LOCOMOTIVE ALTERNATIVE ENERGY FUEL STUDY

Final Report

Prepared By:
LTK Engineering Services

Project Number:	C5284.01
Prepared for:	Regional Transportation Authority
Prepared by:	For LTK: John Alexander PE, David Semple, Troy Alvarez, Michael Condei, Jim Natalo and Alexandria Walker For CMCG: Isabel Cañete-Medina, Ben Medina, Ph.D.
Checked by:	Michael Condei, Alexandria Walker
Approved by:	John Alexander PE
File Name	RTA Locomotive Alternative Fuel Study Single Report R1.docx
Revision/ Date:	Rev. 1 6/28/2019

REVISION HISTORY

Revision	Description	Date	Prepared by
0	Initial Release	6/27/2019	J.Alexander, T.Alvarez, D.Semple, J.Natalo, A.Walker, I. Cañete-Medina, B. Medina
1	Revised to combine 3 separate reports into 1	6/28/19	J.Alexander

Table of Contents

List of Tables

List of Figures

This page is left intentionally blank.

Executive Summary

Project Overview

LTK Engineering Services has been tasked by Contract PO 02808 to conduct a feasibility study for the Regional Transportation Authority (RTA) of alternative energy fuels for use in the diesel fuel powered locomotive fleet of their partner commuter rail agency, the Northeast Illinois Regional Commuter Railroad Corporation, conducting business as Metra. The objective is to weigh the benefits of potential fuel savings and emissions reductions of a diesel fuel alternative with the capital and recurring costs, facilities impacts, safety considerations, operational requirements, governing regulations and return on investment for consideration in a full or partial fleet conversion.

The project has been defined in the contract by four major tasks, with the scope of each major task to be provided in a report following the Contract scope of work, which provides a logical sequence of tasks that lead to a final comprehensive report. Task 1 was the project kickoff meeting with RTA's Steering Committee to review the project scope and timeline, committee member responsibilities, and data collection needs which was held at RTA's offices on October 3rd, 2018.

Task 2 comprises the documentation of best practices and existing conditions related to the most viable alternative energy fuel technology that can be applied to Metra's diesel locomotive fleet. This includes a survey of Metra's fueling facilities and shops, interviews with Metra staff, and the review of Metra supplied data, along with researching and documenting the best practices of industry proven locomotive alternative energy fuel projects; and identifying promising approaches that have been successfully put into practice applicable to Metra's locomotive fleet.

Task 3 comprises a feasibility analysis for the most viable alternative energy fuel options at both a pilot program and system wide level. This includes identifying all necessary locomotive modifications, fueling facility concepts for safely storing and handling the fuel, an analysis of associated regulatory requirement and safety hazards, a determination of impact to routes and schedules, fueling operations, inspections, maintenance, and applicability of current and proposed EPA emissions standards. A financial 'break even' analysis was provided weighing any potential estimated fuel savings with the capital cost of locomotive conversion, fueling infrastructure, safety devices, additional maintenance costs and service constraints, if any. Potential environmental benefits and funding sources were also identified.

All of the above information is combined into the Task 4 final report which also includes a summary of steps that Metra would need to take to implement the alternative fuel, along with potential costs and possible funding sources.

Best Practices and Initial Conditions

The Task 2 Report, *Best Practices and Initial Conditions*, focused on documenting Metra's current practices regarding locomotive fuel consumption, fueling operations and infrastructure; the available alternative fuels and their relevance, availability and service history in locomotive rail applications; the most viable fuel considering Metra's locomotive fleet makeup and available technology on the market today; and governing regulations, codes and standards for the alternative fuel. Additionally, contacts were made with the most knowledgeable, relevant and experienced suppliers of compressed natural gas (CNG) equipment in the rail industry. This report made the following conclusions:

- Natural gas/dual fuel is the most viable alternative fuel based on railroad operating service history and supporting technology, with no impact to locomotive performance, as would be seen with a conversion to 100% natural gas, either liquid natural gas (LNG) or compressed natural gas (CNG).
- Currently NG (natural gas) fuel savings on a per gallon basis is on the order of $1.50 - $2.00 as compared to diesel fuel, based on Metra's current diesel and NG pricing differential. However, this does not consider the capital cost of CNG processing (compression) equipment to increase the gas density to allow for onboard storage, as well as other costs related to facilities modifications, potential changes to operation and maintenance, safety considerations and the meeting of regulatory requirements.
- Of the two options available (LNG & CNG), CNG is the most adaptable to Metra's fleet due to its portability, and the cost and availability of CNG refueling infrastructure, when compared to LNG. It should be noted that LNG locomotive conversions have required a separate rail car (tender) for storage, this would not be compatible with existing Metra operations.
- Adaptation of CNG to Metra's four districts and refueling facilities will be a challenge due to space constraints but may be feasible in some locations. BNSF and UP would also need to be partners in the process.
- There are several suppliers of prime mover engine conversion technology for dual fuel.
- There are several suppliers of CNG on-site compression, refueling and storage equipment.
- Onboard storage is a challenge, even for CNG, given the limited space available within the locomotive.
- There are numerous regulations, codes and standards for CNG equipment as a result of the natural gas vehicle (NGV) industry.
- The Federal Railroad Administration (FRA) requires any railroad planning to convert their locomotive fleet to an alternative fuel to submit a project plan, including a test plan and milestone schedule, as well as a system safety plan, a hazard analysis and a number of other supporting documents.
- Additional work was identified for the investigation of an onboard fuel storage approach, better understanding CNG refueling operations and sizing of on-site facilities, and the development of

a financial model supporting a break- even analysis; these were conceptually developed in the Task 3 report.

Feasibility Analysis and Conversion Details

The Task 3 report, *Feasibility Analysis and Conversion Details*, investigated commercially available CNG storage and refueling equipment, determined possible operating ranges given the variables of fuel consumption rate, trip distances, locomotive daily range and available onboard storage capacity. Dual fuel equipment suppliers were queried regarding locomotive conversion and fueling details.

An operating scenario for the Milwaukee District was developed from a simulation model based on actual train performance data (i.e., event recorder data) for the Chicago Union Station (CUS) to Fox Lake route. Potential refueling locations were surveyed for both mid-day refueling as well as overnight refueling which now becomes a requirement due to limited onboard CNG storage on the locomotives that were evaluated.

Modifications to Metra's facilities were also investigated to meet NFPA (National Fire Protection Association) requirements for servicing locomotives with onboard CNG. Federal Railroad Administration (FRA) mandated test planning and safety related documentation were studied and summarized. A financial break-even analysis was conducted based on estimated capital costs. Reduction in NOx (oxides of nitrogen) and PM (particulate matter) were estimated based on the operating simulation combined with the expected substitution rate for CNG. Several potential state and federal sources were identified for funding a portion of the conversion costs; the primary aim of most of the funding sources is reduction of diesel exhaust emissions, which the CNG conversion would enable.

This portion of the report re-iterates the findings, conclusions and next steps that Metra would need to take to implement a locomotive dual fuel program.

The Milwaukee district was studied in detail as part of the feasibility study. The Milwaukee District lent itself well to the feasibility study for the following reasons:

- The daily travel distances are typical of Metra's routes.
- The quantity of locomotives utilized (38) approximated the number of locomotives available in Metra's fleet which are viable candidates for dual fuel conversion (at mid-life or less), namely the MP36PH-3C, the F59PH and the recently acquired F59PHI.
- This district is fully within Metra's control unlike the UP and BNSF districts, allowing greater flexibility in implementation.
- There is potential for a substitution of approximately 4MM gallons of diesel fuel with CNG and an annual fuel cost savings of $6.5MM annually, based on the diesel-CNG pricing differential of $1.60 used in this report.
- Good operational model data already existed for the CUS to Fox Lake route.

- The Milwaukee District (or one of its routes) could be used as a pilot program for evaluating CNG conversion before deploying on a larger scale. Also, a more limited scale than what was presented herein could also be executed as an evaluation project.

Feasibility for conversion of Metra's entire fleet in other operating districts was not evaluated due to uncertainty of what type of locomotive will replace the approximately 100 F40's that are nearing end of useful life. Metra may choose to replace these with new Tier 4 locomotives; dual fuel conversion has not been applied to any of the currently available Tier 4 commuter locomotives at the time of this report.

A preliminary evaluation was conducted of Metra's major locomotive maintenance facilities (Western Avenue and the 47th Street shops) for compliance to safely handle CNG equipped locomotives, and a preliminary survey of potential space envelopes for CNG refueling stations at all of Metra's mid-day and overnight layover facilities was also provided. From this study the following conclusions can be made:

- The Milwaukee District Operating Scenario demonstrates the feasibility of a dual fuel operation; however, some operational challenges have been identified.
- The most impactful issue identified is that on-board CNG storage capacity is a limiting factor with Metra's current fleet of F59PH, F59PHI and MP36 locomotives due to limited space in the carbody and underframe areas. Initial capacity based on available onboard space was estimated to be on the order of 300 DGE of CNG and up to 1,000 gallons of diesel fuel, when utilizing a novel underframe combination storage tank concept proposed by one of the refueling station suppliers. Additional above-deck CNG storage may be possible but would require a major reconfiguration of the equipment in the car body. Some reconfiguration of underframe equipment would also likely be required to accommodate the larger fuel tank.
  - At the estimated substitution rate of 65% CNG, these locomotives would be limited by the on-board CNG, which would be consumed at an average rate of 2.2 DGE per mile, based on the CUS-Fox Lake run simulation.
  - Because of the onboard CNG storage limitation, the MDN study identified a necessary overnight refueling scenario. This drives additional costs to install and maintain the overnight fueling stations and additional staff to perform the fueling. Weekend refueling would also be required. Metra currently has no need to refuel at remote sites and can typically operate some locomotives throughout the weekend without refueling.
  - Also because of the onboard CNG storage limitation, conversion of the separate diesel HEP engine was not considered. If more onboard CNG storage were available, the diesel HEP engines could be replaced with 100% CNG fueled engines allowing an even greater rate of diesel fuel substitution (another 20%) and additional reduction of exhaust emissions.
  - Although the CNG storage is limited, the larger volume of onboard diesel storage combined with its reduced usage, would ensure that even if all of the onboard CNG were consumed, the nature of the dual fuel engine allows it to run on diesel only.

    - It is noted that the recently acquired EMD SD70MAC (proposed freight conversion to passenger service) locomotives would have greater CNG and diesel onboard storage capability (550 DGE of CNG and 2,000 gallons of diesel) and would be less limited in range than the smaller commuter locomotives (if converted). Per Metra, it is not planned to utilize these locomotives on the Milwaukee district.
- In the case of Metra's mid-day refueling locations, large buffer storage of CNG (up to 10,000 DGE) would be required to expedite the mid-day refueling which will require a large footprint. The site survey shows 3 of the 4 possible fueling locations on the Milwaukee District appears to have available space for installation of the CNG fueling and storage equipment with further assessment needed for the Western Avenue location. There are also several potential locations on the other districts presenting challenges.
- In the case of the Milwaukee District, if space is available, CNG refueling could be accomplished at the Western Avenue mid-day refueling site with fast fill fueling dispensers and a large buffer storage (10,000 DGE) of CNG. The proposed fueling facility presented was sized to refuel 40 locomotives in a two-hour window.
- The overhaul cycle of dual fuel engines is assumed to coincide with the same time or mileage-based cycle that a diesel only engine would require. The cost of performing a dual fuel locomotive engine mid-life overhaul was assumed to be the same as a diesel only engine. Manufacturers do not have long historical data to validate life of engine components or overhaul requirements.
- Owing to the large installed base of CNG fueling stations for large vehicles such as passenger buses, commercial trucks, and other utility vehicles, the fueling equipment is readily available and largely well supported. The equipment is scalable to support the necessarily higher refueling rates and capacities for locomotives. Specific consideration will need to be given in future engineering efforts for space constraints at Metra's facilities.
- Special considerations will need to be made for Metra's locomotive maintenance facilities to ensure electrical and mechanical equipment (lights, heaters, fans, etc.) compatibility with CNG vehicle maintenance facility code requirements. An overview of necessary changes has been provided, but a more detailed assessment and equipment survey of each facility is recommended to determine design criteria before preliminary engineering work can commence.
- The proposed timeline indicated that the conversion process for the Milwaukee District is estimated to be a 4 to 5-year process once funding is available, based on the assumptions made. This is a conservative assumption based on Metra supporting the locomotive conversion with their craft labor and completing the conversions at the rate of one unit per month. The process could potentially be expedited by increasing the rate of conversions through outsourcing of the conversions.
- Accordingly, each facility and overnight fueling location design requirements will need to be thoroughly reviewed with the local Authority Having Jurisdiction (AHJ) for permit planning. This

may also require community outreach and education. These efforts are hard to define and capture in this report.

- The two primary dual fuel conversion equipment suppliers, ECI/EE and Progress Rail have created the kits and they have been installed and operated in pilot projects throughout North and South America on freight railroads, however there is not a large base of installed systems on locomotives currently operating in North America, and none known to be in passenger rail service to date.
- The FRA will require a formal detailed plan to be submitted to demonstrate that locomotives utilizing CNG as a fuel can be safely operated in Metra's districts, including along specific alignments. Obtaining FRA approval is the first step in the process of dual fuel conversion. The FRA has created a Natural Gas Safety Review program for NG and alternative fuel locomotives.
- Based on the estimated capital cost assumptions shown and the diesel-CNG price forecast, payback for the investment in the CNG conversion for the Milwaukee District will take about 13 to 15 years as long as fuel prices remain somewhat predictable. If external funding is secured to cover a portion of the capital expenses, or if the price of diesel fuel rises dramatically, this would improve the payback timeframe.
- If Metra wishes to perform an evaluation of CNG/diesel dual fuel on a smaller scale, one of the three lines (i.e., Fox Lake) in the Milwaukee District, and a limited number of locomotives could be converted along with the necessary CNG infrastructure for a pilot project. The Rock Island line may also be considered for a pilot project as it is a smaller operation than the Milwaukee District.
- It should be noted that once the investment is made in the dual fuel fleet conversion, the refueling infrastructure and other related activities, Metra would continue to benefit from the annual fuel savings indefinitely with the continued availability of dual fuel powered locomotives. To that end it is expected that this would become a requirement in the specifications for future locomotive procurements.
- Substitution of CNG for diesel fuel will have a positive effect on exhaust emissions for the converted locomotives. NO_x and PM will both decrease by proportional amounts of CNG substitution as NG burns 'clean'. It should be noted that CNG substitution begins at notch 3 in a dual fuel locomotive so exhaust emissions at idle will not change. Metra would gain the most emissions improvement by converting unregulated, Tier 0 or Tier 1 locomotives and take advantage of the immediate benefits. There is no current info on what EPA Tier requirement that the converted locomotives could achieve.

It should be noted that this report was specifically prepared to review and make recommendations regarding available alternate fuels for Metra's locomotive fleet. It is beyond the scope of this report, but it is expected that Metra would also evaluate the pros and cons of dual fuel conversion against a Tier 3 or Tier 4 diesel engine conversion. Although the fuel cost savings would not be as significant (Tier 4 engines are more fuel efficient than those in the current fleet), exhaust emissions reductions would be much greater.

Conclusions

The Feasibility Analysis and Conversion Details report provided conclusions of analysis performed, see above. A high-level listing of benefits and challenges for conversion is provided in this section.

Benefits of Dual Fuel Conversion

- Potential for up to 65% NG substitution for diesel, with corresponding fuel cost savings depending on degree of conversion. For the Milwaukee District, this would be on the order of 4MM gallons of diesel fuel replaced at an estimated savings of approximately $6.5MM annually at current CNG and diesel prices. If applied to all Metra districts, the annual fuel cost savings potential would be on the order of $26MM annually.
- Potential for PM and NOx exhaust emissions reductions as NG is a cleaner burning fuel. In addition to the fuel itself, diesel also contains dyes, and lubricants which also contribute to the particulate matter and soot which would be reduced.
- Significantly fewer diesel fuel deliveries (about 580 fewer diesel fuel deliveries to Western Ave. annually, for example), resulting in less traffic in and out of refueling facilities and reduced spill potential as NG is supplied directly to each site by pipeline so no service disruptions due to weather or missed fuel deliveries.
- Dual fuel conversion allows backup operation on 100% diesel if onboard CNG is depleted.
- CNG refueling is simpler than diesel refueling as fuel stations automatically regulate and shutoff when fueling is complete.
- CNG fueling infrastructure is transit service proven, due to the large fleets of CNG powered buses (over 14,000 in operation) and other vehicles in operation for many years; fueling and NG compression equipment is readily available and scalable to Metra’s fleet needs.
- The price of NG is historically more stable and not prone to the wild fluctuations of diesel fuel due to variations in supply.
- Dual fuel conversion kits are available for Metra's existing fleet (645 and 710 engine families) and conversions can be accomplished in Metra's shops by Metra personnel (with engineering support from the supplier).

Challenges for Dual Fuel Conversion

- There are very high capital costs and a multi-year timeline associated with the addition of CNG infrastructure, locomotive fleet and maintenance facility modifications to Metra’s districts and a long payback period as illustrated in the provided financial analysis.
- Based on the financial model of Milwaukee District only, the break-even point may take up to 15 years, assuming no gross fluctuation in prices for either fuel. This may be near the usable life of the converted locomotives. A fifteen-year life was assumed for the locomotives after conversion and overhaul.

- There is some uncertainty about the availability of locomotives for dual fuel conversion; this study identified locomotives in Metra's fleet that are suitable for conversion, however it is unknown at this time if any of the current manufacturers would offer this option for a new locomotive.
- The addition of CNG refueling equipment to Metra's facilities will require an extensive multi-year project planning, engineering, coordination, construction, testing and acceptance planning.
- Limited on-board storage availability for CNG will drive additional refueling, impacting Metra's current operating scenarios.
- Addition of personnel at overnight refueling station locations to accomplish CNG refueling.
- Additional required safety and operational training on the use of CNG.
- Engineering and design engagement of the local permitting authorities early and throughout the design process.
- Timely approval of all testing and conversion plans by the FRA.
- Hazard potential will require detailed hazard analyses and mitigation plans, coordination with municipalities (i.e., first responders along Metra's alignments) and extensive safety training.
- Potential noise nuisance issues with CNG compression equipment at Metra's outlying overnight locations.
- Public perception of locomotives with CNG on board passing through multiple, densely populated communities – significant efforts for community outreach may be needed.
- Potential for additional maintenance and inspection of NG equipment on board locomotives.
- Exhaust emissions reductions, although much improved over Metra's existing diesel locomotive fleet, does not approach the reduction from EPA Tier 4 engines.
- Meeting higher emissions standards such as Tier 4 may require more CNG substitution and exhaust filtering apparatus. More development would be needed to make this technically feasible.

Next Steps

The data provided in this study is intended to aid the RTA and Metra in making an assessment in the feasibility of converting all or a portion of its diesel locomotive fleet to operate on an alternate fuel; the CNG/diesel dual fuel approach is proposed as it allows for a greater substitution of a lower cost and more cleaner burning fuel without compromising available horsepower and train performance. Per the equipment suppliers' pilot programs, the dual fuel approach does not in any way degrade locomotive operation.

These reports provide an initial assessment of the feasibility of the alternate fuel conversion and a roadmap to further investigations and studies to determine the impact to Metra, both positive and negative, on a dual fuel fleet conversion.

If Metra chooses to pursue a dual fuel approach as outlined in this report, the following recommendations are made:

- Engaging the FRA's Natural Gas Safety Review team is key to moving forward and gaining approval before any major investment is made. Contact information for the FRA Supervisory Railroad Safety Specialist is provided in the References section of the Task 3 report.
- An experienced natural gas facilities engineering consultant should be brought on board who can guide Metra through the CNG conversion process, encompassing safety requirements, NG supply, pressurization, storage and fueling, local, state and federal regulations, etc. Pace used this approach to successfully launch their CNG bus project.
- Contact with the NG suppliers in proximity to each facility to determine available gas line pressure to discuss what is needed to provide the gas volumes required at each fueling location.
- A detailed site survey and engineering study of each fueling location to determine suitability of each site for the pumping, storage and dispensing stations.
- A detailed review of Metra's maintenance shops to determine the scope of changes required to be code compliant for handling CNG fuel locomotives.
- Contact with the equipment suppliers identified in this report to begin discussion on the conversion details and detailed cost estimates for the locomotive modifications and the fueling equipment. The cost estimates provided herein are rough order of magnitude.
- Contact with locomotive manufacturers to explore the option of providing dual fuel Tier 4 locomotives for future procurements; and the development of associated specification requirements for future locomotive procurements.
- Development of a more detailed break-even analysis to better evaluate the financial side of the project. The analysis presented makes many assumptions and is considered conservative. Receipt of public funding was not considered to offset the capital cost.
- Monitoring of new motive power technology. The CNG dual fuel approach was selected based on its availability and applicability to Metra's existing fleet. While there is limited development in North America, Europe has been more aggressive in mandating a path away from diesel engines in rail transportation.
- For a local perspective on a CNG based dual fuel conversion process currently underway, Metra may wish to reach out to the Indiana Harbor Beltway to learn more about their switcher conversion process. The supplier of the dual fuel engines, Optifuel™, may be contacted to arrange this if Metra is interested.

Best Practices and Initial Conditions Study

Introduction and Background

The Regional Transportation Authority (RTA) has tasked LTK Engineering Services to evaluate the feasibility of alternative fuels for use by their partner commuter rail agency, the Northeast Illinois Regional Commuter Railroad Corporation (d.b.a Metra). LTK Engineering Services has conducted an evaluation of Metra's existing locomotive fleet, general maintenance and operational practices, refueling facilities, and maintenance facilities. This evaluation provides recommendations on whether an alternative fuel may be viable for some, or all of Metra's locomotives and facilities based on an established set of criteria to be formulated as part of this study.

Metra is one of the largest commuter rail agencies within North America, serving 242 stations over 11 lines. All lines, except for the Metra Electric District, are served by diesel-electric locomotives as push-pull service. The Metra locomotive fleet is of various vintage, with key similarities that will be explained herein.

Metra, however, is not the sole Operator and Maintainer of its rolling stock. Metra contracts with freight railroad carriers Burlington Northern Santa Fe (BNSF) and Union Pacific through purchase-of-service agreements. BNSF and Union Pacific operate several of the Metra lines and maintain Metra locomotives and coaches dedicated to those lines.

Metra Service Profile and Routes

The Metra commuter rail system is comprised of ten diesel-electric locomotive push-pull lines. Each line has some historical reference to the original commuter rail operations of various freight rail lines in the Chicago region. To this day, the names of the lines represent a link to the original railroad designations. Operations and maintenance of these lines is handled by five operating "districts", three of which are directly within Metra (staffed by Metra employees). Each Metra line originates from a depot station within downtown Chicago. The Metra system is shown on Figure 1.

