530 - Duty cycles and calculations. Cornell University Law School. https://www.law.cornell.edu/cfr/text/40/1033.530

FGLK provided detailed fuel records for 2015 that show the fueling date and volume for each locomotive. There was high variation in fuel use between locomotives from month to month with many of them not needing fuel for several months at a time. The monthly fuel use for the owned GE locomotives and leased EMD locomotives were independently averaged (excluding months with no fuel use) to arrive at a typical annual profile for each type of locomotive. Overall, the sum of the fuel use results in an annual average of 26,700 gallons for the GEs and 45,300 gallons for the EMDs. A number of factors affect fuel use data and the GE locomotives could potentially replace the EMDs on the regular line hauls to increase their overall fuel consumption. If FGLK invested in CNG locomotive technology, they would increase that locomotive's use to more quickly recoup costs.

6.1 Natural Gas Feasibility

FGLK's two primary locomotive types have very different engine types and require different CNG technology configurations. The two-stroke diesel engine in the EMD locomotive requires more modifications to make it suitable for CNG. If they were to convert an EMD locomotive to CNG, a dedicated CNG solution would have minimal incremental costs over the dual fuel system. FGLK expressed a preference for a dual fuel CNG solution to reduce investment costs and retain fuel redundancy (it would still work with only diesel). This technology would make an easier transition from what they are currently doing and increase fueling flexibility if issues arise with CNG supply. The existing maintenance facilities would require many of the retrofits discussed earlier in this report at a cost between $150,000 and $250,000. A temporary option to avoid this investment initially while FGLK is piloting this technology is to perform routine maintenance outside and defuel the locomotive if major maintenance requires use of the garage.

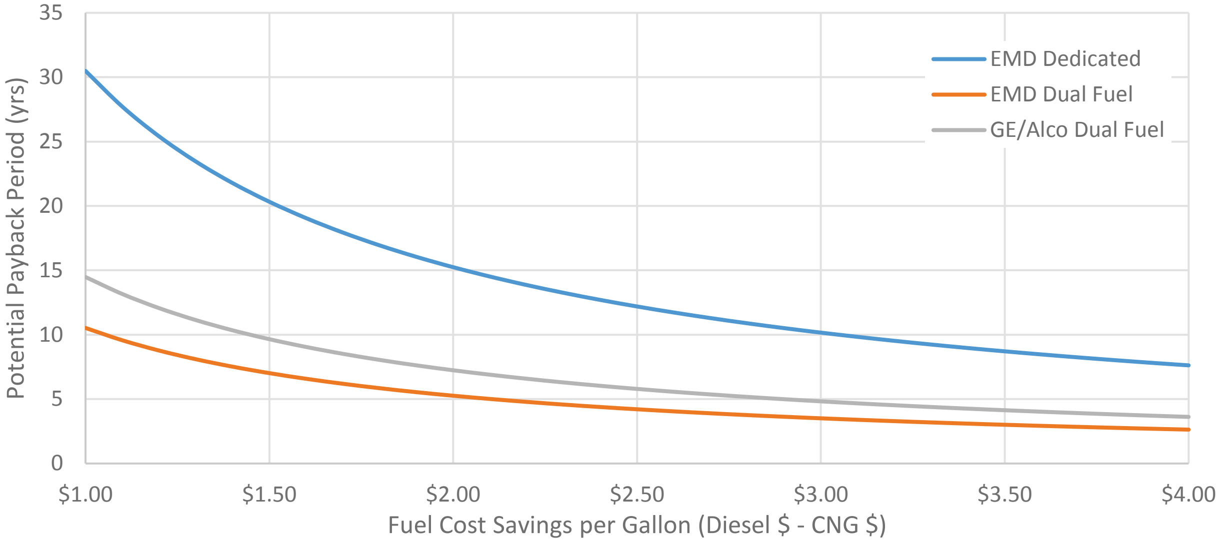
FGLK's Geneva facility has a medium pressure natural gas line onsite which allows several fueling options. An onsite fast-fill or time-fill CNG fueling station could be built with a slight upgrade to the current gas supply that would tie into one of the two major gas transmission mains that run adjacent to the Finger Lakes property. A second fueling option is a fueling trailer that would fill at an existing, but currently out of service, CNG station owned by NYSEG (Iberdrola) that is approximately three-tenths of mile from FGLK. NYSEG is willing to work with NYSERDA and FGLK on this fueling option and possibly offer favorable fuel pricing options.

6.2 Economic Analysis

The economic viability for FGLK to install CNG systems on their locomotives is driven by the cost difference between diesel fuel and natural gas. The CNG fuel cost offered by NYSEG is approximately $1.59 per gasoline gallon equivalent (approximately $1.81 per DGE). In October of 2016, FGLK was paying $1.78 per gallon for off-road diesel fuel. Payback on dual fuel CNG technology is not possible when natural gas costs more than diesel fuel. However, using natural gas has environmental benefits and may provide more stable fuel costs as diesel prices could rise to prior levels or higher (~$4.00 per gallon).[18] Excluding maintenance facility upgrades, Figure 39 shows the potential payback period for various fuel price differentials between diesel and natural gas per DGE (assuming diesel fuel is *more expensive* than CNG fuel, which is not currently the case) for the following scenarios:

- Dedicated CNG system on an EMD ($370,000) with an onsite fueling station ($1 million) and 45,000-gallon annual fuel use.
- Dual fuel CNG system for an EMD ($300,000) with a fueling trailer ($40,000) and 32,500-gallon annual fuel use.
- Dual fuel CNG system for a GE ($140,000) with a fueling trailer ($40,000) and 12,500-gallon annual fuel use.

Figure 39. Potential Payback Periods for CNG Locomotive Technologies



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[18] Short-Term Energy and Summer Fuels Outlook. U.S. Energy Information Administration. https://www.eia.gov/forecasts/steo/report/prices.cfm

Installing CNG technology onto FGLK locomotives is not economically justified by current or near term projected fuel prices. The switch to CNG is a large undertaking requiring significant investment and commitment due to the scale of the locomotive retrofit and the required fueling infrastructure to support ongoing operations. However, future fuel costs trends combined with the potential emission reduction and fuel flexibility, may make this a viable option in the future since a large portion of the FGLK's diesel fuel use could be offset with CNG.

The dual fuel technology proposed for the GE B23 locomotives is the simplest and lowest cost option that has that the potential to offset 46 percent of current diesel fuel use with natural gas, totaling 12,395 gallons annually. Dual fuel CNG technology for the EMD locomotive is more complex and costly, but allows for a higher diesel of 32,450 gallons annually, a 72 percent savings. The highest cost, dedicated CNG option for the EMD locomotives would displace all 45,260 gallons of diesel used annually with natural gas.

Natural gas use in locomotives will reduce harmful emissions. The most significant savings are for NO_X and PM with up to 42 percent and 31 percent less emitted respectively as compared to diesel. CO_2 emissions are also reduced up to 21 percent due to less diesel use. However, there is an increase in certain emissions, such as CO and NMHC, due to natural gas cylinder blow-through and incomplete combustion. Table 2 shows the actual emission reduction potential (shown in tons per year) for each technology proposed for FGLK (negative values denoting an increase).

Table 2. Potential Annual Emission Savings (tons per year)

	GE Dual Fuel Locomotive	*EMD Dual Fuel Locomotive*	*EMD Dedicated*
NMHC	-0.11	-0.19	-0.37
CO	-2.10	-3.50	-7.05
NOx	0.99	1.64	3.31
PM	0.04	0.07	0.15
CO2	29.95	49.81	100.33

CNG use in locomotives may have additional impacts that are more difficult to quantify. Because CNG is a clean burning fuel, soot accumulation should significantly reduce, which results in longer engine oil life and less maintenance. Additionally, sparks from the diesel exhaust under high load conditions can ignite the soot accumulation causing brush fires along the tracks during summer months. Engines will also run quieter and smoother using CNG, which will help improve operating conditions and reduce operator fatigue.

7 Case Study: Depew, Lancaster & Western Railroad

The GVT-owned Depew, Lancaster, and Western Railroad (DLWR) operates on 2.9 miles of track in Batavia. This relatively minimal trackage (mapped in Figure 40) experiences daily use for local deliveries from the main CSX interchange at the southern end of the track.

Figure 40. Depew, Lancaster & Western Railroad Track in Batavia

GVT's headquarters, located at the center of DLWR's track, include the locomotive garage (shown in Figure 41), transloading facility, and miscellaneous sidings for loading/unloading cars. DLWR serves a wide range of customers in Batavia. The largest customer, and the closest to the main line, is Georgia-Pacific Corporation who receives large bulk paper shipments regularly. DLWR also provides storage solutions for Georgia-Pacific Corporation at their Transload facility and transports excess bulk cargo as needed. Genesee Lumber receives weekly shipments from CSX delivered by DLWR. Additional customers include the Consolidated Container Company and Growmark, both located at the eastern portion of the track system. Additionally, Eddie Arnold Scrap Processors use a siding located next to the Transload facility for unloading scrap metal from railcars to trucks.

Figure 41. Depew, Lancaster & Western Railroad Locomotive Garage

DLWR uses two Alco locomotives, an S-6 (built in 1954) and a RS-18 (built in 1964). The S-6, number 1044, contains a four-stroke, turbo-charged diesel six-cylinder Alco 251 engine rated at 900 hp. This locomotive, designed as a switcher by Alco, is the most heavily used year-round. The RS-18, locomotive number 1801, has an Alco 251 four-stroke, turbo-charged V12 diesel engine rated at 1,800 hp. This locomotive is typically stored during the winter months and used the least.

7.1 Natural Gas Feasibility

Due to the limited length of track in a populated area with low speed limits, the locomotives operate at low throttle notch levels (even for the smaller switcher locomotive). These locomotives do not have event recorders because of their low speed operation, so duty cycle data is not available. However, locomotive engineers and conductors determined that most operation is below notch 3 with only minimal time spent in higher notches for accelerating large loads.

DLWR locomotives fuel consumption is quite low because of the smaller engines, short distances, and low speeds. The locomotives consumed 2,200 to 3,500 gallons of fuel each in 2015, due to limited and seasonal use.