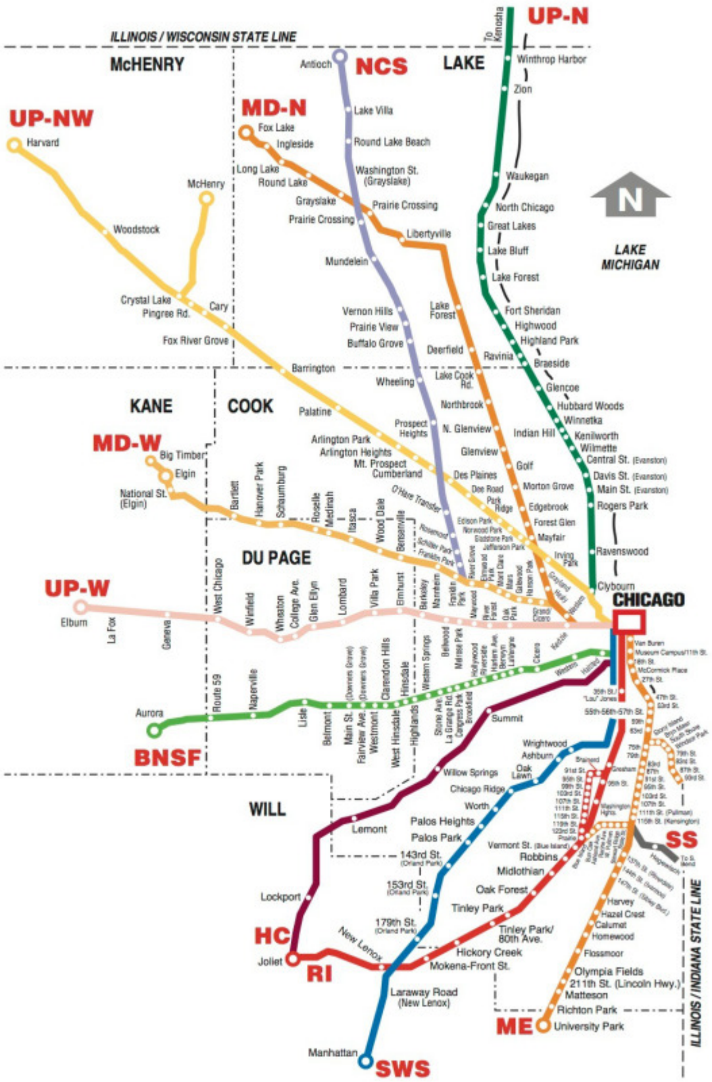


Figure 1 - Metra System Map

Metra Rock Island District

The Metra Rock Island District is owned and operated by Metra. This district serves the Metra Rock Island Line with service from downtown Chicago's LaSalle Street Station to Joliet, IL. The Rock Island Line is comprised of a main line service, and branch service through Chicago's Beverly and Morgan Park neighborhoods. The Rock Island Line alignment and facilities are part of the former Chicago, Rock Island, and Pacific Railroad.

Metra Milwaukee District

The Metra Milwaukee District is owned and operated by Metra. The district serves the Metra Milwaukee District North, West, and North Central lines with service from Chicago Union Station to Fox Lake, IL, Elgin, IL, and Antioch, IL, respectively. Additionally, the Milwaukee district serves the Heritage Corridor line with service between Chicago Union Station and Joliet, IL. The Milwaukee West Line alignment and

Milwaukee district maintenance facility are part of the former Chicago, Milwaukee, St. Paul and Pacific Railroad. The Milwaukee North Line operates on tracks owned and dispatched by Canadian Pacific Railway between Rondout and Fox Lake. The North Central Service operates on tracks owned and dispatched by Canadian National Railway between River Grove station and Antioch. The Heritage Corridor operates on tracks owned and dispatched by BNSF and Canadian National Railway between Chicago Union Station and Joliet.

Burlington Northern Santa Fe

The BNSF District is owned and operated by the Burlington Northern Santa Fe Railroad. The district serves the BNSF Line to Aurora, IL and Southwest Service to Orland Park and Manhattan, IL from Chicago Union Station. The BNSF line alignment and district maintenance facility are part of the former Chicago, Burlington and Quincy Railroad (now owned by BNSF). The Southwest Service rolling stock is maintained by BNSF and operated on alignment owned by Metra and Norfolk Southern Railroad.

Union Pacific

The Union Pacific District is owned and operated by the Union Pacific Railroad. The district serves the Union Pacific West, North West, and North Lines to Elburn, IL, Harvard and McHenry, IL, and Kenosha, WI from Chicago Ogilvie Transportation Center. Each line alignment and maintenance facilities are part of the former Chicago and Northwestern Railroad (now owned by Union Pacific). The rolling stock for all three lines are operated and maintained by Union Pacific.

Metra Electric District

The Metra Electric District is owned and operated by Metra. This district serves the Metra Electric Line, with service from downtown Chicago’s Millennium Station to the South Chicago neighborhood, Blue Island, IL, and University Park, IL. This line is completely electrified (for revenue operations) and not considered in the scope of this report.

Management, Operations and Maintenance

Corporate Management

Metra was established as the Chicago-area commuter rail agency in 1984 following a reorganization of the RTA the previous year to take over operation of the commuter rail divisions of the bankrupt Rock Island and Chicago, Milwaukee, and St. Paul (Milwaukee Road) railroads. Prior to 1984, the RTA directly contracted with railroads under purchase-of-service agreements to maintain and operate their existing commuter rail services. As Metra was initially formed from vestiges of two railroads their management structure, operations, and maintenance (Mechanical) departments mirror those of typical freight carriers or long-established commuter agencies.

Since its establishment, Metra has created a unified zone-fare and common service brand across each line. Rolling stock, facility, and station design standards and efforts are led by Metra (with the partnership of contract carrier and host railroads). Metra is responsible for coordinating all schedules, daily operations, and service needs across the operating districts and host railroads.

Mechanical Department

The Metra Mechanical Department is responsible for establishing maintenance and inspection guidelines, procurement of new and overhaul of existing rolling stock, and for capital (or operating) enhancements to existing fleets. While the BNSF and Union Pacific maintenance facilities are owned and operated by the respective contract carriers, the Metra Mechanical Department is tasked with oversight and coordination of activities within those facilities.

The Metra Mechanical Department's (and contract carriers') maintenance facilities are led by senior management positions with operating superintendent, and job foremen actively managing various craft employees. There are some differences in craft responsibilities between shops and railroads but are typically similar. Items of note related to maintenance and fuel concerns are highlighted in this report, as needed.

Operations Department

The Metra Operations Department is responsible for daily service for each of the five operating districts. The responsibilities include revenue and non-revenue train movements as well as transfer of rolling stock between districts. The Metra Operations Department coordinates closely with the Operating groups of the contract carriers as well as dispatch offices of host railroads (Canadian National, Canadian Pacific, Norfolk Southern, etc.).

Engineering Department

The Metra Engineering Department is responsible for Metra facilities design and maintenance as well as typical railroad bridge, track, and signal system design and maintenance. Design work for host railroads and contract carriers is performed in coordination with or for the external parties, as required.

Metra Districts and Facilities

Metra Rock Island District

The Rock Island District has one central maintenance location, comprised of three separate maintenance facilities and two end-of-line yards. The 47th-49th-51st Street complex is composed of a locomotive shop, capital project heavy maintenance shop, daily fueling track, and main coach yard (51st Street yard).

The daily operation of the yard and facilities requires trains departing LaSalle Street Station (with locomotive leading) to enter the yard through the train washer (attached to the 47th Street locomotive shop). The locomotives are removed from the train consists (connected coaches and locomotive) and the cars are staged at the 51st Street coach yard for daily servicing and cleaning. The locomotives are brought through the fueling and sanding rack adjacent to the 49th Street coach shop. The fueling operation performed as a "top off" as each locomotive may have different fuel tank levels; this depends on that locomotive's particular train service for the past evening and morning. The locomotives are then pulled (backed-in) to the 47th Street locomotive shop for daily inspection. The duration of shop stay is typically short (less than two hours) as locomotives constantly need to be shuttled in and out of the inspection tracks and spotted at the south end of the 51st Street coach yard for afternoon and evening rush hour service. The entire operation of this yard and facility is typically consistent but relatively fast paced as multiple moves and switching operations are required daily between peak operating periods.

The 47th Street locomotive shop is the daily inspection shop for Rock Island District locomotives as well as a heavy maintenance facility for Metra locomotives in general (capital improvements and component replacement activities). The facility is designed as a "dead-end" shop, with space for two locomotives in each bay. The shop has six bays with ramps for daily service and periodic inspections and two bays for heavy maintenance and overhaul activities (although only one is used for locomotive parking). Each bay door is equipped with an overhead, circular heater with fan blower; these heaters are also found throughout the shop. Additionally, several of the inspection bays have exhaust systems to evacuate the diesel locomotive emissions.

The Blue Island yard (Blue Island, IL) is used as a nightly layover location for five currently scheduled trains with capacity for an additional train. Trains parked at this yard are kept powered using wayside 480V connections for the purposes of maintaining minimal interior heat for both the cars and locomotive systems. Any work or maintenance performed here (and all other night locations) is completely minimal to prepare trains for morning service such as daily brake tests.

The Joliet yard is used as a nightly layover location for eight Rock Island and three Heritage Corridor service trains on eleven tracks. As with the Blue Island yard, 480V wayside electrical service is used and maintenance work is minimal.

Metra Milwaukee District

The Milwaukee district has one central maintenance location comprised of a locomotive and coach shop (within the same building), one large yard complex (with three sub-yards), and three end-of-line yards (Elgin, Fox Lake, and Antioch).

The Western Avenue yard and (coach and locomotive) shop are the daily fueling and service locations for equipment assigned to this district (across four lines). The daily operation requires trains departing Union Station to enter the yard through a ladder track near the Western Avenue passenger station. Trains either enter the yard directly or are routed through a train washer adjacent to the shop. Once the train consists are spotted in their designated yard tracks the locomotives are then removed and brought to fuel rack to the north of the locomotive shop bay doors. As with the Rock Island fueling operation, locomotives are “topped off” as fuel usage varies by locomotive and assigned train service. After fueling and sanding, the locomotives are pulled into the shop on the inspection track for daily inspection. The shop (and inspection track) are designed as run-through – locomotives are brought in from the north and exit the south end. Following daily inspection, the locomotives will exit the shop and are attached to their afternoon and evening rush hour consists. The locomotive shop consists of three tracks, two of which are accessible by a ramp and are used for daily and other periodic inspections or running repairs; the other track is used for heavy repairs.

The Elgin yard is used as the nightly layover location for 10 Milwaukee District West service trains. As with the other nightly layover yards, trains are powered through wayside electrical service and maintenance work is minimal.

The Fox Lake yard is used the nightly layover location for 11 Milwaukee District North service trains. As with the other nightly layover yards, trains are powered through wayside electrical service and maintenance work is minimal.

The Antioch yard is used as the nightly layover location for five North Central Service trains. As with the other nightly layover yards, trains are powered through wayside electrical service and maintenance work is minimal.

The Heritage Corridor service trains, are served by the Western Avenue yard and shop layover at the Rock Island District Joliet yard.

Burlington Northern Santa Fe

The BNSF contract carrier district has one central maintenance location comprised of a locomotive and coach shop (same layout as the Metra Milwaukee District Western Avenue shop) and one large yard complex (with two sub-yards), and three end-of-line yards.

The 14th Street yard and shop are the daily fueling and service locations for equipment assigned to this district (across two lines). The daily operation requires trains departing Union Station to enter the yard through the north via a train washer facility or the A-Yard ladder track or B-Yard ladder track. Train consists are spotted in either of the two yards and locomotives are removed and brought to the fuel rack to the south of the locomotive shop via two ladder tracks. At the BNSF shop, unlike the Western Avenue shop, locomotives are not necessarily moved into the shop for daily inspection work. The locomotive shop is used for other routine inspection work and running repairs.

The Aurora yard is used as the nightly layover location for 19 BNSF service trains. As with the other nightly layover yards, trains are powered through wayside electrical service and maintenance work is minimal.

The Orland Park yard is used as the nightly layover location for three Southwest service trains. As with the other nightly layover yards, trains are powered through wayside electrical service and maintenance work is minimal.

The Manhattan yard is used as the nightly layover location for two Southwest service trains. As with the other nightly layover yards, trains are powered through wayside electrical service and maintenance work is minimal.

Union Pacific

The Union Pacific contract carrier district has two central maintenance locations – one locomotive shop and one coach yard; the Union Pacific district utilizes seven remote (end-of-line) tracks and the main depot (Ogilvie Transportation Center) for nightly layover locations.

The California Avenue coach yard and shop is where daily coach maintenance and periodic inspections take place. Complete consists arrive from Ogilvie Transportation Center after the morning rush hour; coaches remain at the California Avenue coach yard and locomotives move to a separate locomotive maintenance facility, M-19-A shop.

The M-19-A shop is utilized for periodic inspections and heavy repairs. M-19-A has three outside tracks accessible by fueling racks to the south of the shop. Additionally, within the M-19-A shop, there are two tracks with fueling capability; this is different than all other Metra district shops (as no other Metra shops have internal fueling capabilities).

The main depot, Ogilvie Transportation Center, also has fueling capabilities – unlike the other Metra districts. There are two fuel pumps located on the northern end of the depot (adjacent to Clinton St.) which can be used to fuel one track. Additionally, there are two dedicated fueling tracks accessible by one fuel rack directly to the north of the eastern-most track (adjacent to Canal St.). Ogilvie Transportation Center is used as the nightly layover location for five trains (dedicated to Union Pacific North, Northwest, and West service). It should be noted that not all locomotives report to the M-19-A facility on a daily basis for fueling; they may be fueled at Ogilvie Transportation Center, dependent upon assigned schedule.

The Elburn yard is used as the nightly layover location for 11 West service trains, as with the other nightly layover yards, trains are powered through wayside electrical service. No maintenance activities occur at this yard, only train preparation for morning service.

The Barrington yard is used as the nightly layover location for four Northwest service trains. The Crystal Lake yard is used as the nightly layover location for six Northwest service trains. The McHenry Yard is used as the nightly layover location for two Northwest service trains. The Harvard Yard is used as the nightly layover location for four Northwest service trains; as with the other nightly layover yards, trains are powered through wayside electrical service. No maintenance activities occur at this yard, only train preparation for morning service.

The Waukegan yard is used as the nightly layover location for seven North service trains. The Kenosha yard is used as the nightly layover location for five North service train; as with the other nightly layover yards, trains are powered through wayside electrical service. No maintenance activities occur at this yard, only train preparation for morning service.

Locomotive Fleet

The Metra locomotive fleet consists of 148 active revenue service units. Of these, several are undergoing rehabilitation and overhaul work and one is considered as wrecked. The active locomotive types are as follows:

F40PH-2

The Electro-Motive Diesel (EMD) built F40PH-2 locomotives are currently Metra's oldest (by means of technology). These locomotives are equipped with older-style module card engine and traction control. These locomotives bear a 1,500-gallon chassis-hung diesel fuel tank and are equipped with a turbocharged EMD 645 16-cylinder, 3200 hp prime mover (main engine) with a direct driven air compressor and Head End Power (HEP) generator. The F40PH-2 locomotive length is 56'-2" over coupler pulling faces with a 260,000 lb weight. The F40PH-2 locomotives are equipped with Mechanical Unit Injection (MUI) fueling.

These locomotives Road Numbers are 150 through 172, inclusive, on Metra's roster and are currently assigned to the Union Pacific district.

F40PH-3

The EMD F40PH-3 locomotives are overhauled or remanufactured F40PH-2 units. These locomotives are equipped with a microprocessor controlled (EM-2000) engine and traction control system and larger fuel tank (2000-gallons). Some other differences, not relevant to this report, include upgraded Event Recorder and front-end structural elements. It should be noted that some of F40PH-3 units are equipped with Electronic Fuel Injection (EFI) and some are equipped with Mechanical Unit Injection (MUI). Both utilize the turbocharged EMD 645 16-cylinder, 3200hp prime mover with a direct driven air compressor and Head End Power (HEP) generator. Physical dimensions and weight are the same as the F40PH-2. The F40PH-3 locomotives overhaul/remanufacture program was performed through two separate contracts to Progress Rail Services (between 2009 and present).

These locomotives are currently assigned to the following districts:

Table 1 - F40PH-3 Locomotive Assignments

Milwaukee	Rock Island	BNSF	Union Pacific
100 - 104, 106 - 111, 115, 118, 120, 123 - 124, 215 - 217		105, 112 - 114, 116, 117, 119, 122, 125, 137	121, 126 - 136, 138 - 149

F40PHM-3

The F40PHM-3 locomotives are overhauled F40PHM-2 units. All F40PHM-2 units will be overhauled and converted F40PHM-3. The F40PHM-2 is very similar to the F40PH-2 locomotive except for the front end. The front end has a more "streamlined" appearance than the F40PH-2 design. These locomotives were first manufactured by EMD during the early 1990s with the same internal features and design as the previous F40PH-2 units. For the purposes of this report all F40PHM-2 units are designated as F40PHM-3 units.

These locomotives are assigned to the following districts:

Table 2 - F40PHM-3 Locomotive Assignments

Milwaukee	Rock Island	BNSF	Undergoing Overhaul
	189, 201 - 203, 207 - 209	186 - 188, 190, 192, 194 - 196, 198 - 200, 210 - 214	185, 191, 193, 197, 204 - 206*, 208

* Locomotive 205 is currently considered wrecked

MP36PH-3S / MP36PH-3C

The Motive Power Incorporated (MPI) MP36PH-3S locomotives are different in body and control systems compared to the Metra EMD fleet. These locomotives are 68' long, with a nominal weight of 298,000 lb and are equipped with a turbocharged EMD 16-645 3,600hp prime mover. These locomotives incorporate a 2,500-gallon chassis-hung diesel fuel tank. These locomotives were originally equipped with a static inverter for a direct driven HEP generator. Metra has begun the process of converting these locomotives to a separate diesel-powered HEP engine and generator (Caterpillar C18, 600hp); these units are designated as MP36PH-3C. For the purposes of this all MP36PH-3S units are designated MP36PH-3C. The other notable differences to the Metra F40PH fleet include electronic air brake control (Wabtec EPIC-II), Wabtec QES computer for engine and traction control, integrated cab air-conditioning unit, and aerodynamic front-end design. Metra has also started a program to replace the Mechanical Fuel Injection system with an Electronic Fuel Injection system for the MP36 fleet.

These locomotives are assigned to the following districts:

Table 3 - MP36PH Locomotive Assignments

Milwaukee	Rock Island
401 - 404, 413 - 415, 417, 419 - 424, 426 - 427	405 - 412, 416, 418, 425

F59PH

The EMD F59PH locomotives were recently purchased from Montreal's commuter rail carrier (AMT). These locomotives were built in 1988 and are equipped with an EMD 710, turbocharged 12-cylinder, 3000 hp diesel engine. These locomotives are equipped with a separate diesel-powered engine and generator (Caterpillar 3412, 670hp) and a 1500-gallon chassis-hung diesel fuel tank. Locomotive length over coupler pulling faces is 58'-2".

The locomotive Road Numbers are 97 through 99, inclusive, and are assigned to the Milwaukee District.

Near and Long-Term Fleet Acquisition and Replacement

Metra has recently entered into an agreement to purchase 21 used EMD F59PHI locomotives from Amtrak. These locomotives were built in 1998 and are equipped with the EMD 710 12-cylinder, 3000 hp diesel engine, a separate diesel-powered engine and generator (Caterpillar C27) HEP unit, and a 2000-gallon chassis-hung diesel fuel tank. Metra is in the process of receiving this fleet and preparing for service.

In addition to the F59PHI purchase, Metra is currently considering proposals for up to 12 new or 15 remanufactured locomotives. As the technical and commercial review process is still active, no further information has been shared for the purposes of this study.

Future locomotive purchases, by Metra, may be funded from the $2B nation-wide settlement between the United States government and the Volkswagen Group. The terms of the settlement indicate that each state will receive a portion of the funds to use as seen fit. There are some discussions of using some of the Illinois ear-marked funds for Metra diesel locomotive replacements. At this time no further details are available regarding possible quantities of new locomotives.

Current Fuel Type, Usage & Fueling Infrastructure

Metra locomotives are powered by a prime mover which uses Ultra Low Sulphur Diesel (ULSD) fuel. Currently, Metra has a contract with Mansfield Oil. Diesel is delivered by tanker truck to each Metra and contract carrier fueling facility on a daily basis (some locations receive more frequent deliveries throughout the day). End-of-line yards also receive fuel deliveries via tanker truck. These yards typically do not have fuel storage and pumping infrastructure.

Fuel Usage

Fuel usage varies by locomotive type and assigned train service. Typical to the operating districts, each locomotive is fueled once a day in the yard or service shop. The fueling operation is a "top-off" type to ensure that the tank is full for the afternoon and evening rush hour service. It has been noted by Metra that additional fueling may occur at the end-of-line yards during winter, as the locomotives are required to remain running (idling) rather than just shut down if outside temperatures fall below 10°F; leading to increased fuel usage.

Metra has performed some internal fuel usage projections based on locomotive odometer readings and fueling gauge tracking. This was performed on the same Milwaukee District train – 2125. It should be noted that no Metra locomotives are equipped with digital fuel gauges or fuel use monitoring. The Metra-provided average usage is given in Table 4 (as information):

Table 4 - Metra Provided Average Usage

Locomotive Type (and Feature)	Gallons / Mile	Gallons / Year (projected)
F40PH-3 (EFI)	4.66	247931
F40PH-3 (MUI)	4.72	250974
MP36PH-3C (EFI)	3.88	206221
MP36PH-3C (MUI)	3.53	187783
F59PH	3.58	190110

Fueling Infrastructure

Each of the locomotive maintenance shops are complemented by a diesel fueling facility. These facilities are serviced by fuel delivery tanker trucks daily.

Metra Rock Island District

The Metra Rock Island 47th-49th-51st Street yard complex is equipped with one fueling rack which is designed to fuel up to three locomotives on one track. This rack is also equipped with infrastructure for providing traction sand to locomotives (stored onboard). This rack is connected by an overhead gantry line to a diesel fuel pumping station. Fuel is stored in underground tanks, served by the pumping house in the parking lot.

Figure 2 - 47th-49th-51st Street Yard Fuel Rack

Figure 3 - Fuel Rack Supply Gantry and Pumping Station

The overhead gantry system was recently installed, replacing underground piping. At this location, there may be usable physical space on the fuel rack for additional fueling infrastructure however on-site storage means will need to be carefully reviewed as this facility and adjacent parking lot are under construction for building expansion.

Metra Milwaukee District

The Metra Milwaukee District Western Avenue Coach yard is equipped with one fuel rack which is designed to fuel up to four locomotives across two tracks. This rack is equipped with infrastructure for traction sand. The rack is connected by underground piping to a pumping station in the main facility parking lot. Fuel is stored in underground tanks, served by the pumping house in the parking lot.

Figure 4 - Western Avenue Fueling Rack

Figure 5 - Western Avenue Shop with Pumping Station in Foreground

At this location the fuel rack does have capability for additional fueling infrastructure at the fuel rack, however on-site storage may be a concern as the existing pumping station is between tracks, adjacent to the parking lot. There may be limited space available in the parking lot for any additional build-out for pumping, compression, and storage at the cost of parking spaces or truck loading areas.

Burlington Northern Santa Fe

The 14th Street yard and shop are equipped with one fuel rack, very similar to the Metra Milwaukee Western Avenue yard and shop. The fuel rack is located to the south of the locomotive shop. The 14th Street yard is equipped with one fuel rack which is designed to fuel up to four locomotives across two tracks. This rack is equipped with infrastructure for traction sand. The rack is connected by underground piping to a pumping station in the main facility parking lot. Fuel is stored in underground tanks. Unlike the Western Avenue rack, the 14th Street rack also has infrastructure for locomotive engine lube oil pumps; this makes for a tighter space between fuel and sanding apparatus. Fuel is stored in underground tanks, served by the pumping house in the parking lot.

Figure 6 - BNSF Fueling Rack

Figure 7 - 14th Street Shop Fuel Pumping Station

At this location the fuel rack does not have much capability for additional fueling infrastructure at the fuel rack; on-site storage may be a concern as the existing pumping station is in the main warehouse truck receiving area and parking lot (limiting ability for trucks to turn around). There may be limited space available in the parking lot for any additional build-out for pumping, compression, and storage at the cost of parking spaces or truck loading areas.

Union Pacific

The Union Pacific district has three main diesel fueling facilities. The M-19-A shop is equipped with outdoor and indoor fueling racks; the main depot, Ogilvie Transportation Center, is equipped with two outdoor fueling racks.