A dedicated, spark ignited system is the only feasible natural gas technology because of the low speeds and limited operation above notch 3. A dual fuel solution only offsets diesel with natural gas in throttle notches above 3, so there would be no benefit for this duty cycle. VeRail's 800 hp dedicated spark-ignited natural gas engine module could provide sufficient power to replace the existing 900 hp diesel engine in the S-6 switcher as only low throttle notches are currently used. This system would provide 100 percent diesel fuel offset as well as significant emission reduction as the engine parameters are designed specifically for natural gas operation. VeRail has reported emission levels 80 percent lower than the EPA's Tier 4 standard of 0.2 graphs of NO_X per horsepower hour.

A fueling trailer is the lowest cost CNG fueling option for DLWR. However, the nearest CNG dispensers are in Rush and Lancaster, which are 24 and 32 miles away respectively. This distance would create significant logistical issues and the fuel required to transport the CNG would likely exceed the locomotive diesel offset. There is sufficient natural gas line capacity to support a CNG fueling station onsite that could fuel the locomotives when at rest, but it is expensive to build.

DLWR's maintenance garage is old construction (built sometime around the early 1920s) and most of the service area is wooden post and beam construction (Figure 42). The roof is heavily insulated and configured so that, in the event of a leak it would trap the gas. The electrical and lighting systems in the repair garage do not meet NFPA 52 or 30A code requirements. The heating system consists of open ceiling vents that can also trap natural gas in the event of a leak creating a potential for ignition because it uses an open flame. Overall, the old maintenance facilities at Batavia are not suitable for upgrading to handle CNG locomotives. Upgrading would require either a completely new structure or the ability to defuel equipment for maintenance or storage without any CNG fuel onboard. Both options are extremely costly.

Figure 42. Existing Maintenance Facilities

7.2 Economic Analysis

Natural gas for DLWR locomotives does not make economic sense because of the extremely low fuel consumption and the high upfront costs for the locomotive retrofit and extensive maintenance infrastructure retrofits. The most feasible fueling option is a fueling trailer with a lease cost that exceeds the current fuel expenditures at DLWR. That expense does not account for the cost for the natural gas fuel or fuel used by the truck to fill the trailer at the nearest CNG station. DLWR’s operation involves cargo storage and handling, which uses much less fuel than line haul transport over long distances. Small short line railroads such as DLWR, while necessary for the movement of goods from the larger rail lines, do not have sufficient locomotive use to justify CNG repowering.

8 Case Study: Falls Road Railroad

GVT-owned Falls Road Railroad (FRR) operates out of Lockport with 45 miles of track encompassing Lockport (where it interchanges with the main CSX line), Medina, Albion, Holley, and Brockport. FRR primarily distributes cargo from the main CSX line in Lockport to its customers along its track, which include: Western New York Energy, Growmark, Crop Production Services Inc, Bonduelle Frozen Foods, and Allied Frozen Foods. Weekly deliveries are Tuesday and Friday with stops at each customer along the track (Figure 43).

Figure 43. Falls Road Railroad Trackage Route

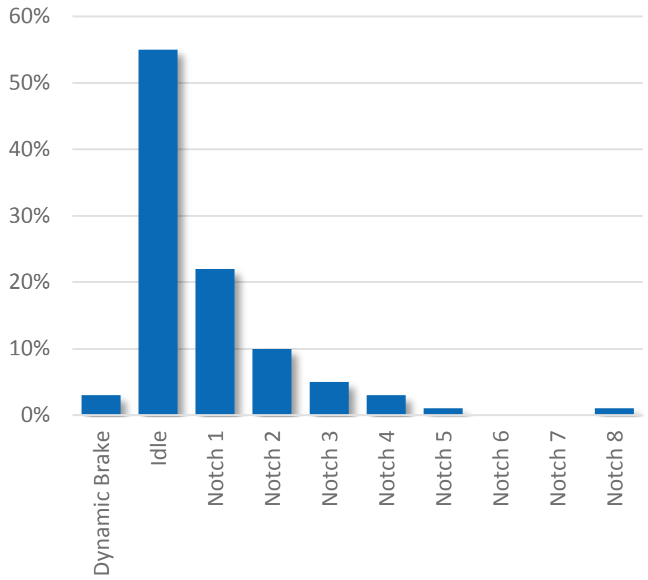
All maintenance and equipment storage is conducted at the locomotive garage, located at the western end of FRR's track, near the CSX exchange. As shown in Figure 44, the garage is large enough to store both FRR locomotives out of the weather, eliminating the need for idling during winter months.

Figure 44. Falls Road Railroad Maintenance Facilities in Lockport

Two locomotives handle all of FRR's transportation needs. They include a RS-11, powered by an 1,800 hp turbo-charged diesel V-12, and a RS-32, powered by a 2,000 hp turbo-charged diesel V-12.

The twice per week, FRR completes the delivery runs using only one locomotive while the other remains in the garage. The route is in an urban setting with fairly short distances between stops, so locomotive speeds are quite slow, throttle notch positions normally average below notch 3. The locomotives do not require event recorders because they do not exceed 30 mph, so detailed duty cycle data was not available. Therefore, onsite staff and operators developed an estimated duty cycle profile (Figure 45). GVT provided monthly fuel usage data that was used to evaluate the potential for CNG use and diesel offset.

Figure 45. Falls Road Railroad Locomotive Duty Cycle



8.1 Natural Gas Feasibility

A dedicated CNG locomotive solution is required to make an impactful benefit since there is minimal operation above throttle notch 3 and a duel fuel system does not inject natural gas in notches 2 and under. Two 800 hp VeRail dedicated CNG spark-ignited engine modules could sufficiently replace the existing 2,000 hp diesel engine since only low throttle notches are currently used. This system would provide 100 percent diesel fuel offset as well as significant emission reduction.

A CNG fueling trailer is the best fueling option because installing a dedicated fueling station onsite is prohibitively expensive. A nearby NYSDOT CNG station in Lockport, approximately 3.7 miles away, is an option.

8.2 Economic Analysis

The FRR maintenance facility is not viable for CNG use and requires a significant overhaul in the heating, electrical, and ventilation systems to meet code CNG repair facilities. The ceiling design would trap any escaping natural gas, the ventilation system is not powerful enough, and the heating system is an open flame fuel-fired system. It would be costly to make all the necessary modifications to perform maintenance or store a CNG locomotive in this facility.

FRR locomotive annual fuel consumption is too low to provide a favorable business case for converting to CNG. A short line operating only two days a week at low speeds over a short distance is not a good application for this technology.

9 Lessons Learned and Study Conclusions

A number of critical factors for short line railroads considering natural gas locomotives emerged throughout this study. Most CNG locomotive projects had focused on large, Class 1 railroads due to their heavy fuel use and extensive operations. This technology trend might also benefit short lines that have fixed routes and return to base each night (favorable characteristics for fleets of heavy-duty vehicles that have successfully switched to natural gas). Interest in alternative fuels was strong when this project was proposed because diesel prices remained high from 2011 to 2014 and there was a surplus of natural gas, which drove down the price. Unfortunately, several factors are currently cost barriers for even the most promising short line applications to use natural gas, and other short lines in NYS have limited operations and implementation barriers for natural gas to ever make financial sense. There is further discussion regarding the primary lessons learned from the five short line operations evaluated.

9.1 Locomotive Fuel Use

When used at high power levels, locomotives consume a lot of diesel fuel, but this drops off significantly at low power levels or when idling. In addition to sharing the power requirements among multiple locomotives during line hauls, many short lines make only one trip per day at most. Some operations only run a few times per week or decrease trips significantly during the winter months. Only two of the investigated operations, FGLK and MHWA, had daily long routes that resulted in significant annual fuel use for those locomotives.

Some short line operations have transitioned to more of a cargo/railcar storage or transload business model than a freight delivery service due to limited local demand. In many instances, existing track can be more profitable if used to store railcars for large, Class 1 railroads than for actually moving freight. Other efforts support multi-modal freight transport that moves cargo around the yard and transload facility for transferring freight to the trucks. Such efforts still require locomotives, but performing operations at low speeds and power settings (often by smaller switchers) lowers fuel consumption and is not favorable for CNG technology that can only inject fuel at higher notches.

The large locomotive diesel engines have relatively good fuel efficiency. Newer diesel technology significantly reduces emissions, but the actual fuel efficiency is often lower than the older, mechanically injected diesels used by these short line locomotives. This efficiency coupled with low speeds, short hauls, and sometimes limited year-round operations, decreased the overall baseline diesel fuel consumption and the potential benefit from CNG technology.

9.2 Locomotive Equipment

The age and type of locomotives used by these short lines is particularly unique to rail operations. GVT primarily uses Alco and MLW locomotives built and purchased in the late 1960s and early 1970s, which are becoming relatively rare because the company went out of business soon after selling these models. Other operations commonly use GE and EMD locomotives, but they also present challenges. The EMD locomotives have two-stroke diesels, which require more complex dual fuel systems that cost almost as much as a dedicated CNG system.

There are limited choices for manufacturers with CNG products for these locomotive types. In addition, most installations would require custom designs since there is not enough volume for manufacturers to produce “off-the-shelf” products for every locomotive age, type, and series. Due to how locomotives operate, it is not a simple scaling up of heavy-duty dual fuel systems that retails for around $20,000. The lowest cost dual fuel system for locomotives is around $150,000 with storage, not including installation.

Older locomotives require more maintenance, so short lines typically have twice as many as needed to accommodate when one or more are out of service for repairs. This results in sharing locomotive use among multiple units, which reduces fuel consumption and hurts the potential return on investment. While short lines would make adjustments in operations to utilize a converted CNG locomotive as much as possible to receive quicker payback, the CNG system installed on an older locomotive will still require frequent maintenance and time out of service.

For increased traction, short lines often use two or more locomotives for line hauls. This is also necessary for providing sufficient power to climb certain sections of the track. This again contributes to lower fuel consumption per locomotive because of sharing among multiple units.

Onboard CNG storage presents challenges for these models, but it is feasible for most locomotives since these applications need limited fuel if they can fill the tanks at least every other trip. Dual fuel technology does not require extensive fuel storage configurations (such as fuel tenders or mother-slug storage). Locomotive operators were not willing to consider placing CNG tanks inside the existing diesel tanks, so other available space is necessary. On some locomotives, certain equipment might need reconfiguration to accommodate the tanks or use special methods, such as tank insulation and reflective materials, to place in the radiator cavities. Dedicated CNG technology would allow for the existing diesel fuel tanks to be completely replaced with CNG cylinders, which can provide sufficient storage capacity for these applications.