The M-19-A locomotive shop has two exterior fuel racks which can serve up to five locomotives across three tracks. The exterior racks also have a dedicated sand application apparatus. In addition to the exterior fuel racks, the M-19-A shop also has interior fueling capabilities as two tracks are equipped with diesel pumps. Each track can fuel up to five locomotives. Fuel is stored in two 150,000-gallon above-ground tanks in the parking lot adjacent to the shop. The fuel racks are served by a pumping station and overhead gantry pipeline across the parking lot and three tracks north of the shop.

Figure 8 - M-19-A Exterior Fueling Rack

Figure 9 - M-19-A Interior Fuel and Service Tracks

Figure 10 - M-19-A Interior Fuel Flow Meter (typical)

Figure 11 - M-19-A Fuel Pipeline Gantry

Figure 12- M-19-A Fuel Pipeline Gantry

Figure 13 - M-19-A Fuel Pipeline Gantry, Pumping Station, and Above-Ground Tanks

The M-19-A exterior fuel racks do have capability for additional fueling infrastructure; the interior have less spare capacity as the pit walkways are narrow, coordination with existing infrastructure will be critical at this location. Additional fuel storage and associated infrastructure may be accommodated by removing some automobile parking or storage track capacity to the north of the main shop building.

The main Union Pacific depot (Ogilvie Transportation Center) has two fueling locations. The main fueling location is on the Clinton Street side of the depot, adjacent to Track 1. This fueling location not only has infrastructure for fuel and engine lube oil pumping, but it is also the main diesel fuel storage for the depot. Two 50,000-gallon tanks sit underneath the track level (at street level) behind concrete walls. About 22 locomotives are fueled daily at Ogilvie Transportation Center.

Figure 14 - Ogilvie Transportation Center Track 1 Fueling Facility

Figure 15 - Ogilvie Transportation Center Track 1 Fueling Racks

Figure 16 – Ogilvie Transportation Center Fuel Storage Tanks

The other fueling location at Ogilvie Transportation Center is referred to as the “Mail Tracks”, these tracks are on the east end of the facility, adjacent to Track 16. Mail Track 1 and 2 are served by two fueling and engine lube oil stations and Mail Track 3 and 4 are served by two fueling and engine lube oil stations.

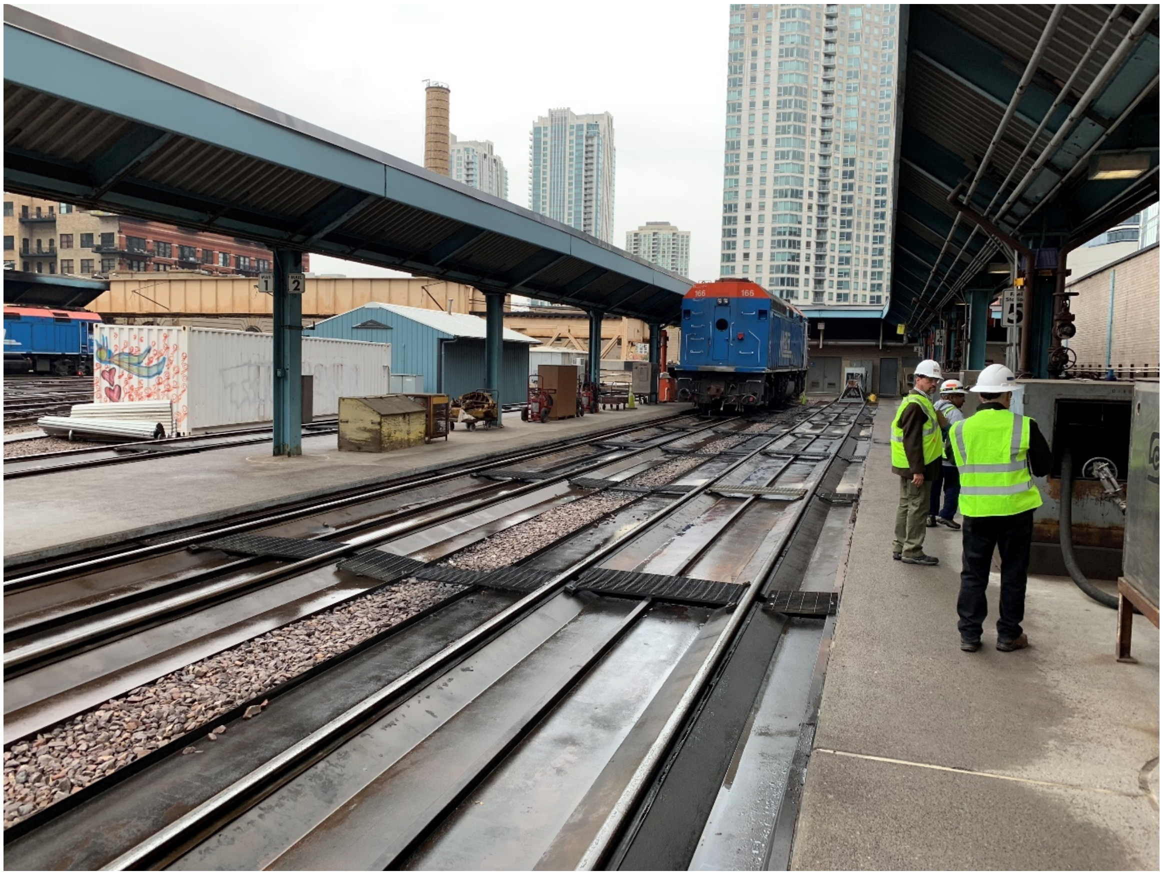


Figure 17 - Ogilvie Transportation Center Mail Track 1, 2, and 3

Figure 18 - Ogilvie Transportation Center Mail Track 4

The Ogilvie Transportation Center exterior fuel racks do not have much capability for additional fueling infrastructure; the fuel storage and pumping facility do not have additional capacity for additional fuel storage within. A summary of Metra shops and fueling sites can be found in Table 5.

Metra Fuel-Driven Constraints

Locomotive Tank Capacity and Schedule

Metra locomotives are fueled daily, on weekdays, at maintenance facility fuel racks. Additional fueling may be called for during cold temperature days, as consumption may be higher (reduced idle-shutdowns). For weekend and extended evening service, locomotives with the largest fuel tanks (MP36PH-3S/3C units) are typically assigned to ensure sufficient fuel until the next day's fueling.

Precision Fuel Monitoring

As noted in this report, the current Metra refueling strategy is typical of daily "top-off" service. Locomotives are typically pulled through the fuel rack before daily inspection (some exceptions for Union Pacific service) and are fueled then. Metra does not have any locomotives equipped with digital fuel gauges or monitoring systems reporting fuel levels to a central information system. Fuel usage is tracked at the pump by the use of punch-cards or keypads by the fueling maintenance technician.

Table 5 - Summary of Metra Locomotive Shops and Refueling Sites

District	Locomotive Shop	Facility Type	Bays	Fueling Location	Notes
Rock Island	47th St. Locomotive Shop	Dead End	6 – Routine Maintenance / Daily Inspection 2 – Heavy Maintenance	49th Street Fuel Rack; 1 Fuel Rack accessible from 1 Track	Locomotives are fueled and then backed into the diesel shop
Milwaukee District	Western Ave. Locomotive Shop	Run Through	2 – Routine Maintenance / Daily Inspection 1 – Heavy Maintenance	Fueling Rack at North End of Locomotive Shop (outside); 1 Fuel Rack accessible from 2 tracks	Locomotives are fueled and then pulled through the shop (north to south) for daily inspection
BNSF	14th St. Yard	Run Through	2 – Routine / Heavy Maintenance	Fueling Rack South of the Locomotive Shop (outside); 1 Fuel Rack accessible from 2 tracks	Locomotives are fueled and serviced (daily inspection) outside
UP	M19-A	Run Through	2 – Fueling / Daily Inspection 4 – Routine Maintenance / Heavy Maintenance	Fueling rack locations: 2 Fuel Racks accessible from 3 outside tracks; multiple fuel racks accessible from 2 inside tracks	Shop has interior fueling capability for daily inspection tracks
UP	Ogilvie Transportation Center	Run Through / Dead End	Track 1 – Run Through Mail Tracks – Dead End	2 Fueling rack locations (outside): 1 Fuel rack accessible from 1 track; 4 Fuel racks accessible from 2 tracks	Primary fueling location adjacent to Track 1; 2nd location on Mail Tracks at East side

Findings and Analysis

Alternate Fuels to be considered in the Study

The principal alternative fuel being considered in this study is natural gas in its two most commercially available forms: liquefied natural gas (LNG) and compressed natural gas (CNG). Natural gas (NG) has become plentiful in the United States to the point where the US is now a net exporter of LNG. In general, natural gas is readily available in all major cities such as Chicago and there is an extensive network of piping to transport it to industrial and residential locations for use as a heating fuel. In addition, the unit price of natural gas in both forms is somewhat lower than diesel fuel. The price of NG has remained stable over time and has been immune to the price volatility of diesel fuel, due to its domestic origins. Figures 19 and 20 display historical pricing data for CNG and versus diesel fuel. NG also purports to be a "cleaner" fuel than diesel, owing to the lack of particulate matter (PM) and oxides of Nitrogen (NOx) being byproducts of its combustion process. For these reasons, the transportation industry, in particular many municipally operated vehicles such as buses and garbage/recycling trucks, are now powered by natural gas.

The rail industry has also shown an interest in using natural gas as a fuel for the same reasons, and a number of pilot demonstration and full-fledged locomotive fleet conversion projects are now in place.

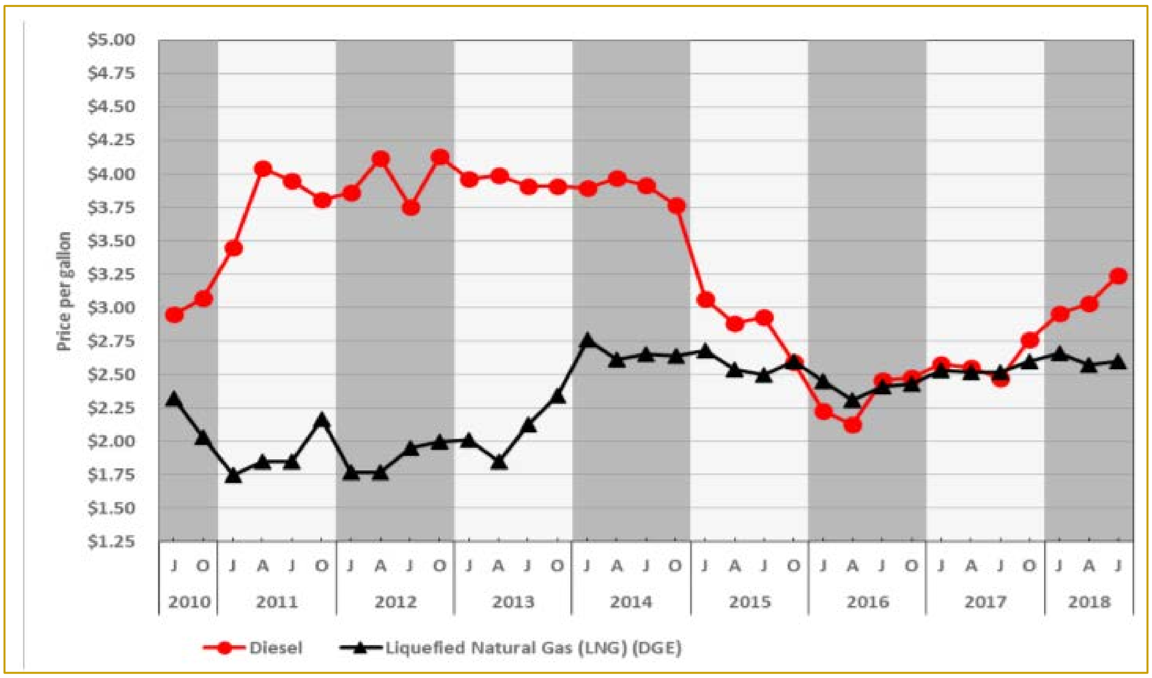


Figure 19 - Historical LNG vs. Diesel Prices Per Gallon/Diesel Gallon Equivalent

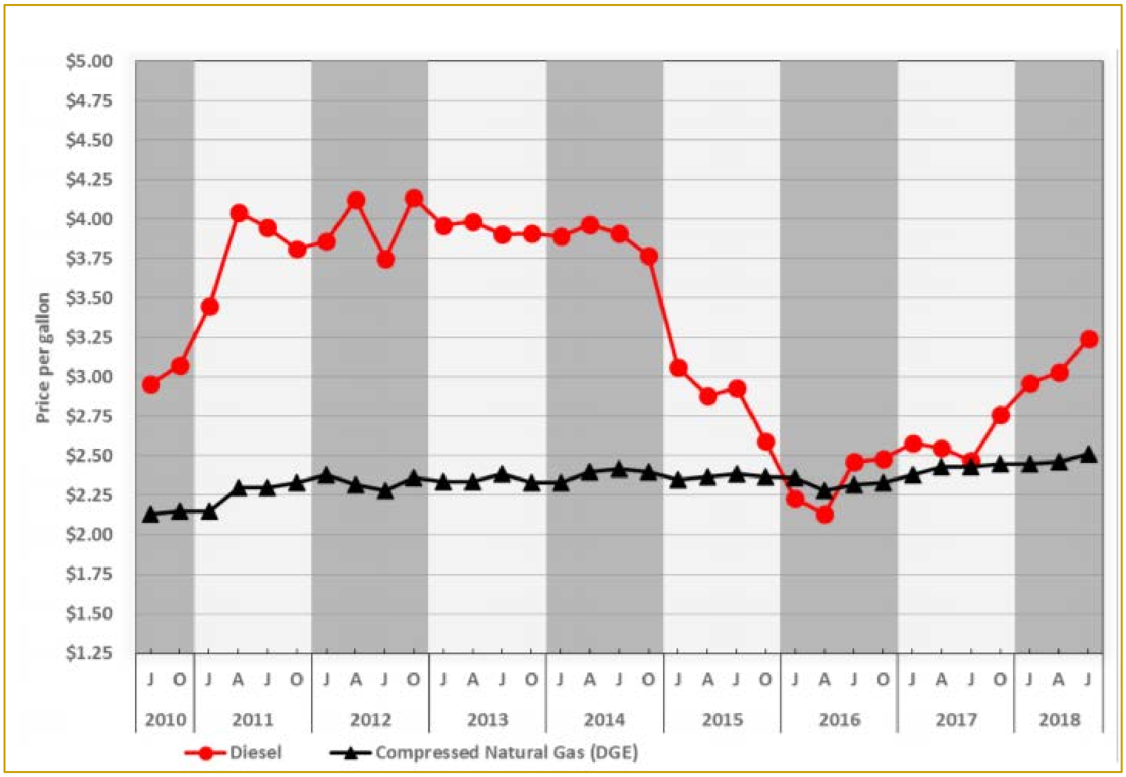


Figure 20 - Historical CNG vs. Diesel Prices per Gallon/Diesel Gallon Equivalent

LNG

Liquefied natural gas or LNG is a liquid form of natural gas that is produced by chilling the gas down to a temperature of -260° F or lower. The reason that LNG is used as a vehicle fuel is that it has a higher volumetric energy density than compressed natural gas. The energy volumetric density of LNG is approximately 60% of the volumetric energy density of diesel fuel. Therefore, LNG requires more space than diesel fuel for an equivalent operating range. However, it requires much less space than CNG.

LNG as a Locomotive Fuel

Internal combustion engines cannot burn LNG directly due to the extremely low temperature of the fuel. In all cases where LNG is used as a vehicle fuel, the LNG is heated to convert it back to a gaseous state before it is used in the engine. The liquid state is only used to reduce storage space.

CNG

Compressed natural gas or CNG, is natural gas that has been compressed to very high pressures, typically 3,600 or 5,000 psi and contained in correspondingly rated cylinders. 100% CNG is utilized successfully in transit buses (i.e, LA Metro, and recently Pace) utilizing spark ignition engines. CNG has approximately 16% of the volumetric energy density of diesel. Therefore, for a given amount of energy, more storage space is needed for CNG compared to LNG or diesel fuel. For this reason, CNG is primarily used in applications where frequent refueling is practical.

GNG (Gaseous Natural Gas)

While natural gas may be stored as a liquid at extremely low temperatures or as a gas at high pressure, the gas is not directly usable in an internal combustion engine in either of these states. The LNG must be heated and vaporized to be usable. Compressed gas must be reduced in pressure. Therefore, in either case, the fuel that is supplied to the engine system is a low pressure gas. The term that is commonly used for this fuel is GNG or gaseous natural gas.

100% Natural Gas as Locomotive Fuel

An engine of a given physical size will produce less power using 100% natural gas compared to diesel fuel. There are several reasons for this including:

- The propensity of natural gas to pre-ignite during compression
- The ability to deliver sufficient energy to the combustion process due to the lower energy density of the natural gas fuel.

Where physical size is not a constraint such is in stationery engine applications, high power spark ignition engines are frequently used for pumping and power generation.

There is only one well documented case of a locomotive that operated on 100% natural gas. This was the MK Rail 1200G which used a Caterpillar G3516 spark ignition V-16 engine, making 1,200 hp (vs. 2,000 hp for the diesel fueled version). See Figure 21. Two locomotives each were delivered to Union Pacific and ATSF (now BNSF) railroads in the early 1990's and were used successfully in Southern California yards for many years and were still operating up until 2012 when they were taken out of service. However no further natural gas powered switching locomotives were put into service in North America.

Figure 21 - MK Rail 1200G 100% LNG Powered Switcher

Dual Fuel (NG/Diesel)

A dual fuel engine is characterized as one that operates on a variably adjusted ratio of diesel and natural gas supplied to a compression ignition engine. The diesel fuel is mixed with the vaporized natural gas in the engine combustion chamber to provide full rated horsepower of the engine while allowing up to 80% natural gas substitution at various loads, thus gaining the dual benefits of reducing exhaust emissions and allowing the use of a lower cost fuel. Typical usage ratios run 70%/30% NG to diesel, with the ratio of NG increasing with the throttle notch. The majority of locomotive natural gas conversions is of the dual fuel variety, and involves either installing a conversion kit on an existing locomotive engine or utilizing a commercially available dual fuel engine. See Engine Conversion Options below for a detailed discussion of available technologies. In each case, the technologies work with both LNG and CNG in either form, as the NG entering the combustion chamber is in a vapor state.

LNG/Diesel

There have been a number of LNG/diesel locomotives put into service within the last 30 years as the Class I railroads have evaluated the use of natural gas as a hedge against the variability in the price of diesel fuel (see Figure 19). As the price of diesel increases, the Class I's increase their investment in LNG/diesel powered locomotives. See Known Locomotive Natural Gas Conversion Projects below for a summary of several of the better documented cases. In all cases, a specially designed tender car for LNG fuel storage is external to the locomotive, and is typically used in tandem with two converted locomotives. To date, all of these conversions have been for freight applications. In addition, both major freight locomotive manufacturers, namely GE and Progress Rail (EMD) have developed dual fuel locomotives and have produced engine conversion kits for retrofit. GE markets their kit as the NextFuel™ Natural Gas Retrofit Kit for their Evolution Tier 2 and 3 locomotives. Progress Rail offers a Dynamic Gas Blending™ system and a Direct Injected Gas system for their EMD locomotive engines as discussed in Engine Conversion Options below.

A limitation in the deployment of LNG fuel is that NG must be converted to LNG by means of the liquefaction process that requires cooling of the gas to a liquid at -260°F which reduces the volume, making it easier to carry large quantities. LNG is limited to a location in proximity to a liquefaction facility, or it must be hauled by tanker to the refueling site.

CNG/Diesel

Whereas long haul freight rail has evaluated LNG/diesel dual fuel as an alternative, yard type switchers are better suited for CNG/diesel due to their proximity to refueling stations and limited travel. Additionally, the use of a fuel tender car is not practical in switching operations. There is now one case of diesel/CNG locomotives currently in operation with supporting fueling and storage infrastructure.

Alternate Fuels Not Being Considered in the Study

Biodiesel

Biodiesel is a domestically produced, renewable fuel that can be manufactured from vegetable oils, animal fats, or recycled restaurant grease for use in diesel vehicles or any equipment that operates on diesel fuel. Biodiesel's physical properties are similar to those of petroleum diesel. Biodiesel fuel produces lower exhaust emissions for PM, CO and HC while having a slight increase in NOx. The decrease in exhaust emissions is directly proportional to the percentage of biodiesel in the fuel. Typical percentages of commercially produced biodiesel are 5% (B5), 20% (B20) and 99-100% (B99-B100); fuel quality is governed by ASTM D6751. The price per gallon of biodiesel parallels and is about the same as diesel fuel, with the exception of the B99-B100 biodiesel which is about 10% more expensive than diesel. It is claimed that biodiesel can be fully substituted for diesel fuel, however verification with engine manufacturers is advised as there may be implications regarding the engine emissions Tier certification. Although there are some emission benefits, there are currently no real cost savings with biodiesel. However this could be a viable alternative fuel which Metra could most readily utilize in some proportion in their existing equipment and would support the RTA's green initiatives.

LPG

Liquid petroleum gas, also known as propane, is stored under pressure, typically 150 psi inside a tank as a colorless, odorless liquid. As pressure is released, the liquid propane vaporizes and turns into gas that is used in combustion. An odorant, ethyl mercaptan, is added for leak detection. For combustion to occur it must be utilized in a spark ignition engine. The energy density of propane is about 66% of that of diesel fuel and it costs on average about 13% less than diesel which makes it appealing. Although many smaller vehicles such as forklifts operate on LPG, a literature search did not find any locomotives (other than steam powered) that have ever been converted to run on 100% LPG in North America.

DME

Dimethyl Ether (DME) is a newer fuel that is created by converting methane and carbon dioxide to form DME from various feedstocks, such as biogas and natural gas. It has an energy density of about 56% compared to diesel and in preliminary testing produces exhaust emissions slightly lower than natural gas combustion. Although a very promising alternative fuel with similar composition and characteristics to diesel, it is not commercially available; minimal fuel production infrastructure exists today, and there are no documented cases of locomotives operating on DME. In addition, to be used as an alternative to diesel, the proper additives and lubricants must be developed and added, and fuel quality standards must be formulated.

Alternate Technologies Not Considered in the Study

Exhaust After Treatment

Although technically not an alternative fuel, if the goal of Metra is to reduce particulate matter and oxides of nitrogen from the locomotive diesel exhaust, a number of after treatment options such as diesel particulate filter (DPF), diesel oxidation filters (DOC) and Selective Catalyst Reduction (SCR) could be retrofitted to the Metra fleet, and are mentioned here for information. After treatments have been applied to locomotives of similar engine configurations and have achieved Tier 3 emissions. The majority of Metra's locomotive fleet has now been upgraded to EPA Tier 0+ which is an improvement in exhaust emissions, but there is still concern regarding public exposure in several of Metra's terminals, notably Chicago Union and Ogilvie stations.

All new locomotive procurements must comply with EPA Tier 4 (reference 40CFR§1033) which represents a reduction of 95% in PM and 86% in NOx compared to Metra's existing fleet. Thus as Metra's fleet ages, older locomotives will be replaced with the newer, cleaner and more efficient locomotives, however these would still be diesel fueled. It is known that Metra has experimented with after treatment on their locomotives as a pilot project.

Electrification

Replacing the diesel electric locomotives with fully electric trains as found on Metra's Electric District Line would eliminate all direct dependence on fuel usage and produce no exhaust emissions, however electrification is a costly alternative requiring years of planning and large sources of funding. Estimates for line electrification run on the order of $3M to $8M per mile, not including the investment in vehicles. This would need to be a very long-term strategy as it may take 10 years or more to fully convert all of Metra's lines to electric.

Hybrid Electric

Similar to a hybrid electric car, a hybrid electric locomotive would still have a conventional engine/alternator configuration but would utilize electrical energy storage via high capacity batteries, such as lithium ion, or capacitors. Although there is much interest here as the energy storage capacity of batteries increase and the price continues to drop, it is recognized that a very large amount of battery (or capacitor) storage is required to provide the tractive effort needed to drive a locomotive. In addition, commuter locomotives must also provide 480VAC power to the consist at all times, driving the storage requirements even higher.

The best use of this technology to date has been in the light rail vehicle (LRV) application where off-wire energy storage is utilized to move the LRV short distances when it is impractical to utilize overhead catenary power. Operating distances tend to be short, on the order of one mile or less.

Hydrogen Fuel Cell

This is still an emerging technology and in the early stages of application. The best-known operating example is the Alstom Coradia iLint, which is just now going into service in Germany on some shorter lines to replace diesel electric commuter locomotives and trailer cars. The Coradia iLint uses a fuel cell manufactured by Hydrogenics. In terms of passenger capacity, the Coradia iLint train is actually more akin to a diesel multi-unit (DMU) as essentially a two-car train with a total capacity of approximately 300 passengers. This program is heavily subsidized by the German government. There are currently no hydrogen fuel cell locomotives in operation in North America, although Metrolinx in Toronto has identified this as a future alternative to electrification.

Known Locomotive Natural Gas Conversion Projects

LNG/ Diesel

The LNG/diesel dual fuel solution has been implemented on a pilot basis on a number of Class I railroad's freight locomotives for over 20 years. The potential benefit to the freight rail industry is a potential for up to 50% potential fuel savings which would approach $1.5B if fully implemented across all Class I's. These pioneering efforts have provided a great deal of data for the rail industry, and both the Federal Railroad Administration (FRA) and the Association of American Railroads (AAR) have begun the process of developing standards and convening studies for the safe integration and operation of LNG to supplement the use of diesel fuel. The engine conversion technology, storage methodology, and refueling process along with industry applicable codes and standards are largely developed and documented, such that a more significant investment could be made should the diesel-NG price differential warrant it. One regional railroad has made the conversion.

BNSF

BNSF and its predecessor, BN, have experimented with LNG/Diesel fueled locomotives for over 20 years. Their first pilot units went into service in 1991, utilizing a tender car modified to carry a LNG tank, fueling two EMD SD40 locomotives equipped with 16-645 engines that were altered to allow the use of a mixture of diesel and LNG. Engine Conversions Inc. (ECI) provided the conversion kits, which included conversion to electronic fuel injection. The engine ran on diesel fuel when idling and NG was gradually introduced through the notch schedule until a maximum of 95% NG was supplied by notch 8. LNG fueling was provided by Air Products. It is reported that $10M was spent on the project. The pilot units were operated until 1995. See Figures 22 and 23.

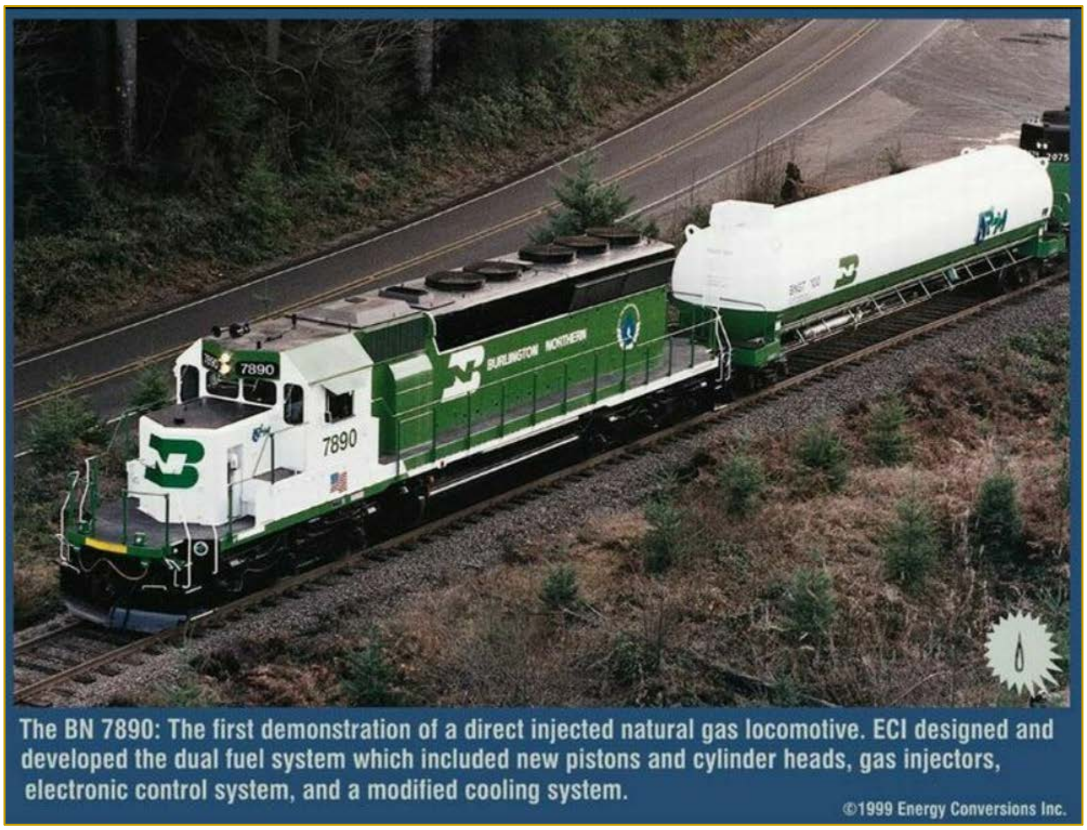


Figure 22 - BNSF LNG Line Haul Locomotive and Tender

Natural gas tandem in coal haul service. Burlington Northern's 7890 and 7149, equipped with ECI dual-fuel conversion systems. The locomotive pair, coupled to the 20,000 gallon LNG tender car, achieves full power and has a range of more than 800 miles between refueling.

©1999 Energy Conversions Inc.

Figure 23 - BNSF LNG Line Haul Locomotive in Service

CN

CN initiated a pilot a LNG/diesel project which operated on a 300-mile route from Edmonton to Fort McMurray, Alberta, Canada from September 2012 to September 2013. The project is very similar to the BNSF project in that two EMD locomotives were modified using the ECI NG/Diesel fuel injection system with a single LNG tender car fueling them both (see Figure 24). CN utilized the pilot to evaluate the feasibility of wider fleet conversion. Lack of LNG fueling infrastructure was identified as a concern. The LNG fuel tenders used for this project are now in the possession of Union Pacific.

Figure 24 - CN Pilot LNG Dual Fuel Locomotives and Tender Car

FEC

Florida East Coast Rail is a regional railroad operating primarily in Florida on its own right of way. Within the past two years they have converted their fleet of 24 GE ESC44C Evolution locomotives using GE's NextFuel™ conversion kits to operate in pairs with a tender car feeding each pair, as previously done by BNSF and CN. The engine modifications were supplied by GE and the FRA crashworthy compliant tenders were built by Chart Industries. FEC also is the first railroad to haul LNG as a commodity (under FRA waiver) and it has an affiliate company that operates a 100,000 gpd NG liquefaction plant, which allows it to cost effectively utilize LNG. The GE engine modification kit allows the locomotives to run on up to 80% NG and also 100% diesel, similar to the previously discussed projects. The locomotives are reported to be EPA Tier 3 compliant. A 900-mile range between refueling is also reported using the LNG tender shown in Figure 25.

Figure 25 - Florida East Coast LNG Tender Car

LNG Tender Cars

The Association of American Railroads (AAR) has created a Technical Advisory Group to work with the FRA to develop LNG tender car standards. The standard would cover the design of fuel tenders, including hoses and piping for locomotive interface connections, safety requirements and inter-operability and interchangeability. The tender cars built for FEC shown in Figure 25 were supplied by Chart Industries, which has also supplied LNG tender cars for European locomotives. Currently the FRA is evaluating LNG powered rail operations utilizing tender cars on a case-by-case basis.

CNG/Diesel

The goals for conversion of locomotives to CNG/diesel stem from similar motivation as the LNG/diesel conversions: fuel savings. However, CNG is seen as a better alternative for switching operations compared to LNG, as it is impractical to utilize a tender car with all of the required equipment to maintain the LNG in its chilled liquid state, in switching operations. To date, there is one known CNG/diesel conversion in the US, namely Indiana Harbor Beltway. An additional benefit to this conversion is exhaust emissions reduction, an important consideration as exposure of the neighboring population to switching yards has been identified by the EPA as a health concern.

Indiana Harbor Beltway

In 2016, Indiana Harbor Beltway (IHB) released a Request for Proposal to repower up to 21 EMD SW1500 switcher locomotives. Per published accounts, the conversion was initially undertaken by RJ Corman as the locomotive integrator using engine/alternator skids provided by Optifuel LLC, high pressure (5,000 psi) DOT approved composite fuel cylinders provided by Hexagon Lincoln for containing the on-board CNG, and a trackside CNG refueling system provided by ANGI Energy Systems. The conversion project was partially funded through Congestion Mitigation and Air Quality Program (CMAQ) a federally funded program administered by the Chicago Metropolitan Agency for Planning (CMAP). This program is providing 64% of the funding with the remaining coming from IHB.

Thus far two locomotives have been delivered (see Figure 26). Each locomotive has two Tier 4 certified 750 hp Caterpillar C18 “genset” type compression ignition engine alternator modules which have been converted to run on a mixture of natural gas and diesel fuel. A skid containing 11 Type IV CNG tanks are skid mounted on the carbody (see figure 27) behind the engine/alternator skids. The existing diesel fuel tank is maintained in the underframe. The CNG tanks contain 700 DGE of CNG which it is claimed allow the switcher to operate for 7 to 10 days between refueling, which are claimed to take 15 – 30 minutes.

Optifuel LLC, the engine supplier indicates that the locomotives are Tier 4 emissions compliant. The switchers will also be outfitted with Automated Engine Start Stop (AESS) feature which can also have a significant reduction in emissions, as switchers spend more than 50% of their operating life in idle. Optifuel also claims to have a line of dual fuel engines available for repower from 600 hp to 3,000 hp.

Figure 26 - Indiana Harbor Belt Dual Fuel CNG Switcher

A consortium of companies consisting of Mainstay Fuel Technologies, Hexagon Lincoln and ANGI Energy Systems, collaborated to supply the fuel storage and refueling infrastructure to IHB. Mainstay Fuel Technologies developed the CNG on-board above deck storage system shown in Figure 27. The CNG tanks were supplied by Hexagon Lincoln and are 5,000 psi rated DOT approved Type 4 filament wound composite cylinders, which provide substantial weight savings over conventional steel tanks. The onboard tank module is sized to provide 700 DGE or 7 to 10 days of switching operation. The diesel fuel tank remains in in its existing location at its current capacity. ANGI Energy Systems, a supplier of CNG refueling systems for the commercial trucking industry provided the fueling infrastructure which included the NG compressor, fast fill stations, storage, piping, valves and safety devices, and dispensing systems. According to a press release, the refueling station can refuel two locomotives in 15 to 30 minutes.

LTK recently held discussions with a supplier of competing fueling and onboard fuel storage technology who claims that the above deck fuel tank configuration utilized on the switchers is non-compliant to FRA fuel tank regulations with regards to crashworthiness as there is no structural reinforcement fully encasing the fuel tanks. To date, only two of the expected twenty-one repowered units have been delivered.

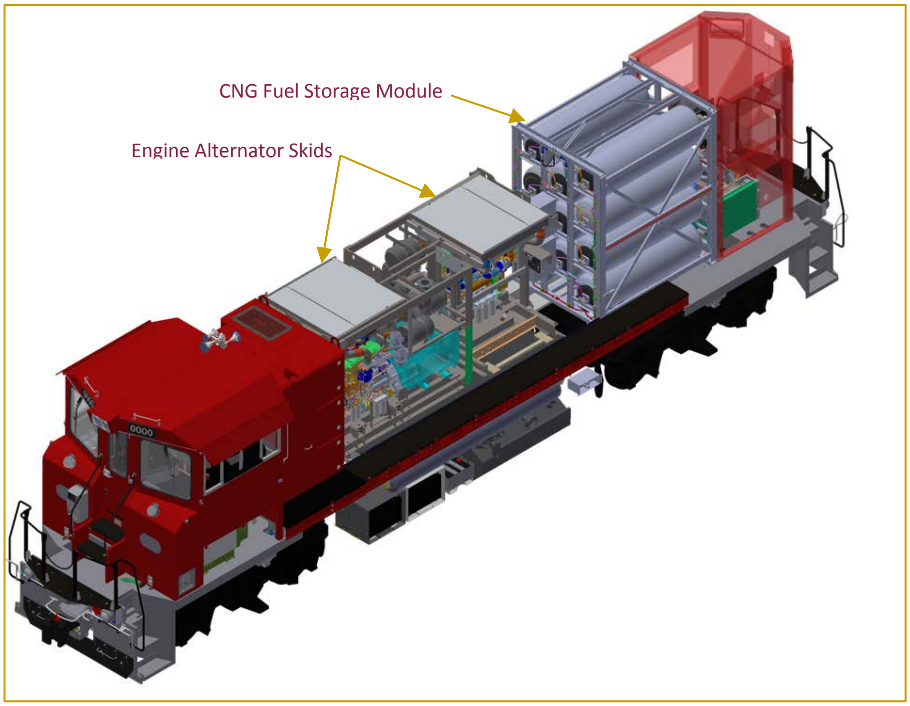


Figure 27 - Indiana Harbor Belt Dual Fuel Switcher Equipment Arrangement

Comparison of Alternate Fuels to Diesel Baseline

Price per Unit of Energy

Diesel as a fuel source is still greatly used due its high energy content when compared to gasoline and other alternative fuels such as CNG, LNG, LPG and Dimethyl Ether. The US Department of Energy maintains data of fuels prices averaged throughout the US. As shown in figures 19 and 20 the price of diesel had spiked in 2011-2013, prompting the industry to experiment with alternative fuels.

Diesel is a superior fuel when measured with British Thermal Units (BTU) energy content. In fact, diesel has more energy content than gasoline. Diesel fuel has become more regulated since 1993 with attention placed on decreasing the Sulfur content. Ultra-Low Sulfur Diesel (ULSD) is used for heating and in compression ignition engines. Reducing the sulfur improves the emissions out of the stack.

Table 6 illustrates the fuels of interest (diesel, LNG, CNG), their retail unit price in dollars per gallon (or diesel gallon equivalent), their energy density and their price in dollars per BTU (British Thermal Unit).

Table 6 - Comparison of Fuels in Price/Gal., Energy Density, and Price/Million BTU

Fuel	Retail Price per Gal (or DGE Equivalent)	Energy Content	Volumetric Energy Density BTU/FT^3	Retail Price per MBTU
Diesel	$ 3.24	128,488 Btu/gal.	993	$ 25.20
LNG	$ 2.60	21,240 Btu/Lb.	600	$ 20.20
CNG	$ 2.51	20,160 Btu/lb.	242	$ 19.65

On a price per BTU basis, LNG is 19.8% and CNG is 22.6% less than diesel fuel, based on the pricing provided in the DOE report.

Price trends

As previously presented in Figure 19, the price per gallon of diesel fuel has fluctuated from as high as $4.57 per gallon to as low as $1.90/gallon over just the last five years and has been as much as five times more expensive than NG on a comparable basis. As the graph shows, the trend is upwards; it is expected that the price of diesel fuel will continue to increase. The price of Brent Crude Oil has increased by 40% in the last four years with diesel fuel increasing as well. Uncertainty due to international developments strongly impacts the price of diesel, which is dependent on the availability of crude oil. Due to the large annual volume of fuel it consumes, Metra enjoys a much lower price which is based on the daily Platz Report index pricing with a small margin ($0.0597) per gallon applied. Pricing data supplied by Metra in October indicated a price per gallon of $2.4644, which compares favorably to the Midwest US average retail price of $3.17/gallon used in the most recent US DOE Clean Cities Alternate Fuel Price Report.

However, it is because of these price fluctuations that natural gas has shown itself to be a more stable option as the unit price of natural gas has increased only 8% in the last four years, with production steadily increasing. For a large user such as Metra, consuming on the order of 25MM gallons of diesel fuel per year, rapid increases in the price per gallon as seen in 2013-2014 can adversely impact Metra's budget planning.

Availability

Predicting the availability at a global level for both diesel oil and natural gas is outside the scope of this study, however Metra has provided supplier information for its bulk supplier of diesel oil (Mansfield Oil) which supplies fuel via 7,200-gallon tankers on a frequent basis. Data supplied by Metra for the year 2017 indicates that about 3,600 deliveries a year are made to all refueling sites, or about 14 deliveries per day. Delivery by tanker truck is generally reliable, however safely transporting the fuel to the five sites (and occasionally the outlying areas) and filling Metra's bulk tanks can be labor intensive, and spillage can occur. Weather can also be an impediment, particularly in the winter where road conditions may be poor, resulting in late or cancelled deliveries in the case of a severe storm. Chicago can have as many as 21 days per year where daily snowfall exceeds 8 inches, although this fluctuates significantly on a year to year basis.

Metra receives natural gas at all five of its refueling facilities for heating, using Chicago's gas regional gas distributors People's Gas, North Shore Gas, Nicor and Mansfield Power and Gas for their larger accounts. In order to deliver NG to these sites, a fuel delivery sizing study would be need to be conducted based on Metra's anticipated usage. However, this would reduce but not eliminate the number of diesel fuel deliveries for Metra with the dual fuel approach. The most recent data provided by Metra shows an average price of $3.11 per MBTU or $0.44/DGE, a difference of about $2 per gallon when compared with the price of diesel fuel. Bear in mind that this is the price "at the meter" and does not reflect the cost of supplying to Metra locomotives as either LNG or CNG.

Pace has recently converted a portion of its bus fleet to operate on 100% CNG at its South Division location which serves southern Cook county, the south side of Chicago and the DuPage County suburbs; there are now 91 CNG powered buses operating from this location, which became a CNG fueling station in 2016 and was retrofitted in 2017-18 to allow for indoor maintenance on CNG buses. Pricing and fuel savings data was not available at the time of this report.

Emissions

The EPA has standards for diesel locomotives and off-road diesel engines typically used in a locomotive (40 CFR §1033), see Table 7. The locomotive or engine is required to maintain the standard for which it was certified. Therefore, use of natural gas as a blend will require certification. The immediate gain is a reduction in the Oxides of Nitrogen (NOx) and Particulate Matter (PM); however natural gas produces other toxic gases when ignited. The natural gas dual fuel solution is to augment an older diesel engine subjected to a lower Tier standard. For example, a 16-645E3B certified to a Tier 0 standard can have exhaust NOx reductions as much as 50%.

Table 7 - EPA Locomotive Emissions Standards and NG/Dual Fuel Measured

Line – Haul Locomotives								
Year of original manufacture	Tier of standards	Standards (g/bhp-hr)				Opacity		
		NOx	PM	HC	CO	Steady State	30 Second peak to Peak	3 Second peak to Peak
1973-1992	Tier 0	8	0.22	1	5	30	40	50
1993a -2004	Tier 1	7.4	0.22	0.55	2.2	25	40	50
2005-2011	Tier 2	5.5	0.10	0.3	1.5	20	40	50
2012-2014	Tier 3	5.5	0.1	0.3	1.5	20	40	50
2015 or later	Tier 4	1.3	0.03	0.14	1.5	20	40	50
Natural Gas Dual Expected*	Predicted Results	3.6	0.195		8.5			

*Based on 1 set of measurements by ECI

Diesel fuel does not produce high levels of CO upon combustion. Introduction of natural gas which is primarily composed of methane produces carbon dioxides. The example shown in Table 6 is for emissions in a dual fuel engine are when NG is blended at ideal rates with diesel.

When selecting a newly built diesel engine or a conversion kit the cost might be forcing the owner to produce a locomotive compliant to 40 CFR §1033.640 which in short requires a Tier 4 level of emissions as a result of cost of the equipment.

More recent claims by engine conversion integrators claim emissions compliance with Tier 3 and even Tier 4 with their dual fuel kits.

Operational Performance Comparison

As Table 8 illustrates, the theoretical horsepower of locomotive engines converted to operate on 100% natural gas with spark ignition would be much lower than diesel fuel. If Metra converted to 100% natural gas, the locomotives would suffer a loss of horsepower and the corresponding reduction in tractive effort. This also requires converting the prime mover engines from compression ignition to spark ignition to run on 100% natural gas. A replacement spark ignition engine would need to be a much larger displacement to match the horsepower of the existing engines.

The reduction in available horsepower translates to a reduction in tractive effort and hauling capacity, thus impacting trip times and/or reducing the trailer cars in the consist. Thus a 100% natural gas solution is not a viable one from a train performance standpoint.

Table 8- Locomotive Rated HP on Diesel Fuel and NG

Locomotive	Rated HP (Diesel Fuel)	Theoretical Rated HP (100% NG)
F40PH	3,200	2,560
F59PH	3,000	2,400
MP36PH	3,600	2,880
F59PHI	3,200	2,560

Therefore, based on the table above, it can be concluded that conversion from 100% diesel fuel to 100% natural gas is not a viable option for Metra.

With only one exception (MK 1200G), all locomotive natural gas conversions to date have used compression ignition and a blend of natural gas and diesel fuel. This arrangement provides full horsepower capability and the ability to substitute 60% to 70% of the diesel fuel for natural gas. These conversions also provide the flexibility to operate on 100% diesel fuel if necessary.

Fuel operating cost for the dual fuel engines depends on the amount of diesel fuel that can be substituted by natural gas. Engine suppliers advise that higher substitution rates occur at higher power settings. Therefore, the amount of diesel fuel that can be substituted by natural gas depends on the duty cycle of a particular operation. Event recorder data has been analyzed to predict the substitution rates on typical Metra routes. For example, as learned through an analysis of supplied event recorder data from Metra locomotive 422, about 50% of a run can be in notch 8; a substitution rate of 60-70% could be achieved.

Engine Conversion Options

Spark Ignition

These types of engines are normally used in stationary applications where size and weight are not as important. Additionally, there is no demand for spark ignition versions of current locomotive engines due to significant horsepower losses as discussed above. Therefore, spark ignition 100% natural gas engines are not seen as viable alternatives for Metra locomotives as previously discussed.

Compression Ignition

Dynamic Gas Blending (DGB)

Dual fuel engines and conversion kits are available for EMD 710 engines from Progress Rail/EMD. EMD has provided current technology locomotives equipped with dynamic gas blending. As mentioned earlier, high substitution rates of natural gas will result in pre-ignition of the fuel in the engine. This condition must be avoided. The EMD engines with DGB utilize pre-ignition sensors to control the substitution levels of natural gas. This permits the highest possible substitution levels to be achieved while providing reliable engine performance.

Another company, Energy Conversions Incorporated has also developed and provided conversion kits for EMD 645 and 710 diesel engines, as previously discussed.

High Pressure Direct Injection (HPDI)

Progress Rail has also developed a system for the 710 engine that uses high pressure direct injection (HPDI). By injecting the natural gas as the piston reaches the top of its stroke, pre-ignition is eliminated. However, very high pressure is needed to overcome the compression pressure in the combustion chamber and to inject the natural gas in a very short time duration. While diesel fuel is still used for ignition, high substitution rates of 95% can be achieved with HPDI.