9.3 Maintenance Facilities

Short line facilities used for locomotive maintenance and storage are not properly equipped to meet code for CNG use. Their design, with exposed beams, creates pockets where escaping natural gas can collect. Locomotives are never lifted to perform work underneath as is typically done for on-road vehicles (facilities have a pit below where the locomotive parks to access underneath), so garages have minimal clearance between the top of the locomotive and roof. This impedes proper ventilation of any escaping natural gas that would rise to the ceiling. None of the short line facilities had a ventilation system capable of providing the required 5 ACH. Lowering most electrical equipment on the ceiling down 18 inches would meet that code requirement and mitigate the potential for ignition of any natural gas that might accumulate there. Heating systems are another facility item that will need significant modification to meet CNG code. Most garages had an open flame heater fueled by propane or natural gas that require isolation in a separate room or completely changed out to another type of heating. Additionally, gas detection and other safety equipment are necessary.

Completing all of these modifications would likely cost between $150,000 and $250,000 depending on facility, but no current short line maintenance garage is fit to support a CNG locomotive without a significant investment. This is a significant cost barrier to CNG technology deployment for short lines. The investment to modify the locomotive garage for CNG code compliance is similar for a short line with one CNG locomotive or if the entire fleet runs on CNG (unless using separate buildings, in which case the space used by the CNG locomotives would need modification). Therefore, it sometimes makes better financial sense to go “all-in” with CNG technology by converting the entire fleet at the same time, but no short line operation in NYS would make that commitment for a technology that is not fully proven. Potential options suggested in a few of the case studies was to perform regular maintenance on the CNG locomotives outside or defuel the CNG tanks prior to moving the locomotive into the garage for major maintenance work. As mentioned, these locomotives are quite old and regularly require maintenance so it is unlikely and inconvenient to have this all done outside. Dual fuel locomotives would have limited CNG stored onboard due to space restrictions and the ability to run on only diesel if needed, and the CNG tanks would unlikely be fully filled if staff knew the locomotive needed maintenance. Therefore, there would not be a significant amount of natural gas to release for defueling, but it is still not environmentally sound to just release that into the air (although it can be done). Special defueling equipment that captures the gas for using later to fill the tanks is available, but comes at an additional cost.

The ideal situation for meeting CNG code compliance in a locomotive maintenance facility is to address the requirements during the construction of a new garage. The incremental costs to upgrade heaters, ventilation, design, and other elements is very minimal at this stage. Unfortunately, few short lines are planning on building a new maintenance garage, although the Adirondack Scenic Railroad secured funding to do this. Any short line in the process of designing or building a new maintenance garage with operations that include regular line haul favorable to CNG technology should consider facility features that support future CNG use.

9.3.1 Fueling Infrastructure

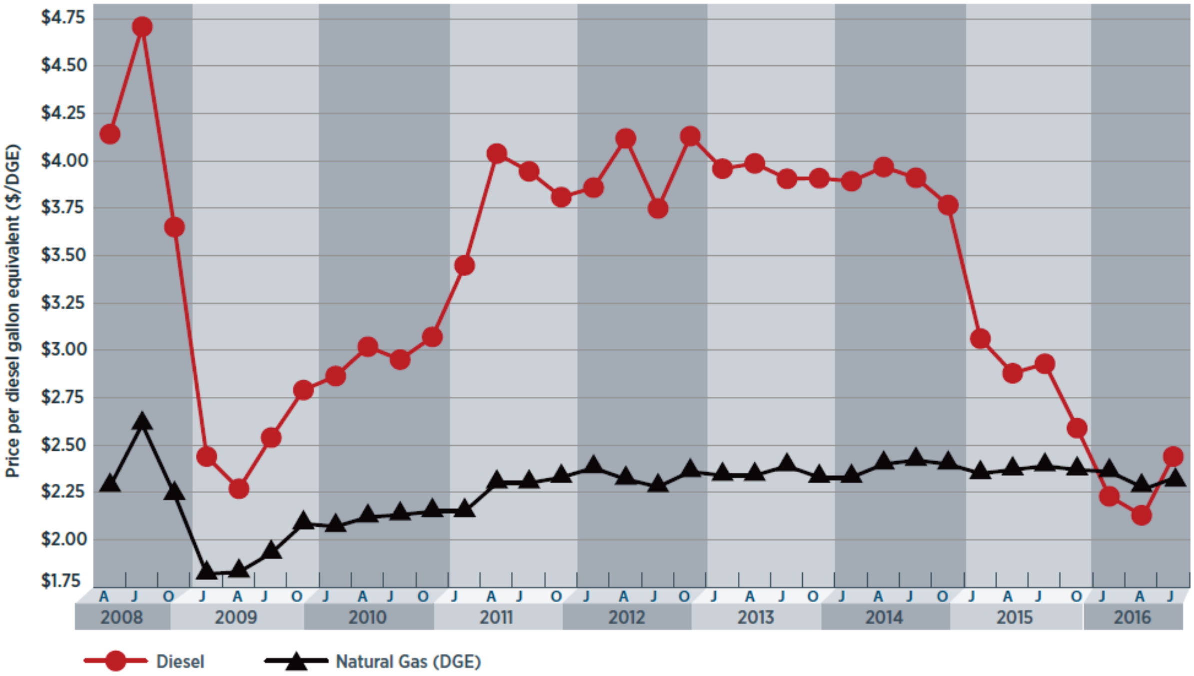
Similar to maintenance facility upgrades, CNG fueling infrastructure is most cost effective when part of an “all-in” strategy for multiple vehicles. This will rarely be the case for short line railroads that only have a few locomotives at each location. Justifying high costs for a fast-fill station would almost never happen unless needed for a fleet of dedicated CNG locomotives or if the station collaborated with another fleet for fueling when not in use by the locomotives. The issue is that railroad facilities, particularly near the tracks where locomotives would need to fuel, is not a desirable site for a CNG station that other fleets would use. The most cost effective station for use only by the short line locomotives is a time-fill station that could connect to the locomotives at the end of each trip and fuel them overnight. Unfortunately, no company currently offers small “off-the-shelf” time-fill stations that were previously on the market for individual owners of CNG vehicles (although these might be too small for this application). Therefore, even a time-fill station would need a custom design and build costing over $100,000 with all the proper components and redundancy. Maintaining the station may also require a service contract to handle maintenance and repairs. One critical limiting factor for a short line to build its own CNG fueling station is existing natural gas supply. It is likely very expensive to install a new service if no available gas line exists on the property, and existing service lines may need upgrading for sufficient capacity. Performing this work in a railyard where the lines need to go under active tracks could get complicated and costly.

The most economically feasible fueling solution for short line railroad applications is purchasing a fueling trailer for approximately $40,000 or leasing it for $1,000 per month. This is a logical option for initially piloting CNG technology in a single locomotive to test feasibility and performance. A fueling trailer could potentially supply multiple dual fuel CNG locomotives if deployment expanded. The limiting factor to this strategy is the availability of a nearby CNG station that offers it at a reasonable price. Having to drive farther than a few miles to fill the trailer with CNG would be a logistical burden and require more fuel for that vehicle to obtain the fuel. The two most favorable operations for CNG use, MHWA and FGLK, are located very close to CNG stations, but this was not the case for the FRR or DLWR.

9.3.2 Fuel Costs and Payback

There is currently no financial benefit for locomotives to use CNG due to low off-road diesel costs that are less than natural gas. This was not the case when the study was proposed in 2014 as shown in Figure 46.[19] Petroleum costs will likely increase in the future, which will help provide some economic justification for a few of the examined operations. Because railroads do not pay road tax on their fuel, cost savings will always be slightly lower than for on-road applications.

Figure 46. Historical Compressed Natural Gas Prices versus Diesel



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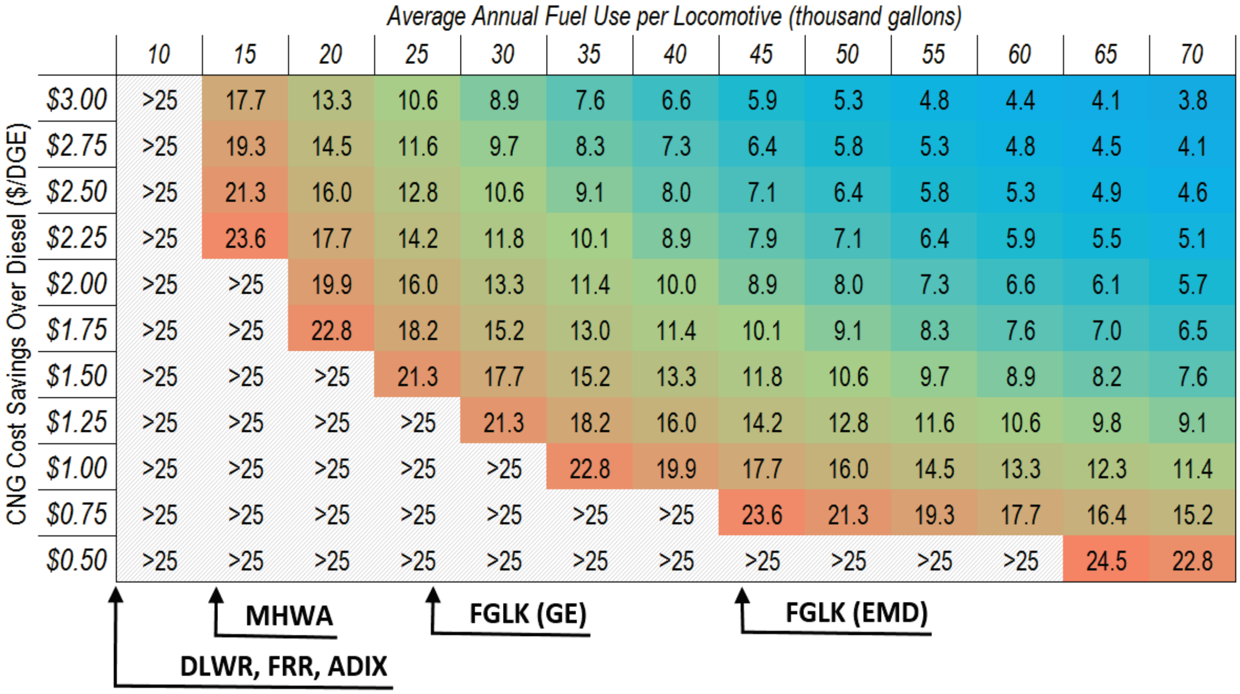
[19] U.S. Department of Energy. Clean Cities Alternative Fuel Price Report – July 2016. http://www.afdc.energy.gov/uploads/publication/alternative_fuel_price_report_july_2016.pdf