Characteristics of an Alternate Fuel Rail Operation

The ideal alternate fuel to be used to operate in locomotives utilized for commuter rail would be:

- Considerably less expensive than diesel fuel on a comparable unit basis
- Readily available at all refueling locations
- Does not adversely impact locomotive performance
- Allows locomotive refueling within current allowable time parameters (no more than 2 hours)
- Can be stored on board the locomotive
- Minimizes impact to maintenance activities and potentially improves equipment longevity
- Dramatically reduces exhaust emissions
- Can be used, stored and transported safely

To utilize 100% NG, an engine conversion from compression to spark ignition is required. Additionally, the subsequent loss of horsepower due to the lower energy density of natural gas compared to diesel fuel places limits on Metra's operation in terms of passenger capacity and adherence to train schedules. Of the fuels reviewed in this study, the dual fuel NG/diesel options best meet the above criteria, although not satisfying all the criteria.

- As noted, the available dual fuel engine conversion maintains the engine horsepower while allowing the engine to utilize greater amounts of the cleaner and less expensive NG at the higher notch levels so there is no performance impact.
- Depending on the price differential, an expected 50% NG usage helps to offset volatile diesel fuel pricing and has the potential to provide a net reduction in fuel expenses; does not eliminate the need for diesel fuel.
- Technology is available to allow NG refueling perhaps not as quickly as diesel can be refueled (at up to 200 gpm) but within Metra's allowable time window.

- Onboard storage is a challenge and space availability that would allow adequate storage of both NG and diesel fuel may be a limiting factor, based on preliminary estimates. This may require more frequent fueling than what Metra currently employs and may also require weekend refueling, which Metra is typically able to avoid.
- As NG is cleaner burning, it is expected that buildup of combustion residue in the cylinders would be reduced; however, the addition of NG equipment on the locomotives would add to the overall periodic inspection, maintenance and safety certification of the components.
- Exhaust emissions may be reduced potentially to a Tier 3 emissions level from the Metra fleet's current Tier 0+/1+ levels as claimed by some of the conversion kit suppliers but will depend on the ratio of NG to diesel fuel combusted at any given time in the locomotive's engines. Limited emissions data is available at the time of this report.
- Safety standards for NG usage, storage and refueling have already been clearly defined for the natural gas vehicle industry, and many are applicable to the rail industry. However, approval of natural gas usage on locomotives operating in revenue service requires approval of the FRA which is granting approval on a case by case basis. The FRA has laid out the information to be submitted when requesting approval for a plan to test CNG or LNG in railroad service. Since NG has never been utilized in a passenger rail application, a very comprehensive safety and hazard analysis would need to be submitted with the test plan.
- Usage of NG at all five fueling locations will also require input and approval by BNSF and UP.

LNG vs. CNG

For a NG/diesel dual fuel locomotive conversion to be considered, a decision will need to be made on whether LNG or CNG will be utilized as the onboard storage system. From an engine combustion perspective, what is introduced into the engine is NG in vapor form regardless of whether stored in a liquid or highly pressured state. If LNG is selected, the cooled liquid must be heated to vapor before being introduced into the combustion chamber of the engine. If CNG is used, the gas must be greatly reduced in pressure before being introduced into the combustion chamber.

LNG Production, Storage and Distribution

From an onboard storage point, LNG is the more difficult to store owing the fact that it must be kept chilled to -260°F. As the NG is in liquid form, a larger volume can be stored onboard the locomotive. However, a double walled insulated cryogenic tank must be used which reduces the usable tank volume. In addition, gasification equipment must also be integrated to return the NG to a vapor state before injection into the combustion chamber.

A greater issue for LNG is the liquefaction process required for refueling (see Figures 28 and 29). The NG must undergo a phase change from the gaseous state provided by the supply pipeline to a liquid state. Based on the size and scale of the plant itself, it would not be feasible to construct at all of Metra's five refueling locations. A central liquefaction plant would need to be constructed, which would then require a fleet of LNG tank trucks to haul and distribute the fuel to all of Metra's refueling sites. Building a liquefaction plant that can provide up to 100,000 gpd requires a significant financial investment (on the order of $40M) and substantial space allocation for the process (Figure 29). As an alternative, rather than invest in the LNG infrastructure, Metra may choose to purchase LNG from a third party, such as Air Products, Air Liquide or other specialty gas supplier, as BNSF did for their pilot project. The third party would also operate the NG liquefaction plant and tank truck fleet and be responsible for refueling

Metra's fleet. However, it is noted that there are no major LNG liquefaction facilities in the state of Illinois (see Figure 30). The LNG would need to be trucked in from the south or one of the coasts. Incremental costs for production, storage, delivery, and refueling of LNG are shown in Figure 31.

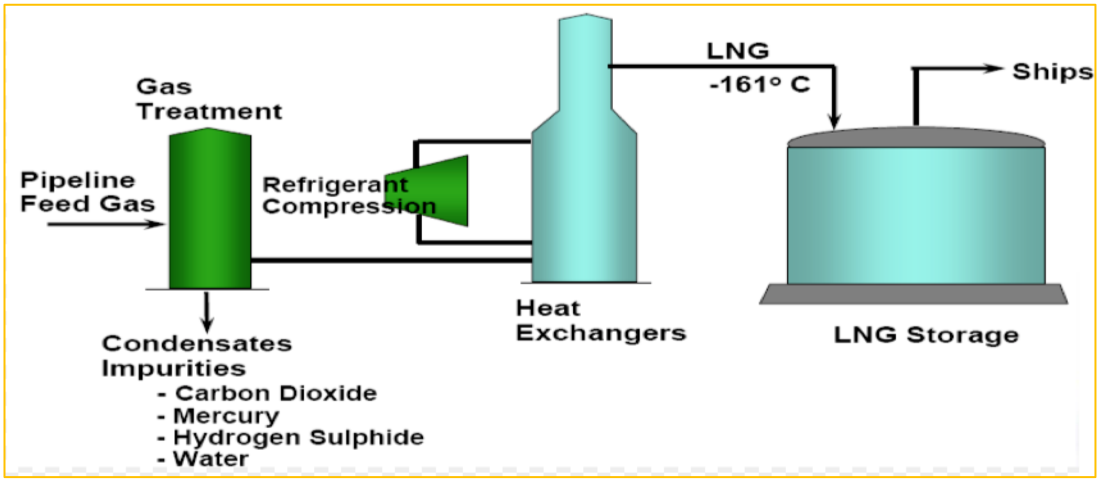


Figure 28 - Simplified View of LNG Liquefaction process

In the case of BNSF, CN and FEC, tender cars have been used to store LNG to supply locomotives, typically one tender supplying two locomotives per consist. The use of tender cars would allow Metra to refuel at non-peak hours and trade empty for refueled tender cars during the mid-morning refueling cycle. A LNG tender car could also be designed to store enough LNG to potentially allow for 1 – 2 fueling operations per week. However, every locomotive utilizing NG in operation would potentially require two tenders: one in operation and one in refueling, to maintain Metra's current daily locomotive turnaround window, with a potential investment of up to $1M per tender car per some published estimates. The onboard diesel fuel tank would still be required to be refueled as it is currently, but with a potential 50% reduction in diesel usage, this could eliminate the need for daily refueling. However, refueling of the LNG tender cars could become a significant operation; FEC claims that their tender cars, which carry enough fuel to supply two locomotives for 900 miles, can be filled in 90 minutes; this is in comparison with Metra's typical refueling time about 15 minutes or less. The addition of a tender car to existing consists may be an issue; train lengths would be impacted by the addition of the tender car which may in turn impact train operations and station position due to increased train length.

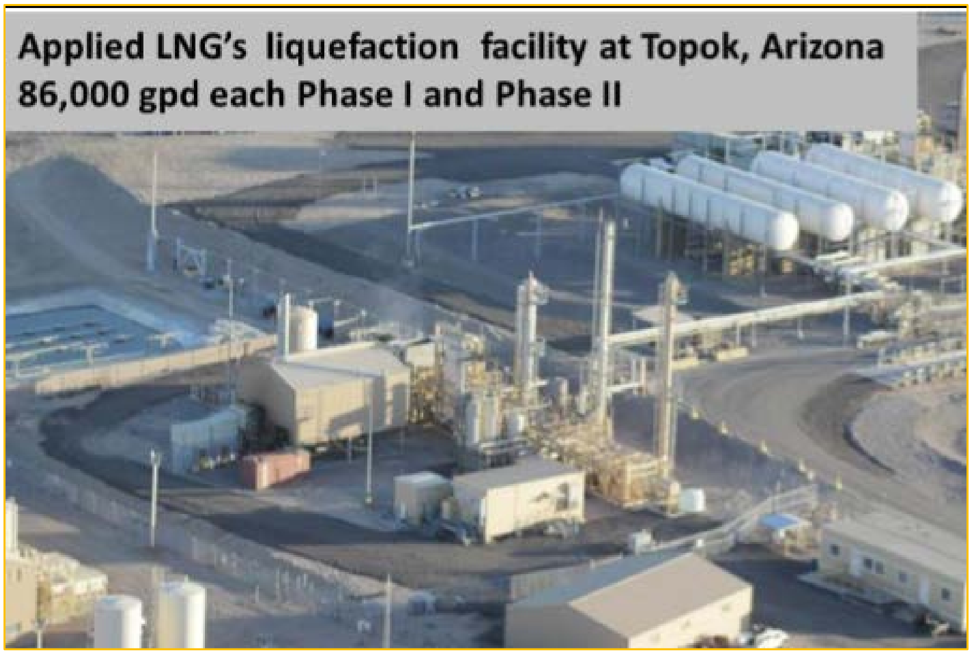


Figure 29 - Typical LNG Liquefaction, Storage and Distribution Facility

It is currently uncertain if the Metra fleet could accommodate onboard storage of LNG and its ancillary equipment. And if it were possible, refueling of onboard LNG locomotive storage tanks does not easily lend itself to Metra's current refueling scenarios, as at nearly all sites there is no ability to bring a tank truck sufficiently close to the locomotive for direct refueling. Thus, a LNG storage tank farm would be required to be located remotely from the refueling site as is currently done with the diesel fuel, with pumps and insulated supply lines to bring the NG to the locomotive refueling sites. Maintaining cryogenic temperatures adds more complexity and expense to the LNG storage and refueling facility. To date, only the tender car approach has been applied in the rail industry and FEC is currently the only US railroad operating with dual fuel/LNG powered GE locomotives in tandem with a tender car.

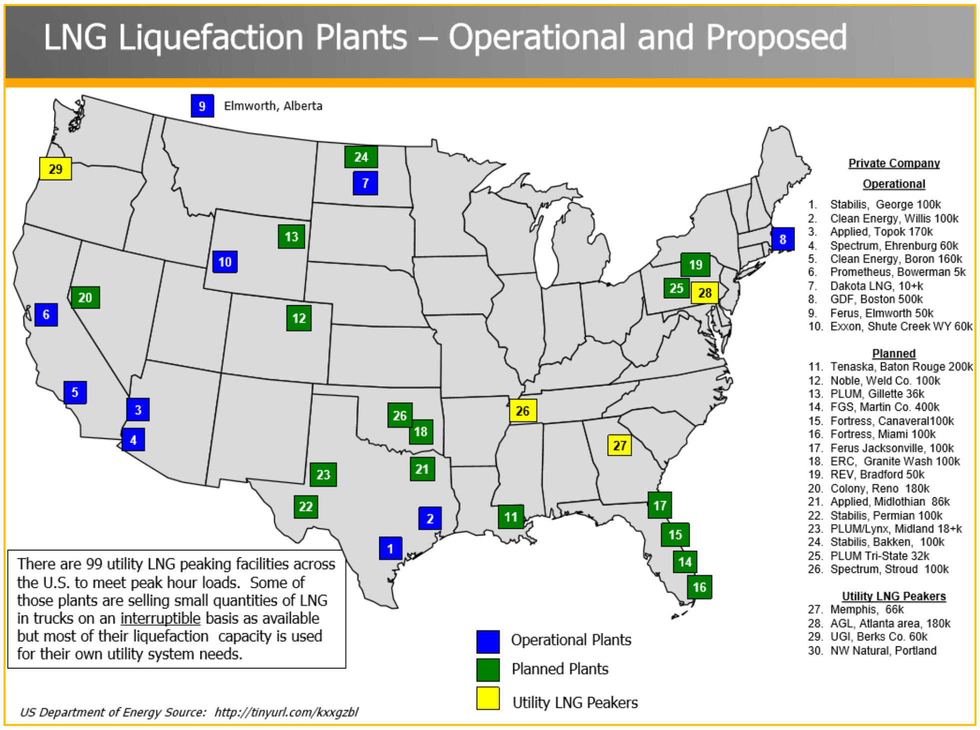


Figure 30 - Location of Existing & Planned US LNG Liquefaction Plants

LNG Production, Supply & Storage	Delivery Logistics & Distribution	Fueling, Storage and Cryogenic Equipment	Field Services and Customer Satisfaction
100,000 gpd LNG Plant Cost $49 MM	$300,000 per ISO tanker and delivery cost per mile	Cost for fueling & storage facility	Safe operations, listening, partnering, results
LNG production at $0.52/gal diesel equivalent - DGE	Transportation of LNG by tanker truck 150 mi. $0.15/DGE	Infrastructure at user $1.7 MM or $0.02/DGE	Sales Price to customer at 25% off retail diesel (diesel at $2.70 makes sales price $2.03/ DGE)

Figure 31 - Estimated Costs for Production, Delivery and Distribution of LNG

CNG Production, Storage and Distribution

LNG has been found more viable for freight applications, due its higher energy density in liquid form and thus greater storage capacity for the same tank volume which can supply the locomotive over longer distances. CNG is typically preferred on railroads with shorter runs and readily available NG supplies for frequent refueling. Thus, a more viable alternative for a commuter railroad may be CNG, which is far easier to provide at point of use (see Figures 32 and 33). The primary components lend themselves more easily to be scaled to Metra's refueling sites. Pressures on the order of 3,600 psi to 5,000 psi must be maintained however there is a great deal of relevant experience in operating these stations from the NGV industry, such as transit buses. Due to the large volume of CNG powered buses in the US (over

16,000) and many other CNG burning vehicle fleets, such as trash and recycling trucks, establishment of CNG point of use facilities is well understood and the technology has been developed to provide safe onsite pressurization, storage, pumping and dispensing facilities which can rapidly refuel a vehicle. Modular CNG pressurization, storage, pumping and delivery systems are available from multiple suppliers. Preliminary estimates put the cost of CNG fueling stations in the $4M to $6M range.

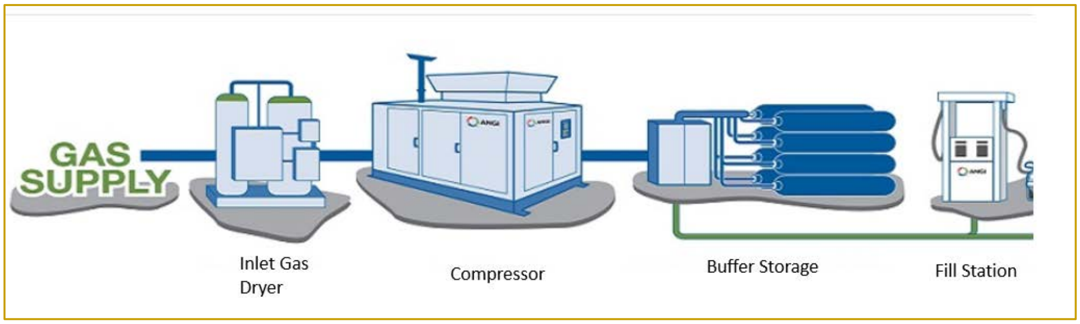


Figure 32 - Conceptual CNG Refueling Station Design

In terms of on-board fuel storage, based on preliminary sizing calculations, up to 600 DGE of CNG could be stored on-board a locomotive by reconfiguring the existing diesel fuel tank. Higher delivery pressures allow for higher density fuel storage; this is dependent on supply line pressure. Innovative dual fuel storage methods have been developed by a potential supplier that can be retrofit within the existing fuel tank area of a locomotive. Fast fueling stations are also available so that CNG tanks could be refilled in times only slightly longer than Metra's diesel refueling times, in the order of 15 – 30 minutes for two locomotives.

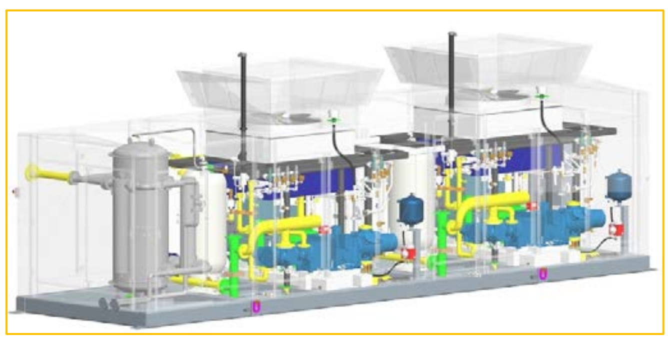


Figure 33 - Modular Intermediate Capacity (2,000 cfm) Compressor Station, Example

Locomotive Conversion

Conversion of each locomotive to operate as a diesel/CNG dual fuel locomotive will consist of the following:

- Installation of a dual fuel conversion kit on the prime mover engine which consists of new gas inlet valves, cylinder heads, pistons, aftercoolers, injection controls and sensors. The diesel injectors and fuel rack must also be recalibrated.
- Replacement of the existing fuel tanks with a crashworthy fuel tank containing both diesel fuel and DOT certified, light weight, high pressure onboard storage tanks for the CNG. These tanks

may or may not be integral with the diesel tank. A high pressure, an ANSI certified compressed NGV fuel receptacle rated for the gas operating pressure is required on the CNG tank(s).

- If equipped with a HEP engine, it may be modified to operate on dual fuel or may be left as a diesel only engine. The C18 HEP engines provided for installation on the MP36PH locomotives are EPA tier 2 rated and can continue to operate on diesel fuel. However dual fuel conversion kits are available if a complete conversion to dual fuel is desired.
- All required fuel piping, valves, regulators, gas leak detectors and emergency shut off devices and pressure relief valves are required by both the FRA and the NFPA for safe fuel operation.
- Submittal of a test plan, safety plan and hazard analysis to the FRA for approval.

Applicable Regulations and Codes Governing Natural Gas

Numerous federal, state and local regulations govern the safe storage, transport and usage of NG. In addition, the NGV community has also worked with government, standards organizations and industry to define governing requirements for NG storage, transport and usage in vehicles. Table 9 lists a number of those standards and what they pertain to. For the purposes of this study, the table is limited to higher level regulations and codes relevant to CNG (i.e., NFPA, CFR, etc). There are regulations and standards covering various components such as fuel hoses, safety devices, dispensing systems, valves and piping.

There are also numerous regulations governing the usage of LNG as well, but these are not listed in the table.

Table 9 - Relevant NG Related Regulations

Governing Document	Summary Description
NFPA 52 – Vehicular Natural Gas Fuel Systems Code	Applies to the design, installation, operation and maintenance of compressed natural gas (CNG) and liquefied natural gas (LNG) engine fuel systems on vehicles of all types and for fueling vehicle (dispensing) systems and associated storage, including the following: Original equipment manufacturers (OEMs),Final-stage vehicle integrator/manufacturer (FSVIM), Vehicle fueling (dispensing) systems; Includes marine, highway, rail, off-road and industrial vehicles. Covers facility equipment, storage, fueling, and gas detection, alarm and shutdown systems and other related requirements.
NFPA 54 National Fuel Gas Code	Applies to the installation of fuel gas piping systems, appliances, equipment, and related accessories from the point of delivery to the appliance connections; Piping systems include design, materials, components, fabrication, assembly, installation, testing, inspection, operation, and maintenance. Appliances, equipment and related accessories include installation, combustion, and ventilation air & venting
NFPA 70 National Electrical Code*	Covers installation of electrical conductors, equipment and raceways, signaling and communication conductors, equipment and raceways, and optical fiber cables and raceways for stationary applications. Some pertinent sections:

Governing Document	Summary Description
	Article 500: Hazardous (Classified) Locations, Classes I, II, and III, Divisions 1 and 2 Article 505: Zone 0, 1, and 2 Locations Article 511: Commercial Garages, Repair, and Storage Article 514: Motor Fuel Dispensing Facilities
49 CFR Part 393.65 & 68 Fuel systems and CNG fuel Containers	The rules in this section apply to compressed natural gas (CNG) fuel containers used for supplying fuel for the operation of commercial motor vehicles or for the operation of auxiliary equipment installed on, or used in connection with commercial motor vehicles 393.65(5) A fuel line does not extend between a towed vehicle and the vehicle that is towing it while the combination of vehicles is in motion
49 CFR Part 571.301 Fuel systems integrity & 571.303 Standard No. 304; Fuel system / container integrity of compressed natural gas vehicles	571.301 standard applies to all vehicles which use fuel with a boiling point above 0 °C. 571.303 standard specifies requirements for the integrity of motor vehicle fuel systems using compressed natural gas (CNG), including the CNG fuel systems of bi-fuel, dedicated, and dual fuel CNG vehicles. Focus is on the prevention of fuel leakage during and after motor vehicle crashes.
49 CFR Part 229 Railroad Locomotive Safety Standards	All locomotive safety standards apply regardless of fuel type; standards relevant to alternate fuel are: 229.43 Exhaust and Battery Gasses 229.93 Safety Cut-off Devices (fuel lines) 229.95 Venting Safety Requirements 229.97 Grounding Fuel tanks 229.101 Engine Safety Requirements 229.209 Alternative Locomotive Crashworthiness 229.217 Fuel Tank Crashworthiness 229.301-319 Locomotive Electronics Safety Requirements
49 CFR 238 Passenger Equipment Safety Standards	238.103 Fire Safety 238.105 Train electronic hardware and software safety 238.117 Protection against personal injury 238.223 Requirements for Tier I Locomotive Fuel Tanks
29 CFR Part 1910 OHS Standard	Sec 101 – OHS Standard – Compressed Gases – General Requirements Sec 106 – OHS Standards for Flammable Liquids Sec 110 – OHS Standard – Storage and handling of Liquefied Petroleum Gases Sec 1000 – OHS Standard – Toxic and Hazardous Air Contaminants
29 CFR Part 1910.119 and 1926.64 – OHS Std. –	Contains requirements for minimizing the consequences

Governing Document	Summary Description
Process Safety Management of Highly Hazardous Chemicals	of catastrophic releases of toxic, reactive, flammable, or explosive chemicals - May result in toxic, fire or explosion hazards - Applies to: Process which involves a chemical at or above the specified threshold quantities Process which involves a Category 1 flammable gas on site in one location, in a quantity of 10,000 pounds
NSI NGV1-2006 Compressed Natural Gas Vehicle (NGV) Fueling Connection Devices	Examination, testing and certification of compressed Natural Gas Vehicle (NGV) fueling nozzles and receptacles only.
ANSI NGV 2-2007 Compressed Natural Gas Vehicle Fuel Containers	Safe operation, substantial and durable construction and performance testing of containers for the on-board storage of compressed natural gas for vehicle operation. Requirements for material, design, manufacture and testing of NGV containers intended only for the storage of CNG for vehicle operation.
ANSI NGV 3.1 Fuel System Components for Compressed Natural Gas Powered Vehicles	A standard for the safe operation, substantial and durable construction and performance testing of natural gas vehicle fuel systems

Chicago Electrical Code

Specific articles and sections of the NEC (National Electrical Code, NFPA 70) are modified by the Chicago Electrical Code (Municipal Code of Chicago, Title 14E). Sections modified by the Chicago Electrical Code are designated so below. It should be noted that the Chicago Electrical Code has adopted, by reference, NFPA 70 National Electrical Code 2017, with specific modifications. The listing below is not meant to be exhaustive; for electrical installations within the City of Chicago, all applicable Articles of both NFPA 70 and the Chicago Electrical Code (with relevant modifications) shall need to be considered.

Article 500: Hazardous (Classified) Locations, Classes I, II, and III, Divisions 1 and 2

500.5 – Classifications of Locations

(A) General

Locations shall be classified depending on the properties of the flammable gas, flammable liquid – produced vapor, combustible liquid - produced vapors, combustible dusts, or fibers/flyings, that could be present, and the likelihood that a flammable or combustible concentration or quantity is present. Each room, section, or area shall be considered individually in determining its classification.

(B) Class I Locations

Class I locations are those in which flammable gases, flammable liquid - produced vapors, or combustible liquid – produced vapors may be present in the air in quantities sufficient to produced explosive or ignitable mixtures. Class I locations shall include those specified in 500.5(B)(1) and (B)(2).

(1) Class I, Division 1

A Class I, Division 1 location is a location:

(1) In which ignitable concentrations of flammable gases, flammable liquid - produced vapors, or combustible liquid – produced vapors can exist under normal operating conditions, or

(2) In which concentration of such flammable gasses, flammable liquid - produced vapors, or combustible liquid – produced vapors above their flash points may exist frequently because of repair or maintenance operations or because of leakage

(1) Class I, Division 2

A Class I, Division 2 location is a location:

(1) In which volatile flammable gases, flammable liquid – produced vapors, or combustible liquid – produced vapors are handled, processed, or used, but in which the liquids, vapors, or gases will normally be confined within closed containers or closed systems from which they can escape only in case of accidental rupture or breakdown of such containers or systems in case of abnormal operation of equipment, or

(2) In which ignitable concentrations of flammable gases, flammable liquid – produced vapors, or combustible liquid – produced vapors are normally prevented by positive mechanical ventilation and which might become hazardous through failure or abnormal operation of the ventilating equipment, or

(3) This is adjacent to a Class I, Division 1 location, and to which ignitable concentrations of flammable gases, flammable liquid – produced vapors, or combustible liquid – produced vapors above their flash points might occasionally be communicated unless such communication is prevented by adequate positive – pressure ventilation from a source of clean air and effective safeguards against ventilation failure are provided.

Informational Note No. 1: This classification usually includes locations where volatile flammable liquids or flammable gases or vapors are used but that, in the judgement of the authority having jurisdiction, would become hazardous only in case of an accident or of some unusual operating condition. The quantity of flammable material that might escape in case of accident, the adequacy of ventilating equipment, the total area involved, and the record of the industry or business with respect to explosions or fires are all factors which merit consideration in determining the classification and extent of each location. Other relevant sections are:

500.6 – Material Groups
(A) Class I Group Classifications
Class I groups shall be according to 500.6(A)(1) through (A)(4)

500.7 – Protection Techniques
(A) Explosionproof Equipment

(E) Intrinsic Safety
(F) Nonincendive Circuit
(G) Nonincendive Equipment
(H) Nonincendive Component
(J) Hermetically Sealed
(K) Combustible Gas Detection System
500.8 – Equipment
(A) Suitability
(B) Approval for Class and Properties
(C) Marking
(D) Temperature
(E) Threading
(F) Optical Fiber Cables
Article 501: Class I Locations
501.1 Scope
501.5 Zone Equipment
501.10 Wiring Methods
(A) Class I, Division 1
(1) General
*Modified by Chicago Electrical Code
(2) Flexible Connections
*Modified by Chicago Electrical Code
(3) Boxes and Fittings
(B) Class I, Division 2
(1) General
*Modified by Chicago Electrical Code
(2) Flexible Connections
*Modified by Chicago Electrical Code
(3) Nonincendive Field Wiring
(3) Boxes and Fittings
501.15 Sealing and Drainage
(A) Conduit Seals, Class I, Division 1
(1) Entering Enclosures
(2) Pressurized Enclosures
(3) Two or More Explosion Proof Enclosures
(4) Class I, Division 1 Boundary
(B) Conduit Seals, Class I, Division 2
(1) Entering Enclosures
(2) Class I, Division 1 Boundary
(C) Class I, Divisions 1 and 2
(D) Conduit Seals, Class I, Division 2
501.20 Conductor Insulation, Class I, Divisions 1 and 2
501.25 Uninsulated Exposed Parts, Class I, Divisions 1 and 2
501.30 Grounding and Bonding, Class I, Divisions 1 and 2

501.35 Surge Protection
501.100 Transformers and Capacitors
(A) Class I, Division 1
(B) Class 1, Division 2
501.105 Meters, Instruments and Relays
(A) Class I, Division 1
(B) Class 1, Division 2
501.115 Switches, Circuit Breakers, Motor Controllers, and Fuses
(A) Class I, Division 1
(B) Class 1, Division 2
501.125 Motors and Generators
(A) Class I, Division 1
(B) Class 1, Division 2
501.130 Luminaires
(A) Class I, Division 1
(1) Luminaires
(2) Physical Damage
(3) Pendant Luminaires
(4) Supports
(B) Class 1, Division 2
(1) Luminaires
(2) Physical Damage
(3) Pendant Luminaires
(4) Portable Lighting Equipment
(5) Switches
(6) Starting Equipment
501.135 Utilization Equipment
(A) Class I, Division 1
(B) Class 1, Division 2
(1) Heaters
(2) Motors
(3) Switches, Circuit Breakers, and Fuses
501.140 Flexible Cords, Class I, Divisions 1 and 2
(A) Permitted Uses
(B) Installation
501.145 Receptacles and Attachment Plugs, Class I, Divisions 1 and 2
(A) Receptacles
(B) Attachment Plugs
501.150 Signaling, Alarm, Remote – Control, and Communications Systems
(A) Class I, Division 1
(B) Class I, Division 2

Article 505: Zone 0, 1, and 2 Locations

This article covers the requirements for the zone classification system as an alternative to the division classification system covered in Article 500 for electrical and electronic equipment and wiring for all voltages in Class I, Zone 0, Zone 1, and Zone 2 hazardous (classified) locations where fire or explosion hazards may exist due to flammable gases, vapors, or liquids.

Article 511: Commercial Garages, Repair, and Storage
(Note, this may not apply directly to Metra facilities, but this Articled does give guidance for determining Class I, Division 1 or Division 2 locations within a building or room)

- 511.1 Scope
- 511.2 Definitions
- 511.3 Area Classification General
  - (B) Repair Garages, With Dispensing
  - (C) Repair Garages, Major and Minor
- (D) Repair Garages, Major
- (E) Modifications to Classification
  - (1) Specific Areas Adjacent to Classified Locations
- 511.4 Wiring and Equipment in Class I Locations
  - (A) Wiring Located in Class I Locations
  - (B) Equipment Located in Class I Locations
    - (1) Fuel Dispensing Units
    - (2) Portable Lighting Equipment
- 511.7 Wiring Equipment Installed Above Class I Locations
  - (A) Wiring in Spaces Above Class I Locations
  - (1) Fixed Wiring Above Class I Locations
    - *Modified by Chicago Electrical Code
  - (2) Pendant
  - (B) Electrical Equipment Installed Above Class I Locations
  - (1) Fixed Electrical Equipment
    - (a) Arcing Equipment
    - (b) Fixed Lighting
- 511.9 Sealing
- 511.10 Special Equipment
  - (A) Battery Charging Equipment
- 511.12 Ground – Fault Circuit Interrupter Protection for Personnel
- 511.16 Grounding and Bonding Requirements
  - (A) General Grounding Requirements
  - (B) Supplying Circuits with Grounding and Grounded Conductors in Class I Locations
    - (1) Circuits Supplying Portable Equipment or Pendants
    - (2) Approved Means

Article 514: Motor Fuel Dispensing Facilities

- 514.1 Scope

514.2 Definitions
514.3 Classification of Locations
(A) Unclassified Locations
(B) Classified Locations
(1) Class I Locations
(2) Compressed Natural Gas, Liquefied Natural Gas, and Liquefied Petroleum Gas Areas
(3) Fuel Storage
514.4 Wiring and Equipment Installed in Class I Locations
514.7 Wiring and Equipment Above Class I Locations
514.8 Underground Wiring
*Modified by Chicago Electrical Code
514.9 Sealing
514.11 Circuit Disconnects
514.13 Provisions for Maintenance and Service of Dispensing Equipment
514.16 Grounding and Bonding

Chicago Building Code

The following are relevant chapters which may need to be considered for Metra facilities, specifically for the storage and handling of fuel:

Title 13 Buildings and Construction
Title 14E – Electrical Code
Title 15 Fire Prevention
Chapter 15-8 Fire - Resistive Requirements
Chapter 15-16 Fire Protection Equipment
Chapter 15-26 Fume and Flammable Compressed Gases
Article I – General
Article II – Buildings and Rooms
Article III – Transportation
Article V – Liquefied Petroleum Gas
Title 18 Building Infrastructure
Chapter 18-28 Mechanical Systems
Article I – Administration
Article II – Definitions
Article III – General Regulations
Article IV – Ventilation
Article VI – Duct Systems
Article XIV – Fuel – Gas Piping

Federal Railroad Administration and Natural Gas

Due to the high interest and resulting pilot programs initiated by the Class I (and more recently regional lines) on LNG dual fuel locomotives for freight applications, the FRA has provided some guidance to the railroads on a case by case basis and has worked with the Association of American Railroads (AAR) to develop standards for the use of LNG tender cars. In 2013, the FRA published a letter to the American Short Line and Regional Railroad Association (ASLRRA) with information that provided guidance for creating and submitting a plan and requesting a waiver (if required) to test the use of CNG or LNG for railroad service, including a safety analysis:

> "Prior to initiating the testing of new dual-fuel locomotives or tender vehicles, railroads and vendors must conduct a comprehensive safety analysis that must be provided to FRA for approval. This analysis must identify the risks of the operation and any measures designed to mitigate those risks."

A detailed project plan must be provided, which includes a test plan, a schedule with milestones, test location, coordination of relevant stakeholders (such as vendors, subcontractors, emergency responders, etc.), physical layouts, operation descriptions, flow diagrams and equipment design information, among other items. In total, there are 17 line items identified for railroad submittal in the FRA's guidance letter to the ASLRRA.

Other required documents include a structural analysis and crashworthiness evaluation of the equipment and fuel storage elements, maintenance and test procedures, leak detection, communication plans and hazard analyses. Most of what guidance the FRA has provided is aimed at the LNG tender car approach planned by most of the railroads. It is less clear what the requirements are for a locomotive with onboard CNG storage. It is presumed that the existing FRA fuel tank crashworthiness requirements would apply as a minimum.

The FRA also has provided guidance to the railroads that 40 CFR 174, Carriage by Rail of Hazardous Materials, is not applicable where the locomotive is using NG as a fuel. As shown in Table 8 there are a number of existing FRA locomotive and passenger rail safety regulations that apply, regardless of fuel type.

Results Summary

This study has focused on a NG/diesel dual fuel approach as the most viable alternative fuel for Metra's locomotive fleet. As described herein, some very limited, pilot type feasibility studies have been conducted in the last 20+ years in the railroad industry using NG as a replacement and/or supplemental fuel, driven primarily by the price differential with diesel fuel, which at times has been as much as $4 per gallon.

More recently two regional railroads, Florida East Coast and Indiana Belt Harbor, have initiated locomotive fleet conversions to either LNG/diesel or CNG/diesel dual fuel. In the case of FEC, it is driven by the fact that they also produce and haul LNG, thus having ready access to low cost NG to power their GE ESC44C freight locomotives. IHB's motivation is a combination of fuel savings and exhaust emissions reduction and is matching funded by a consortium of public agencies. The funding will pay for the conversion of IHB's fleet of twenty-one 1,500hp EMD built switching locomotives to CNG/diesel dual fuel operation upon completion. To date, two locomotives are in service and two more are in the process of conversion.

Fuel cost reduction, based on the data provided, is an attractive goal with a potential to be high, based on Metra's annual locomotive fuel consumption. Exhaust emissions will be improved, but not significantly, based on available published test data. Some of the engine conversion suppliers are claiming up to Tier 4 emissions, however data to back up this claim have not yet been received at the time of publication of this report; this will be pursued further under Task 3.

The logistics and complexities of LNG liquefaction, storage and transport, in combination with the high capital cost of either building a plant and purchasing tanker trucks makes this an unattractive option for Metra. LNG could potentially be hauled in by truck from a LNG supplier, but it must come from long distances and would require a large fleet to meet Metra's needs.

The portability and scaling of CNG equipment utilizing already available NG supply piping makes it an attractive option. In addition, there is a large installed base of CNG refueling equipment due to high numbers of NG fueled vehicles, such as public transit buses. Onsite NG supply would also reduce the number of diesel fuel deliveries by up to 50% if adopted across all of Metra's refueling sites. Several suppliers of such equipment have been contacted and will provide conceptual refueling systems and rough order of magnitude costs once NG supply pressures are known at Metra's refueling sites. Based on published data for NGVs, this could be in excess of $4M per site, although still far less than the cost of a LNG liquefaction and storage plant.

Sufficient space for onboard storage of both fuels on the locomotive is a concern and may not be adaptable to all of Metra's fleet. Ongoing work with a supplier of onboard fuel storage will yield a more definitive answer during Task 3. The storage tanks must be FRA crashworthy.

Engine conversion will be a significant capital cost; again, suppliers have been contacted and a clearer picture of the cost and details associated with engine conversion or repower will be a part of Task 3.

In general, due to the NGV industry, regulations and standards for NG and in particular CNG fuel usage, storage, handling, facilities and operation are well defined. The FRA still considers NG as a locomotive fuel an experimental undertaking and has established guidelines for a railroad to submit for approval.

Conclusions and Recommendations

This is an interim report (Task 2) and is focused on documenting Metra's current practices with regard to locomotive fuel consumption, fueling operations and infrastructure; the available alternative fuels and their relevance, availability and service history in locomotive rail applications; the most viable fuel considering Metra's locomotive fleet makeup and available technology on the market today; and governing regulations, codes and standards for the alternative fuel. Additionally, contacts have been initiated with the most knowledgeable, relevant and experienced suppliers of alternate fuel conversion, storage and refueling equipment and much information is still pending at this time. There are still a few outstanding items required from the RTA and Metra to complete the study, however the following conclusions can be made:

- Currently NG fuel savings on a per gallon basis is on the order of $2 as compared to diesel fuel, based on Metra's current diesel and NG pricing differential, however this does not take into account the capital cost of CNG processing equipment to increase the gas density to allow for onboard storage.
- NG/dual fuel is the most viable alternative fuel based on railroad operating service history and supporting technology, with no impact to locomotive performance, as would be seen with a conversion to 100% NG, either LNG or CNG.
- Of the two options available (LNG & CNG), CNG is the most adaptable to Metra's fleet due to its portability, and the cost and availability of CNG refueling infrastructure, when compared to LNG.
- Adaptation of CNG to Metra's five districts and refueling facilities will be a challenge due to space constraints but may be feasible in some locations. BNSF and UP would also need to be partners in the process.
- There are several suppliers of prime mover engine conversion technology for dual fuel.
- There are several suppliers of CNG on-site compression, refueling and storage equipment.
- Onboard storage is a challenge given the limited space available on the locomotive; discussions are underway with a potential supplier of onboard dual fuel storage that may work with Metra's fleet.
- There are numerous regulations, codes and standards for CNG equipment as a result of the NGV industry.
- The FRA requires any railroad planning to convert their locomotive fleet to an alternative fuel to submit a project plan, including a test plan and milestone schedule, as well as a system safety plan, a hazard analysis and a number of other supporting documents.
- There is more work to do on developing an onboard storage approach, understanding CNG refueling operations and sizing of on-site facilities, as well as refining the capital costs.

Next Steps (Task 3: Alternative Fuel Options & Implementation Plan)

The Task 3 report will build upon what has been initiated in this report and will focus on the feasibility portion of the study, focusing on the following steps and actions:

- Continue to obtain data from suppliers on technical solutions and capital costs of engine conversion and/or repowers and other locomotive conversion costs, on-site CNG compression, storage and refueling equipment.
- Obtain a more accurate estimate on estimated cost to Metra for CNG based on representative volumes to use in the break-even analysis.
- Investigate potential facilities modifications and related costs to accommodate CNG.
- Conduct train simulations using the Milwaukee District North Fox Lake run to determine baseline diesel fuel consumption and estimated exhaust emissions, and then CNG/diesel fuel consumption and its associated exhaust emissions. Extrapolate the data and apply to Metra's other operating districts and fleet to estimate global dual fuel costs and exhaust emissions improvements.
- Provide an operational impact assessment that covers key criteria such as operating range between locomotive fueling, time to refuel, onsite fuel storage and delivery.
- Prepare a high-level analysis of the safety hazards associated with storage, handling, and usage of CNG as a locomotive fuel.
- Develop a financial model and break-even analysis based on current pricing and various diesel fuel to NG price differentials, including capital and recurring costs associated with dual fuel conversion, including operations and maintenance expenses.
- Define a pilot or other limited operational program where a dual fuel strategy would be employed such that Metra would be able to evaluate the challenges and benefits to such a program.
- Identify potential partnerships and sources of public or private funding to affect an alternate fuel conversion.

Feasibility Analysis and Conversion Details Study

Introduction

In the previous report, entitled Best Practices and Existing Conditions, the diesel/CNG dual fuel approach was identified as the most readily available and viable alternative fuel solution for the Metra locomotive fleet. This study report examines the feasibility of dual fuel conversion, by:

- Visiting the Pace Markham transit bus maintenance facility that recently converted to CNG fuel to better understand the operational challenges and benefits associated with the conversion.
- Reviewing available locomotive engine conversion, on-board storage and fueling infrastructure suppliers and technology.
- Utilizing train operating simulations to determine fuel consumption and operating range.

Pace Markham, IL CNG Fueling Facility

A regional example of the use of compressed natural gas (CNG) for fleet fueling can be found at suburban Chicago bus operator, Pace. The Pace Markham, IL facility is a CNG-only bus maintenance and fueling site. While the Pace facility was designed for bus fueling, there would be many similarities to a locomotive fueling operation considering reasonable scaling.

The CNG fueling operation was commissioned in May 2016, replacing the prior diesel fueling system. In conjunction with the facility conversion, Pace purchased a fleet of 102 buses which are stationed at the Markham facility. Each, in-service, bus is fueled nightly here via two fuel dispensers. The buses were specifically designed with Cummins natural gas spark ignition combustion engines and on-roof CNG tank storage; on-board storage is 189 DGE, stored at approximately 4000 psi.

Figure 34 - Pace Bus within Fueling Shelter

The fueling location consists of dedicated compressor and buffer storage stations as well as a back-up power generator. Pace representatives have noted concerns with local utility power and ability to keep their fleet fueled during outages, leading to the generator added to the site as a design criterion. The equipment is housed on a 60’ x 120’ concrete pad, enclosed by 8’ tall chain-link fencing. The pad is within the Markham facility grounds, away from adjacent (industrial and commercial) neighbors. There are no residential areas nearby the facility. The equipment at this location is maintained by Trillium CNG, with a requirement to be on-site for equipment repairs within two hours of a service call. The configuration, type and arrangement of the drying, compression, storage and dispensing components, while at a lower capacity for this facility, are typical of what could be used for a locomotive refueling station at Metra's facilities.

The incoming natural gas line is sized to 8”, which branches from a Nicor (local natural gas utility) main distribution line within the local area; the incoming line pressure is nominally 120-130 psi. The pressure is reduced to a steady 80 psi via an inline regulator. The Pace staff who provided the tour indicated that Nicor extended the incoming gas line approximately one mile at no cost to Pace.

Figure 35 - Nicor Incoming 8" Line with Downstream Valves and Pressure Regulator

The pressure regulated gas is then dried via a skid-mounted dryer station. The design of the station provides for two drying towers with automated control. The two drying vessels are intermittently switched so that one provides removal of water while the other is regenerated (dried) through adsorption.

Figure 36 - Dryer Station

The dry (80 psi) gas is distributed via a main trunk line to one of five compressor module enclosures. The compressors are housed within pre-packaged enclosures. The compressors are rated at 200 hp each. The control configuration provides for three compressors to run with two in reserve in a lead-lag arrangement. The lead-lag arrangement is used to ensure compressor run time is balanced between the units.

Figure 37 - Pre-Packaged Compressor Enclosure

Each enclosure is equipped with a control PLC (Programmable Logic Controller) and pressure regulation. The control PLC is connected to the main PLC system (lead-lag controller) and main MCC (Motor Control Center) contactors. Additionally, there is a methane detector at the ceiling of each enclosure to detect leaks. The walls of the enclosure are equipped with sound deadening baffles while allowing for cooling air ventilation.

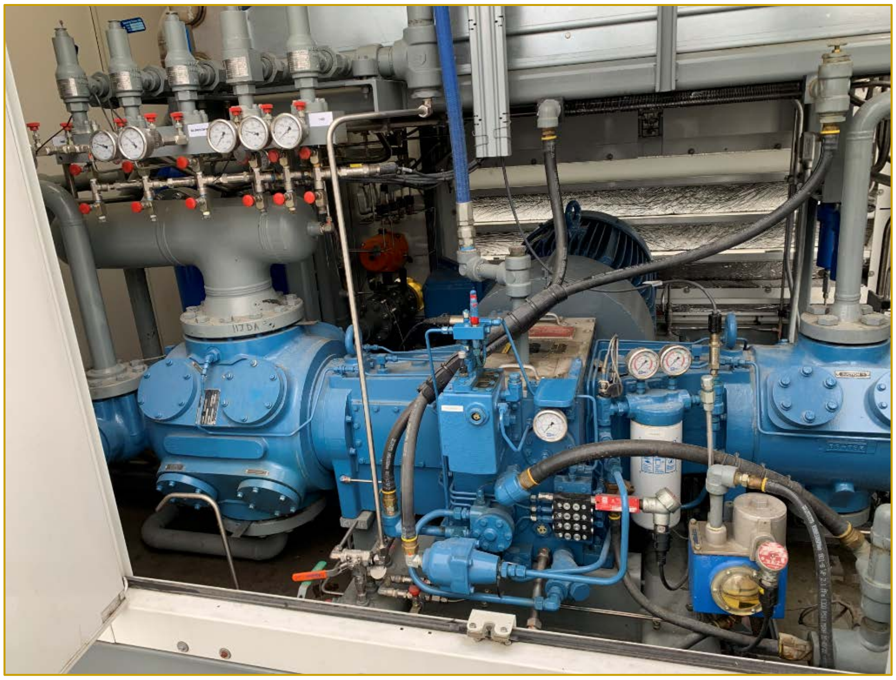


Figure 38 - Interior of Enclosure showing multi-stage pumps

Figure 39 - Methane Detector inside of pump enclosure

Figure 40 – MCC and Main PLC Cabinet

Figure 41 – Main PLC HMI (Human Machine Interface) Cabinet

Figure 42 - Compressor Modules Feed (Yellow Pipe) and Output (Stainless Pipe) with Buffer Tanks

The compressor output lines are piped to nine buffer tanks, sized at 89 DGE each. From the buffer tanks, the 4000 psi output is routed to a dyer and pressure regulator and to the fueling dispensers.

Each fuel dispenser is capable of either 4000 psi (fast-fill) or 2000 psi (slow-fill), dependent on the bus fuel fill port used.