Dual fuel CNG technology on four-stroke locomotive engines using a fueling trailer has the lowest upfront cost and would likely return the shortest return on investment for any short line railroad. Dual fuel technology would not completely eliminate the locomotive's use of petroleum fuel, but it could significantly reduce the amount. Additionally, having a redundant fuel source would provide security in the event of volatile fuel prices. The average overall expected payback periods for a dual fuel system on a locomotive with a four-stroke engine, assuming the use of a fueling trailer and average maintenance facility modification costs is shown in Table 3 for various annual fuel usage and CNG fuel cost differential. Dual fuel technology for EMD locomotives with two-stroke engines requires a slightly more complex and costly system but offsets a higher percentage of fuel that results in a 14 percent lower payback period. If maintenance facility modifications were not completed and outside work on the locomotive was possible, payback periods would decrease by 45 percent.

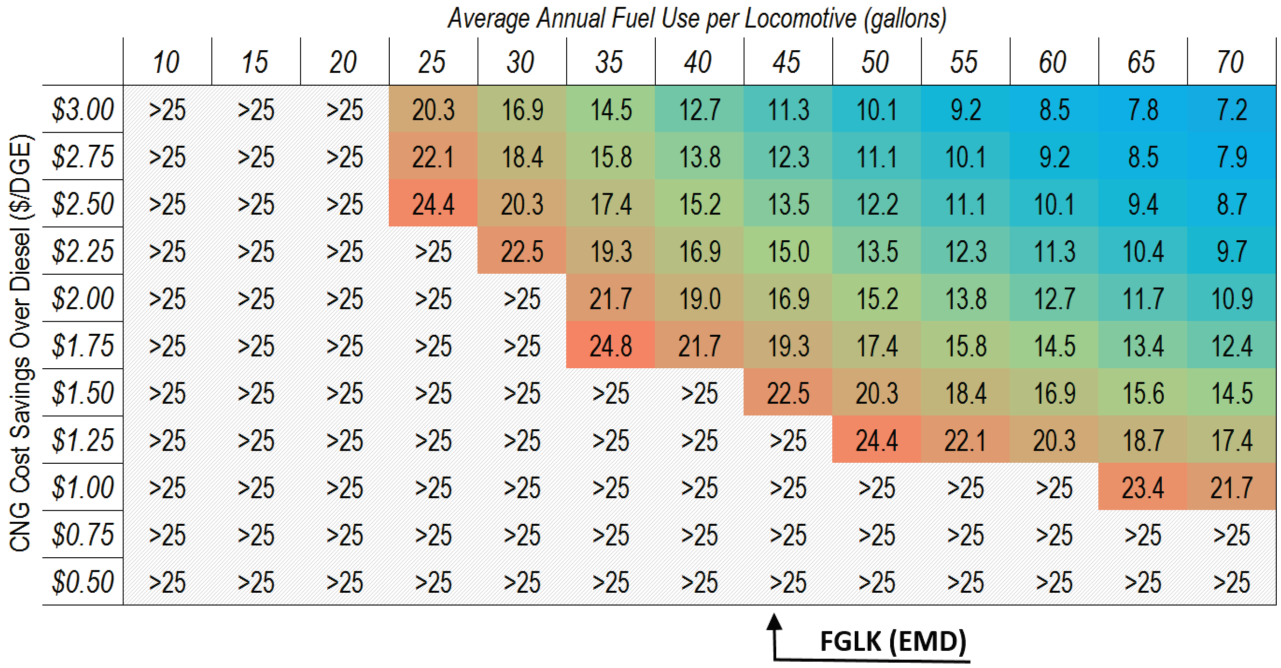
Table 3. Average Dual Fuel Payback Periods



CNG Cost Savings Over Diesel ($/DGE)	Average Annual Fuel Use per Locomotive (thousand gallons)												
	10	15	20	25	30	35	40	45	50	55	60	65	70
$3.00	>25	17.7	13.3	10.6	8.9	7.6	6.6	5.9	5.3	4.8	4.4	4.1	3.8
$2.75	>25	19.3	14.5	11.6	9.7	8.3	7.3	6.4	5.8	5.3	4.8	4.5	4.1
$2.50	>25	21.3	16.0	12.8	10.6	9.1	8.0	7.1	6.4	5.8	5.3	4.9	4.6
$2.25	>25	23.6	17.7	14.2	11.8	10.1	8.9	7.9	7.1	6.4	5.9	5.5	5.1
$2.00	>25	>25	19.9	16.0	13.3	11.4	10.0	8.9	8.0	7.3	6.6	6.1	5.7
$1.75	>25	>25	22.8	18.2	15.2	13.0	11.4	10.1	9.1	8.3	7.6	7.0	6.5
$1.50	>25	>25	>25	21.3	17.7	15.2	13.3	11.8	10.6	9.7	8.9	8.2	7.6
$1.25	>25	>25	>25	>25	21.3	18.2	16.0	14.2	12.8	11.6	10.6	9.8	9.1
$1.00	>25	>25	>25	>25	>25	22.8	19.9	17.7	16.0	14.5	13.3	12.3	11.4
$0.75	>25	>25	>25	>25	>25	>25	>25	23.6	21.3	19.3	17.7	16.4	15.2
$0.50	>25	>25	>25	>25	>25	>25	>25	>25	>25	>25	>25	24.5	22.8