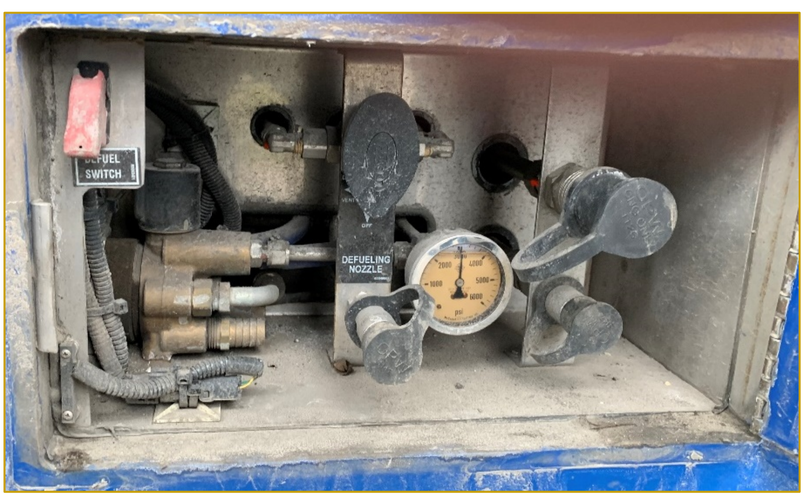


Figure 43 - Bus CNG Fill Manifold

Figure 44 – Fueling Dispenser (2000 and 4000 psi capability)

In addition to fueling capability there is also a fuel evacuation (de-fueling) system which may be used to remove CNG from the on-board storage tanks. It should be noted that this pump is rarely used as buses are serviced within the maintenance facility with tanks at various levels of fill. The defueling station is utilized only if the onboard fuel supply and storage system must be evacuated for specific maintenance.

Figure 45 - Bus CNG Tank Evacuation System Connection

Pace representatives have noted particular success and satisfaction of this facility and CNG system. They are planning to expand this system to other bus fueling locations, as they plan for further bus fleet purchases in the future.

The bus maintenance facility was also upgraded to be compliant to CNG related regulations and standards such as NFPA 52, which allows buses to be brought indoors for maintenance and staging for daily operation. Major modifications included replacing gas heaters with steam heat, additional ventilation, new compliant light fixtures and installation of methane detectors and alert systems.

The Pace facility refills its 102 buses in an eight-hour night shift, dispensing an average of 10,000 DGE of NG nightly. This works out to an average fast fill rate of 20 DGE/min.

Other notable lessons learned from the tour of the Pace facility:

- Pace has employed a CNG refueling consultant with experience in the transit industry who oversaw the development of and installation of the fueling facility and Pace's conversion from diesel fuel to natural gas.
- The fueling facility is fully automated with remote monitoring and diagnostics.
- Pace utilizes a third party (Trillium CNG) to service and maintain the refueling facility. An average monthly service cost of $0.08 is figured in to the DGE equivalent cost of the NG. Other operating costs, such as electricity, are shown in Figure 46.
- Pace has saved $1.9M in fuel costs through November 2018.
- From the Pace website:

  "Pace South Division serves southern Cook County, the south side of Chicago, and the DuPage County suburbs. The 191,000 sq. ft. facility was constructed in 1988 and, in 2016, became a compressed natural gas (CNG) fueling station. It is currently being converted into a CNG bus maintenance facility. Pace is proud to lead the transportation industry in use of CNG buses because natural gas burns far cleaner than diesel fuel reducing carbon dioxide by up to 30% and toxic emissions by up to 90%. Replacing just one older diesel bus with a natural gas bus is equivalent to taking 21 cars off the road! Additionally, natural gas costs significantly less than diesel, substantially reduces maintenance costs, and results in a longer vehicle lifespan."

CNG Natural Gas Bill November 2018

The DGE used from Fleet Watch for November is 103,190.8 DGE.

Mansfield Power & Gas Natural gas cost for November is $53,731.12

Nicor Invoice cost for November is $16,920.81

Com Ed cost for November is $7,214.84

CNG Station maintenance cost for November is $8,589.24

The total cost per DGE for November 2018 is $0.8302.

Mansfield Power & Gas

Natural gas cost per DGE =	$0.5206
Nicor Invoice cost per DGE =	$0.1639
Electric cost per DGE =	$0.0625
CNG station maint. cost per DGE =	$0.0832
	$0.8302

The average price of Diesel fuel for November 2018 was $2.28 per gallon.

This is $1.45 savings per DGE over diesel fuel.

$1.45 X 103,190.8 = $149,626.66 savings for November 2018.

Total savings in 2018 thru November $1,958,059.93

Figure 46 – Pace November 2018 CNG DGE Cost Breakdown

Key Rail Industry Suppliers

As previously noted, upward fluctuation of the price of diesel fuel drives interest in natural gas as an alternative fuel, due to its relative stable price and increasing supply. As previously shown in Figures 19 and 20 of the Best Practices report, diesel fuel reached a peak of over $4.00 per gallon retail in 2012 and has been steadily decreasing since. During this study the price of diesel fuel has decreased by approximately 8%, which has served to bring an end to innovation in the rail industry with regard to the natural gas/diesel dual fuel locomotive pilot programs at all of the major railroads. Virtually all of the Class 1 railroads pursuing dual fuel (BNSF, UP, CN, CP and NS) have curtailed their programs for the moment. Only the two Class 3 railroads of FEC and IHB have continued on the path of the dual fuel approach.

ECI/Engenious Engineering™

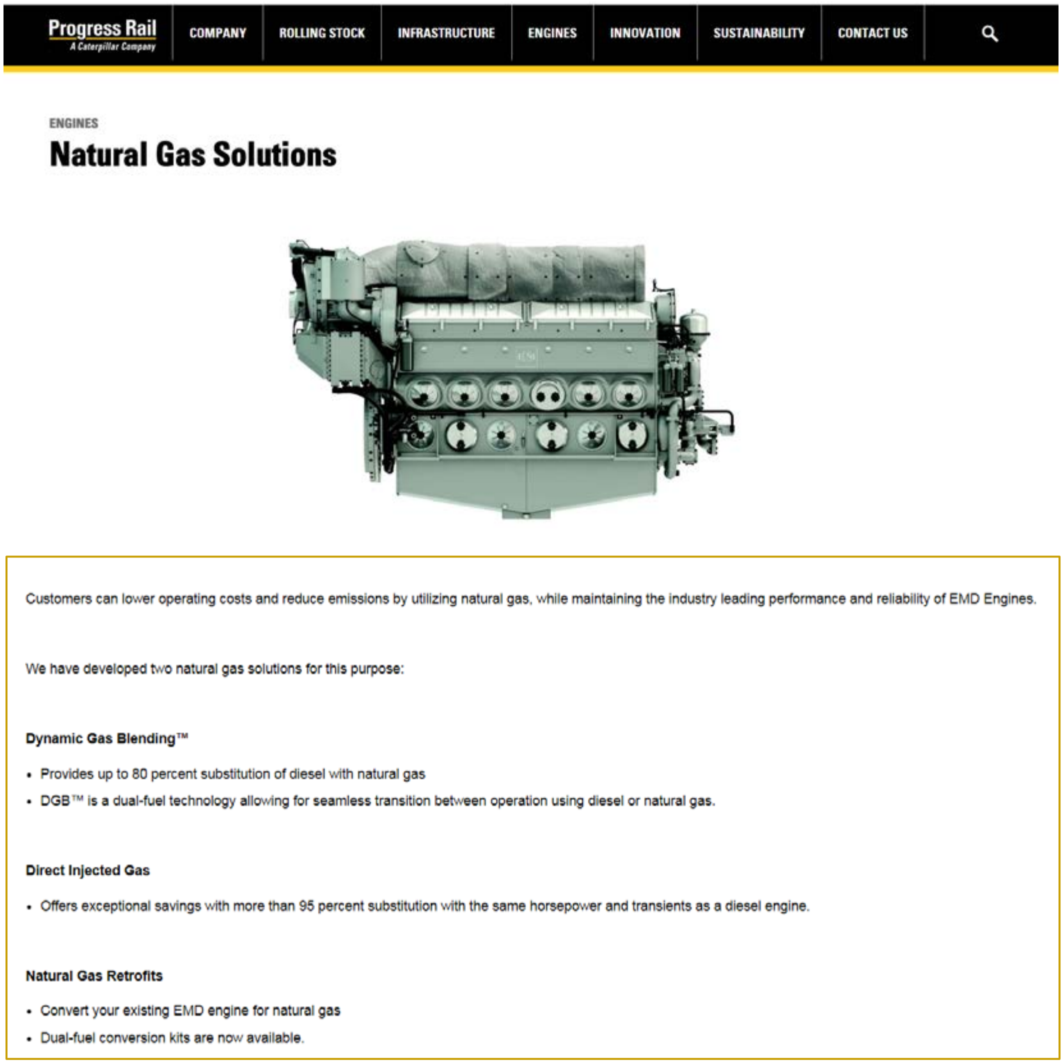
In the case of Energy Conversion, Inc., (ECI), they have now been absorbed by Peaker Services and have changed their name to Engenious Engineering™ and are now focusing on potential conversion of slow speed diesel engines in the stationary engine market. Mr. Scott Jensen has been a principal in ECI for about 30 years and is now an application engineer with Peaker. Mr. Jensen has been a pioneer in the NG and dual fuel conversion of locomotives and has at one time or another worked with nearly all of the Class 1 freight railroads on pilot dual fuel locomotive projects, beginning with the BN project in the early 90's. Mr. Jensen has published several papers on the engine conversion kits that he developed with ECI for both EMD and GE engines. He was interviewed for this study and provided the NG/Diesel fuel usage vs. notch schedule that is the basis for the fuel consumption and fuel usage ratio portion of this study. The specifics of the conversion kit can be found in Metra Locomotive Modifications.

Figure 47 - ECI/Engenious Engineering Website

Progress Rail

Progress Rail, which also advertises dual fuel conversion solutions for its EMD engines, has also been reluctant to provide additional information when requested, other than some ballpark figures for engine conversion estimates. No other data has been furnished

As the only two experienced dual fuel conversion specialists for large, low speed diesel engines, it may take a substantial conversion project or another jump in diesel fuel prices for them to be active in the rail market again. In fact both of these suppliers were looking to the Class 1 railroads to market their products. Several of these railroads made substantial investments in locomotive conversions, LNG tender cars and refueling systems. Now that virtually all of the Class 1 alternative fuel projects have been shelved, it seems that the suppliers are focusing elsewhere. GE's NextFuel™ dual fuel retrofit program for its ES44AC locomotives has only been applied to the FEC fleet.


Progress Rail
A Caterpillar Company
COMPANY | ROLLING STOCK | INFRASTRUCTURE | ENGINES | INNOVATION | SUSTAINABILITY | CONTACT US

ENGINES

Natural Gas Solutions

Customers can lower operating costs and reduce emissions by utilizing natural gas, while maintaining the industry leading performance and reliability of EMD Engines.

We have developed two natural gas solutions for this purpose:

Dynamic Gas Blending™

- Provides up to 80 percent substitution of diesel with natural gas
- DGB™ is a dual-fuel technology allowing for seamless transition between operation using diesel or natural gas.

Direct Injected Gas

- Offers exceptional savings with more than 95 percent substitution with the same horsepower and transients as a diesel engine.

Natural Gas Retrofits

- Convert your existing EMD engine for natural gas
- Dual-fuel conversion kits are now available.

Figure 48 - Progress Rail NG Engine Website

CNG Motive

CNG Motive is a group of rail industry and CNG refueling professionals who have formed a venture to market some patented and proprietary technologies primarily related to on-board fuel storage and rapid refueling. Information that they have provided for this study will be provided in the Proprietary Appendix of the report. The principals of CNG Motive have been cooperative and very supportive of this study and have contributed to this study by providing both on-board storage and refueling station cost and performance information and conceptual models based on Metra's operating scenarios. Their fuel storage method for combining a high pressure CNG tank with a conventional locomotive diesel onboard storage tank is novel and makes good use of the limited space available for onboard storage of two fuels. A presentation on their storage and refueling approach may be found in the Propriety Appendix. They have also supplied much of the data related to locomotive refueling rates and cost estimates for the CNG refueling stations. They have a proprietary "Chill Fill®" fast fill CNG fueling technology which allows a relatively fast refilling while maintaining a low gas temperature during the filling operations. With competing CNG fueling systems, due to the heat of compression, the fuel flow must be periodically interrupted to allow cooling of the tank so that it can be completely filled which slows the refueling process. Although CNG Motive could be categorized as a startup company, their technical and managerial expertise is extensive, with key personnel from both GE and EMD locomotive groups encompassing relevant NG experience as well as CNG fueling.

Figure 49 - CNG Motive Cover Slide for Locomotive Alternative Fuel Study

Optifuel

Optifuel provided the CNG/diesel dual fuel integration of the CAT C18 EPA Tier 3 engine modules for the IHB switcher conversion project, which is still ongoing. The Optifuel president Mr. Scott Myers has been very forthcoming with information related to the IHB locomotive dual fuel conversion. He provided information related to the IHB project, specifically the details on the fueling arrangement and has proposed some very advanced concepts for a commuter locomotive.

The locomotive model concept is based on the IHG experience and requires underframe modifications and a reconfiguration of the carbody to accommodate a new equipment arrangement and above-deck on-board CNG storage, similar to the IHB switcher conversion. Mr. Myers estimates a 70% NG/30% diesel fuel usage ratio with this engine combination and up to 1,000 DGE of on-board CNG storage, as well as meeting EPA Tier 4 exhaust emissions requirements. Optifuel's submitted information can be found in the Proprietary Appendix to be provided in the report.

Figure 50 - Optifuel Cover Slide for Locomotive Alternative Energy Study

Other Potential Suppliers

A California company, Rail Propulsion Systems is also developing a dual fuel type locomotive conversion package aimed at the EMD F40/F59 locomotive retrofit market and lists ECI as a partner, among others. An onboard storage concept is shown in Figure 51, utilizing a variation of the existing fuel tank size envelope to contain CNG tanks. This concept carries CNG only. A separate tank would need to be utilized to carry the diesel fuel.

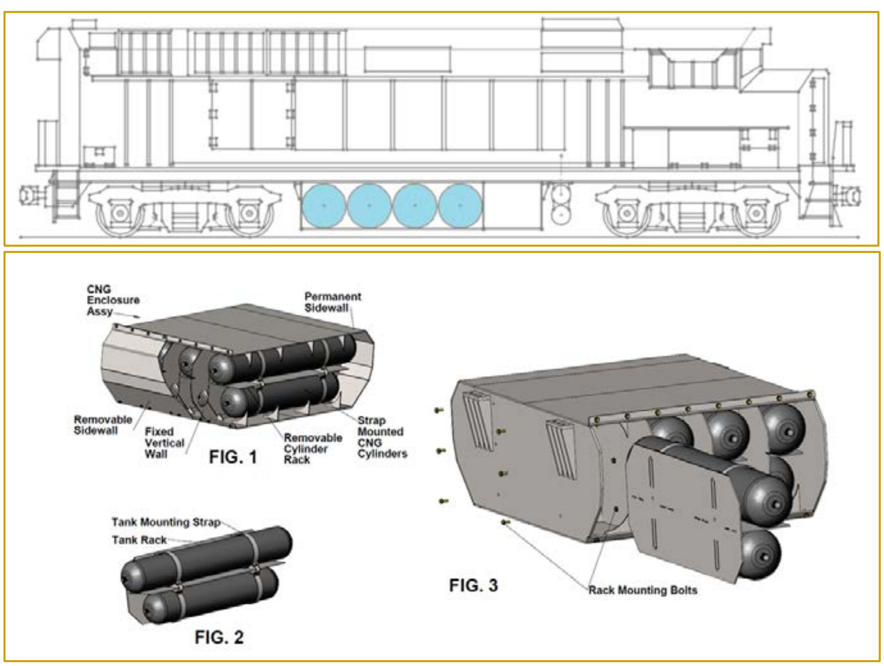


Figure 51 - On-Board CNG Storage Concept

Energy Conversion Methodology for CNG

To compare the replacement of diesel fuel with CNG, the energy density of the CNG must be represented in a comparable set of units. The Diesel Gallon Equivalent or DGE has been adopted by the alternative fuels industry and the US Department of Energy as a means of capturing the energy content of CNG in a weight and/or volumetric equivalent to a gallon of diesel fuel. As CNG is commercially available, the DGE allows consumers to compare the costs of diesel fuel replacement with CNG; this is also a regulated entity, as commercial retail CNG refueling pumps use this standard to charge customers by the DGE (or GGE). Per the DOE, Alternative Fuels Data Center, 6.38 lb or 139.30 scf of CNG is equivalent to one gallon of diesel fuel or DGE as shown in Figure 52. As shown in the figure, there are 128,488 Btu's of energy in a gallon of diesel; there are 20,160 Btu's per pound of CNG.

Pounds Mass/Diesel Gallon Equivalent Calculation

$$\frac{128,488 Btu}{gal} \; x \; \frac{lb}{20,160 Btu} = 6.38 lb \, / \, dge$$

Standard Cubic Feet/Diesel Gallon Equivalent Calculation

$$\frac{6.38 lb}{gal} \; x \; \frac{scf}{0.0458 lb} = 139.30 scf \, / \, dge$$

Figure 52 - Calculation of DGE for CNG from the US DOE Alternative Fuels website

CNG and RNG

Natural gas is a hydrocarbon-based fuel, consisting primarily of methane (CH_4) and is considered a fossil fuel. However, in recent years a version of natural gas termed RNG or Renewable Natural Gas, has become available. RNG is also known as bio methane and is produced from the anaerobic digestion of organic materials such as livestock waste or plant material. RNG is chemically identical to conventional natural gas and can be compressed for use in vehicles. RNG is considered a more environmentally friendly alternative as it utilizes organic waste material to produce methane and does not rely on the methods associated with crude oil production, such as hydraulic fracturing or "fracking". While the majority of RNG is used in electricity production, it is now finding its way into gas pipelines in many locations in the US and is considered a 'greener' alternative to conventionally produced NG.

Metra Train Simulation Calibration Results and Dual Fuel Usage Prediction

To quantify the potential offset of diesel fuel with CNG in actual operation, a train simulation of the Metra Union Station to Fox Lake route was conducted. The Simulation was based on the use of the LTK TrainOps® rail network simulation software. TrainOps® is the proprietary LTK operations and electrical network simulation software for all types of rail systems. This model was used to quantify the effect of locomotive alternative fuel conversion on travel times, fuel consumption, and emissions. A full report of the simulation study results and predictions will be provided in the Appendix.

A preliminary modelling effort was undertaken to ensure the accuracy of the model, by calibrating travel times and fuel consumption outputs for the existing Metra MP36PH-3C locomotive to their present-day values, as measured or estimated from available performance data. The calibration process consists of first matching simulated travel times and speed profiles, then calculating fuel consumption for a matched trip, applying corrective factors as necessary and appropriate to match the source data. All simulations were performed on the Milwaukee District North Line, since the most complete source data on vehicle performance and fuel consumption was available for this service.

The resulting baseline simulation model serves as a benchmark with respect to travel times, full consumption and emissions. Based on equipment performance data provided by a supplier, a future alternative-fuel scenario has been compared to this benchmark trip. The alternative fuel of choice is a “dual-fuel” mixture of conventional diesel and compressed natural gas (CNG). As outlined in this report, it is possible to modify existing diesel engines to accept such a mixture, with the ratio of the two fuels varying depending on the engine’s power output to maximize the available tractive effort. The substitution of CNG for a substantial fraction of the diesel fuel which would otherwise be consumed by a standard revenue trip has implications for the type and quantity of emissions generated.

The vehicle modeled for calibration corresponds to the MP36PH with EFI and CAT HEP engine, identified elsewhere as “MP36PH-3C.” Since this is the only locomotive for which data is available for both performance (speed profile) calibration and fuel consumption, this is the only vehicle for which full results have been computed, using a consist of six Nippon-Sharyo gallery cars and a single Nippon-Sharyo cab car. The head-end power demand of the consist was estimated based on a 50 kW/car load for each of the seven total trailer and cab cars, plus an 18-kW load for the locomotive itself, for a total load of 368 kW. The fuel consumption rate as a function of load of the Caterpillar C18 diesel generator set requires the generator to run with a constant ultra-low sulfur diesel fuel burn rate of 28.05 gal/hour. For the purposes of this study, the HEP engine was evaluated in a diesel engine configuration.

The total time spent in each notch by simulated Trip 2125 during the 1:25:09 of simulation is summarized in Table 10.

Table 10 also presents the total energy used in each notch setting, in units of horsepower-hours, for use in emissions calculations. Dwell times have been increased to match the end-to-end travel time of the trip to that which would exist if the appropriate 10.0% schedule margin were included. This results in an effective dwell time at each inline station of 74 seconds.

Table 10 - Time and Energy in Notch for Simulated Trip 2125

Notch Setting	Time in Notch	Energy Expended, bhp-hr	Diesel Fuel Consumption, gal
Dynamic Brake	0:18:49	11.92	4.11
1	0:03:52	13.21	0.85
2	0:00:20	2.64	0.14
3	0:02:47	46.62	2.43
4	0:01:40	37.58	1.92
5	0:04:22	136.53	6.83
6	0:03:54	179.79	8.6
7	0:01:43	98.82	4.68
8	0:32:54	2119.86	101.16
Propulsion Total	**1:10:21**	**2646.97**	**130.73**
Idle	0:14:48	2.22	0.78
HEP Generator	1:25:09	740.45	38.15
Total	**1:25:09**	**6036.61**	**169.67**

Engenious Engineering™ has provided an estimate of the fraction of diesel fuel which can be replaced by CNG at each notch setting, shown in Table 11. These values can be understood as the fraction of energy provided by each source. For the purposes of this study, it is assumed that this substitution schedule does not cause any decrease in available power at any rpm, such that the tractive effort curve and vehicle performance are not negatively affected by operating on dual-fuel.

Table 11 - CNG Substitution for Diesel by Notch Using ECI/EE Conversion Kit

Throttle	Fraction of Fuel Diesel, By Diesel Volume	Fraction of Fuel CNG, By Diesel Equivalent Volume
Dynamic Brake	100%	0
Idle	100%	0
Notch 1	100%	0
Notch 2	100%	0
Notch 3	30%	70%
Notch 4	30%	70%
Notch 5	20%	80%
Notch 6	20%	80%
Notch 7	10%	90%
Notch 8	10%	90%

To calculate the volume of CNG needed to replace the volume of diesel fuel substituted out, the concept of the standard cubic foot (SCF) of gas is useful. Natural gas volume is dependent on its state, unlike liquid fuels. Within the natural gas market, it is therefore conventional to describe a quantity of gas based on its volume at standard temperature and pressure, though in reality a given quantity of natural gas occupies a much smaller volume when held at the pressures which are sold and used as CNG. Based on a volumetric energy density for diesel fuel of 128,488 Btu/gal and a mass energy density for CNG of 20,160 Btu/lb at standard conditions, 139.30 SCF of CNG are equivalent to one gallon of diesel fuel.

Applying the substitution schedule outlined in Table 11 to the fuel consumption by notch calculated for the simulated trip results in the fuel substitution presented in Table 12. The consumption of a total of 110.65 gallons of diesel fuel is avoided by substituting CNG, representing 65.27% of the fuel consumed by the same trip when fueled exclusively by diesel. A total of 15,413.75 SCF or 110.65 DGE of CNG are used in its place. Since the simulated train spends a plurality of the trip in Notch 8, where CNG substitution is maximized, a comparatively large fraction of the fuel is replaced by CNG. Averaged over the entire period during which the locomotive is in Notch 8, the engines consume CNG at a rate of 385.5 SCF/min.

A dual fuel system would supply an existing diesel prime mover with a mixture of diesel and CNG, with the aim to minimize diesel fuel usage without restricting the tractive effort available at any speed. Based on comparison to the benchmark simulation of Trip 2125 and system performance as related by the manufacturer of the conversion system, this alternative fuel system reduces diesel fuel consumption by 65.27%. Diesel fuel use by the prime mover alone is reduced by 84.14% (the HEP generator is assumed to continue to be fueled solely by diesel).