A dedicated CNG solution has significantly higher upfront costs than a dual fuel solution but would replace all diesel fuel use with natural gas. One drawback to a dedicated system is that the additional CNG requirements would likely necessitate an onsite fast-fill fueling station, estimated to cost over $1 million. Dedicated CNG technology requires a more committed approach from the railroad and a possible logical “second step” after introducing CNG use through the use of a dual fuel solution. Table 4 shows the estimated payback period for dedicated CNG locomotive systems, using the upfront costs discussed earlier. If it is a possibility to use a fueling trailer instead of building a dedicated onsite fueling station, the average payback period could decrease by 62 percent. If all maintenance was completed outside and the facility modifications were not included, payback periods would decrease by an additional 10 percent.

Table 4. Average Dedicated CNG Payback Periods



CNG Cost Savings Over Diesel ($/DGE)	Average Annual Fuel Use per Locomotive (gallons)												
	10	15	20	25	30	35	40	45	50	55	60	65	70
$3.00	>25	>25	>25	20.3	16.9	14.5	12.7	11.3	10.1	9.2	8.5	7.8	7.2
$2.75	>25	>25	>25	22.1	18.4	15.8	13.8	12.3	11.1	10.1	9.2	8.5	7.9
$2.50	>25	>25	>25	24.4	20.3	17.4	15.2	13.5	12.2	11.1	10.1	9.4	8.7
$2.25	>25	>25	>25	>25	22.5	19.3	16.9	15.0	13.5	12.3	11.3	10.4	9.7
$2.00	>25	>25	>25	>25	>25	21.7	19.0	16.9	15.2	13.8	12.7	11.7	10.9
$1.75	>25	>25	>25	>25	>25	24.8	21.7	19.3	17.4	15.8	14.5	13.4	12.4
$1.50	>25	>25	>25	>25	>25	>25	>25	22.5	20.3	18.4	16.9	15.6	14.5
$1.25	>25	>25	>25	>25	>25	>25	>25	>25	24.4	22.1	20.3	18.7	17.4
$1.00	>25	>25	>25	>25	>25	>25	>25	>25	>25	>25	>25	23.4	21.7
$0.75	>25	>25	>25	>25	>25	>25	>25	>25	>25	>25	>25	>25	>25
$0.50	>25	>25	>25	>25	>25	>25	>25	>25	>25	>25	>25	>25	>25

If the cost of diesel rises from its historic lows and is more expensive than natural gas, there will still be several barriers and challenges to using natural gas at one of these existing short line operations. This is primarily because the current operations and facilities were designed for liquid fuel and converting over to gaseous fuel requires several modifications resulting in higher implementation costs. In some cases, retrofitting an existing railroad maintenance facility requires all new ventilation, heating, and electrical. As explained earlier, the type of locomotive will also influence how costly it is to convert to using natural gas and where available space is for onboard natural gas storage. All of these factors can make a conversion to natural gas unfeasible for many existing short line railroads. However, any railroad planning to expand their services, acquire another locomotive, or build a new maintenance facility should consider opportunities to use natural gas or prepare for potential natural gas in the future. Selecting or designing new acquisitions and facilities for natural gas use is an option. The incremental cost to integrate natural gas technology and supporting services is very minimal in comparison to the initial cost for these new purchases. In many cases, the selection of a locomotive that is more easily retrofitted for natural gas or the design of a maintenance facility for future compliance to natural gas codes, may not be more expensive. However, these choices during any acquisition could make a conversion to natural gas in the future much more economically viable.

9.3.3 Environmental Impact

Using natural gas in locomotives will reduce CO_2, PM, and NO_X emissions and may also lower noise pollution as well as reduce the potential for fires started when soot builds up in the diesel engine exhaust. Some of these impacts will have direct benefits to the operators that work near these locomotives every day, while overall, a smaller environmental footprint will have an even broader benefit. One motivating factor for the railroad to use cleaner fuel is the positive image this can provide, which may help generate more business. Railroad operations are more efficient and less polluting than trucks, but that message is hard to convey as trucks have improved their emission controls so you no longer see the exhaust where as black exhaust smoke is still often visible from locomotives. Switching to cleaner burning natural gas helps portray the environmental benefits from using railroads and would provide a marketing angle to potentially generate more business. There are also opportunities to utilize local, State, and federal grant funds on cleaner burning fuel projects that could significantly reduce the initial cost of converting to natural gas. The potential impact from one locomotive conversion to natural gas is much greater than converting several trucks, which is key criteria examined when determining grant allocations. This is particularly advantageous for short lines operating in non-attainment areas classified by the U.S. Environmental Protection Agency. These areas have poor air quality and funding is available to target projects that would have a meaningful impact on emission reduction. By leveraging grant funding and effectively marketing a clean burning transportation option, short line railroads may discover that natural gas is a smart economical investment.

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New York State
Department of Transportation

50 Wolf Road
Albany, NY 12232

telephone: 518-457-6195

dot.ny.gov

New York State
Energy Research and
Development Authority

17 Columbia Circle
Albany, NY 12203-6399

toll free: 866-NYSERDA
local: 518-862-1090
fax: 518-862-1091

info@nyserda.ny.gov
nyserda.ny.gov

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