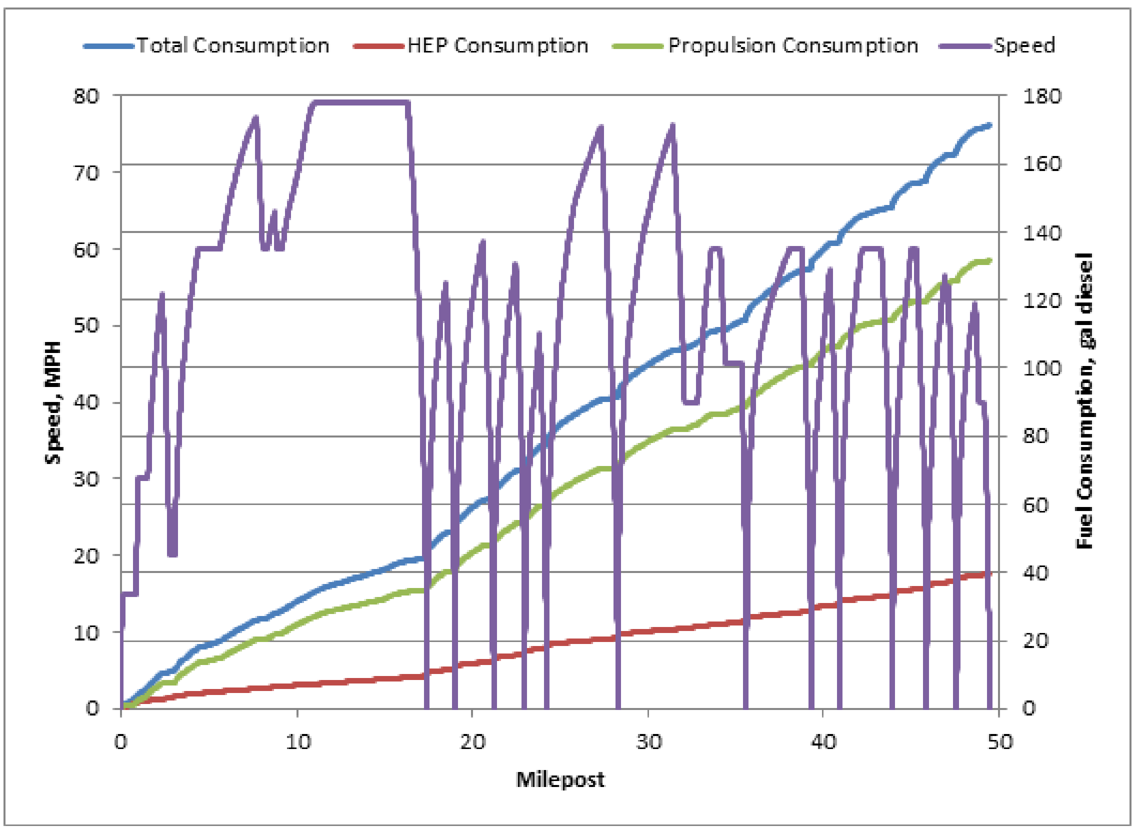


Figure 53 - Simulated Speed and Cumulative Fuel Consumption for TrainOps Trip 2125

Table 12 - Dual-Fuel Use by Simulated Trip 2125

Fuel Use Component	Duration	Diesel, Gal	Volume of Diesel Replaced by CNG (DGE)	SCF of CNG Replacing Diesel
Dynamic Brake	0:18:49	4.11	0.00	0.00
Idle	0:14:48	0.78	0.00	0.00
Notch 1	0:03:52	0.85	0.00	0.00
Notch 2	0:00:20	0.14	0.00	0.00
Notch 3	0:02:47	0.73	1.70	236.48
Notch 4	0:01:40	0.58	1.34	187.25
Notch 5	0:04:22	1.37	5.47	761.58
Notch 6	0:03:54	1.72	6.88	958.74
Notch 7	0:01:43	0.47	4.21	586.86
Notch 8	0:32:54	10.12	91.05	12682.80
Propulsion Prime Mover Subtotal	**1:25:09**	**20.86**	**110.65**	**15413.75**
Auxiliary Power (HEP)	1:25:09	38.03	0.00	0.00
Total	**1:25:09**	**58.89**	**110.65**	**15413.75**

Operating Scenarios and Equipment Locations

Metra Operating Scenario – Milwaukee District

In order to illustrate how a dual fuel conversion operation would look to Metra, a detailed conversion scenario was overlaid on the existing Milwaukee district. The Milwaukee District was selected for the following reasons:

- It is fully within Metra's control unlike the UP and BNSF districts, allowing Metra greater flexibility in implementation.
- The number of locomotives utilized approximates what could be available from Metra's newest available locomotives.
- The detailed operational model of the Milwaukee District North line that was developed using LTK's proprietary TrainOps® software to create an accurate simulation of train performance and fuel usage.
- The potential for substantial cost savings due to the quantity of fuel consumed on this line.

As shown in Table 13, the Milwaukee District locomotives consume over 6 million gallons of diesel fuel annually. A potential reduction in the usage of diesel fuel on the order of 4 million gallons could be achieved with the substitution of natural gas. Based on current fuel pricing and considering the 'as delivered' costs of CNG to the locomotive, a savings of $5.6 million dollars annually is possible. The savings are based on $1.60 savings per gallon at the current diesel-CNG price per gallon differential. Annual fuel savings for all Metra Districts would be approximately $26MM if a full conversion is implemented.

Table 13 - Annual Fuel Usage by District, Based on 2017 Fuel Deliveries

District	Operator	Fueling Location	Fuel Usage (gal)	Lines Serviced	No. of Locomotives
Milwaukee	Metra	Western Ave	6,235,935	MDN, MDW, NCS	38
Rock Island	Metra	49th St.	2,692,684	RI	20
BNSF	BNSF	14th St.	5,741,447	BNSF, SWS	30
UP	UP	M19	3,620,785	UPW, UPN, UPNW	51
		Ogilvie	7,170,932		
		Total:	**25,461,783**		**129***

*Note: some locomotives were out of service for upgrade/rehabilitation work when this number was provided.

It is assumed that due to size and/or weight limitations, the locomotives previously identified as candidates for dual fuel conversion (F59PH, F59PHI, MP36PH) will be limited on CNG storage capacity. Based on preliminary tank sizing calculations and below deck-space availability, an on-board storage capacity of no more than 300 Diesel Gas Equivalent (DGE) of CNG and 1,000 gallons of diesel fuel is estimated for use in this scenario. At the expected fuel consumption rates, overnight refueling will be necessary to avoid unscheduled refueling as discussed below in the Dual Fuel Expected Operating Section below. Refueling is scheduled to occur when 250 DGE of CNG is consumed in operation; diesel fuel capacity is assumed not to be a limiting factor, based on the previously predicted consumption rates of each fuel type. Below is a proposed operating scenario for the Milwaukee District that will allow Metra to operate on its current Monday-Friday schedule with a dual fuel locomotive fleet.

Milwaukee District North – Overnight Layover and Refueling

- Fox Lake to CUS distance: 49.3 miles
- Monday through Friday Schedule
- 11 trains overnight at Fox Lake – Inbound to CUS
- Trains are CNG fueled overnight using CNG slow fill
- Assume 250 DGE per locomotive or 3,000 DGE of CNG is required per night, worst case

The refueling window is fairly wide as the first 'overnight' train (2125) arrives at Fox Lake at 5:24 pm and could be refueled well before its inbound trip as 2124 with its first stop at 7:28 am. As seen in Table 14, most locomotives have large windows for overnight refueling. The locomotives on the last two outbound trains for the day have the smallest windows of only four hours; however, that is well within the needed time to refuel. According to an estimate provided by one of the equipment suppliers, a small three 200 hp compressor station (2 active and one backup) would suffice for overnight refueling, with 2 fuel dispensing stations. Buffer tank capacity on the order of 4,000 DGE would supplement stations which would allow the refueling compressors to run during the day to maintain tank volume for the overnight refueling. Buffer tanks would increase reliability by reducing the start and stop of the compressors while reducing maintenance and component deterioration. Additionally, the peak draw is reduced allowing the use of a smaller compressor ratable or average stable flow through the day is advantageous to receive a reduced rate from the gas utility supplier. Actual refueling rate would be on the order of 10 DGE per minute, keeping fill time for each locomotive on the order of 25 minutes, worst case for 250 DGE refuel. A benefit of the slow filling station noted by the supplier is that it reduces the size of the refueling station, saving on capital costs. Refueling could be accomplished as each locomotive returned from its last run and before being put into layover. From Figure 54, it appears that there would be adequate space for the modular pump stations, buffer tanks and other related CNG compression and storage infrastructure. Estimated equipment cost for the facility, excluding NRE, site preparation and permitting, would be in the $2.5M range.

Table 14 - Overnight Train Refueling Time Windows at Fox Lake

Outbound	Fox Lake Location	Last Stop	Inbound	First Stop	Approx. Refueling Time Window (hr)
2125	EAST END No. 4	5:24 P.M.	2124	7:28 a.m.	12
2129	WEST END No. 4	6:04 P.M.	2112	6:30 a.m.	12
2131	EAST END No. 5	6:18 P.M.	2106	5:35 a.m.	11
2135	EAST END No. 2	6:43 P.M.	2108	6:08 a.m.	11
2139	WEST END No. 5	6:55 P.M.	2104	5:13 a.m.	10
2143	EAST END No. 1	7:19 P.M.	2116	6:53 a.m.	10
2149	EAST END No. 8	8:36 P.M.	2122	7:16 a.m.	11
2151	EAST END No. 3	9:09 P.M.	2118	6:58 a.m.	10
2155	EAST END No. 7	11:19 P.M.	2114	6:38 a.m.	7
2157	WEST END No. 1	12:09 A.M .	2102	4:46 a.m.	4

2159	WEST END No. 3	1:59 A.M.	2110	6:14 a.m.	4
				Avg.	9.3

Figure 54 – Fox Lake Overnight Layover Location

Milwaukee District West – Overnight Layover and Refueling

- Elgin to CUS distance: 43.3 miles
- Monday through Friday Schedule
- 10 Trains overnight in Elgin– Inbound to CUS
- Trains are CNG fueled overnight using CNG slow fill
- Assume 250 DGE per locomotive or 3,000 DGE of CNG is required, worst case

The overnight refueling scenario at Elgin is comparable to the scenario at Fox Lake in that the total quantity of trains laying over is similar and the majority of the trains have fairly large 11 to 12-hour windows for refueling. The last two outbound trains of the night, 7062 and 7142 have the shortest refueling windows. However, based on the worst case as described for the Fox Lake refueling scenario, 25 minutes would be needed at a slow fill rate. The biggest drawback to the Elgin location is the very constricted space for train layover. Two fueling stations at the entrance to the layover tracks would allow refueling as the trains return to the Elgin facility for layover. Available space for the three pump stations, storage tanks and related equipment may be challenging for this location; a portion of the parking lot shown in Figure 55 would need to be utilized to contain the pump stations and buffer tanks. The size of this pump station is anticipated to be the same as Fox Lake's: a three 200 hp compressor station (two active and one backup) with two fuel dispensing stations and buffer tank capacity on the order of 4,000 DGE. Compressor hp requirements will be determined upon site-specific engineering as it is directly related to actual gas pressure available to the facility. Estimated equipment cost for the facility, excluding NRE, site preparation and permitting, would be in the $2.5M range.

Table 15 - Overnight Train Refueling Time Windows at Elgin

Outbound	Elgin Location	Last Stop	Inbound	First Stop	Approx. Refueling Time Window (hr)
2233	RIVER	6:07 P.M	7041	5:05 A.M.	11
2235	PLATFORM	6:11 P.M	2208	6:08 A.M.	12
7162	No. 3 (2231)	6:25 P.M.	7101	5:38 A.M.	11
2241	MIDDLE No. 1	6:33 P.M	2218	7:02 A.M.	12
7122	EAST END No. 1 (2243)	7:15 P.M.	2212	6:29 A.M.	11
7102	No. 6 (2237)	6:45 P.M.	7161	6:26 A.M.	12
2245	No.4	7:24 P.M	2214	6:39 A.M.	11
7022	No. 5 (2253)	11:17 P.M.	7061	5:08 A.M.	6
7062	No. 2 (2255)	12:17 A.M.	2200	4:17 A.M.	4
7142	WEST END No. 1 (2257)	2:17 A.M.	2202	4:52 A.M.	3
				Avg.	9.3

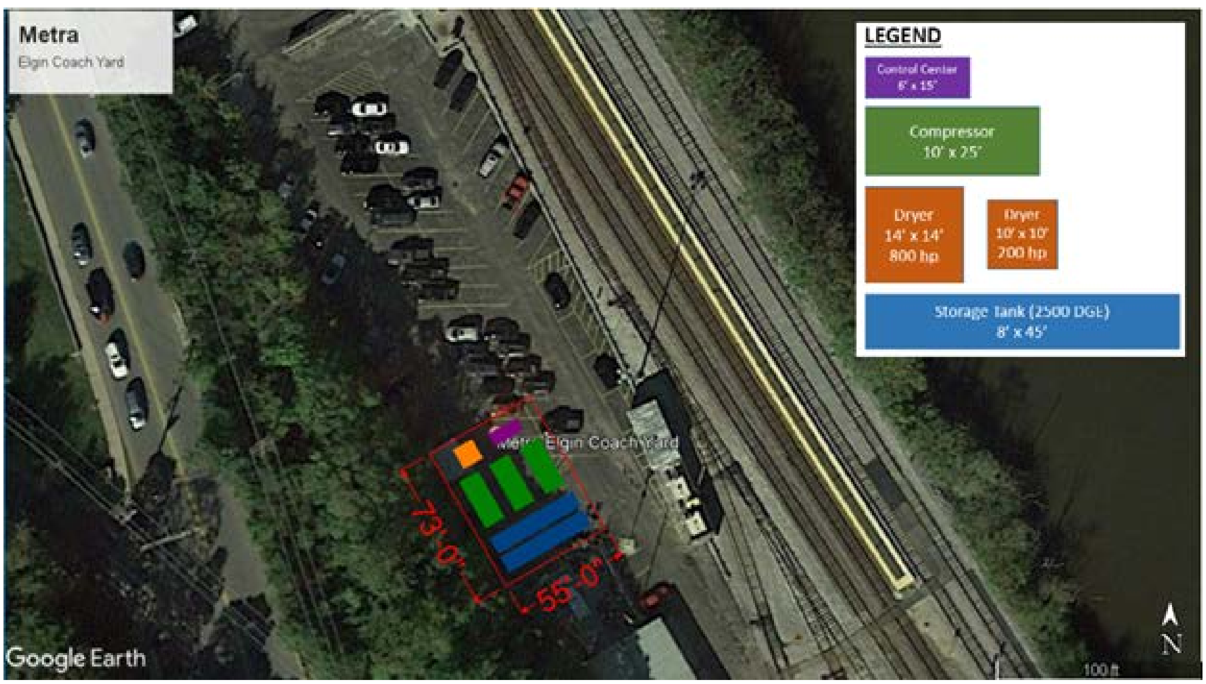


Figure 55 - Elgin Overnight Layover Location

Milwaukee District North Central – Overnight Layover and Refueling

- Antioch to CUS distance: 53.4 miles
- Monday through Friday Schedule
- 5 Trains overnight in Antioch– Inbound to CUS
- Trains are CNG fueled overnight using CNG slow fill
- Assume 250 DGE per locomotive or 2,000 DGE of CNG is required, worst case

As Antioch only has five trains laying over, a two-pump station with one fuel dispenser and 2,500 DGE buffer tanks would suffice, at an estimated cost of $1.5M.

Table 16 - Overnight Train Refueling Time Windows at Antioch

Outbound	Antioch Location	Last Stop	Inbound	First Stop	Approx. Refueling Time Window (hr)
109	TRACK3	6:05 P.M.	108	6:33 A.M.	11
113	TRACK4	6:38 P.M.	110	6:49 A.M.	12
115	TRACK7	7:07 P.M.	102	5:55 A.M.	11
117	TRACK6	7:37 P.M.	104	6:06 A.M.	11
119	TRACKS	8:34 P.M.	100	5:20 A.M.	8
				Avg.	10.6

Figure 56 - Antioch Overnight Layover Location

Milwaukee District – Western Avenue Mid-Day Refueling

For mid-day refueling at the Western Avenue facility, CNG fast fill stations would allow the 38 locomotives for the Milwaukee District North, Milwaukee District West and North Central Service lines to be refueled in a similar fashion to the current diesel refueling process. A two-hour refueling window was proposed to one of the station suppliers who estimated a three fueling station approach. A refueling facility was sized to the requirement of servicing up to 40 locomotives at up to 250 DGE each in 2 hours resulting in 83 DGE per minute combined refueling capacity. Cost estimates for a 10,000 DGE station with three 800 hp compressors and up to 10,000 DGE buffer storage would be in the $6M range, excluding NRE, site preparation and permitting, for the facility. 250 DGE of CNG would be refilled in approximately nine minutes with this equipment. Diesel fueling would continue to occur as it currently does. Due to possible space constraints at the Western Avenue location, as seen in Figure 57, the storage tanks are stacked 2 high to try and conserve space. Even with this layout it appears that alternative options may still need to be considered such as the acquisition of additional land.

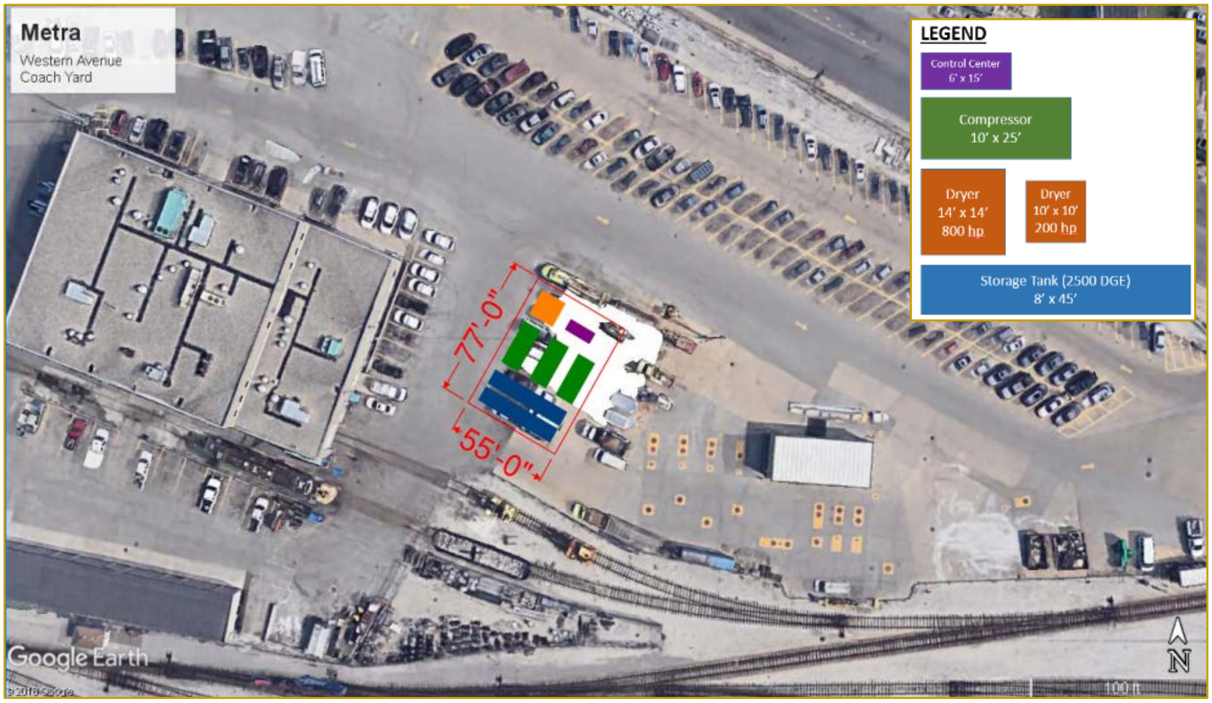


Figure 57 - Western Avenue Mid-Day Fueling Facility

Pump Stations and Buffer Storage

For all refueling locations, higher incoming gas pressure impacts the size of the required compressor. For example, to allow for a 20 DGE/min refueling rate:

- 40 psig incoming pressure requires a 2,200 hp compressor
- 200 psig incoming pressure requires a 1,500 hp compressor
- 600 psig incoming pressure requires a 1,000 hp compressor

600 psig incoming gas pressures is typically not available, however it is likely that 200 psig could be provided to these locations. It is expected that the local gas supplier can provide this capacity to all locations; however, this would need to be verified in the planning stages. Due to the high volume of fuel being consumed at each location, a favorable installation price is negotiable with the gas supplier. As noted at the Pace CNG bus facility, the gas supplier Nicor paid for the 200 psig line to be run approximately a mile to the facility.

Based on supplier provided data for sizing and costing of the fast fill stations, if direct filling, a station would require approximately 4,000 hp. With buffer storage, an estimated optimal compression at about 800 hp with buffer storage of 10,000 DGE is sufficient for refueling of the 40 locomotives at 250 DGE each in the mid-day cycle. Excluding permitting and electrical interconnection, the cost of the dryer and balance of plant would be about $600K in addition to the compressors and buffer storage. Compressors are generally $1,300-$2,000/hp depending on the size of the package and options. Buffer storage should be considered at $150/DGE installed.

From the scenario above, CNG fast fuel and slow fuel stations could be added to the three overnight fueling locations and the mid-day fueling location in the Milwaukee district at an estimated equipment cost of $12.5M, less NRE, site preparation and permitting. Table 17 summarizes CNG pump station equipment, fill rates and estimated costs for each fueling location in the Milwaukee District.

Table 17 - Milwaukee District pump Stations/Storage and Costs

Location	Compressors	Dispensing Stations	Storage	Fill Rate	Cost
Western Avenue (Mid-day)	3 (800 hp)	2	10,000 DGE	Fast	$6M
Fox Lake (Overnight)	3 (200 hp)	2	4,000 DGE	Slow	$2.5M
Elgin (Overnight)	3 (200 hp)	2	4,000 DGE	Slow	$2.5M
Antioch (Overnight)	2 (200 hp)	1	2,500 DGE	Slow	$1.5M

General Equipment Layout and Considerations

General equipment locations were provided for each yard; these can be seen throughout the document for each rail line. Equipment positioning was based on satellite images of each location. Although estimates were made a land survey is required for actual equipment placement as equipment may have been placed outside of the property limitations. There are also several layout considerations that must be incorporated into the equipment placement:

- Station equipment – 10 Ft. minimum from nearest building
- Station equipment from nearest property line – 10 ft. minimum distance
- CNG storage – 50 ft. minimum from other dispensing devices
- CNG storage – 20 ft. minimum from flammable above ground tanks
- CNG Fueling point – 3 ft. minimum from CNG storage
- CNG equipment – 50 ft. from active mainline rail
- Dispenser and fueling point – 10 ft. minimum from nearest building or building opening

Dual Fuel Locomotive Expected Operating Range

Weekday Schedules

Some sample locomotives in the Milwaukee district were evaluated based on the Metra supplied CUS equipment cycles. The three locomotives evaluated (C3, C4 and C5) are shown in Table 18. With overnight and mid-day CNG refueling, locomotives C4 and C5 can meet their schedules, running for distances of 183.4 and 132.6 consecutive miles with CNG refueling. Locomotive C3, with its 299.4 miles of continuous operation from CUS starting 2:35 PM and ending at Fox Lake at 1:59 AM would likely not be able to cover this distance without CNG refueling. Either fewer runs need to be made or, optionally the last run could be made on diesel fuel only, as the dual fuel system does allow diesel only operation if CNG is unavailable.

Table 18 - Assessment of Sampling of MDN Weekday Dual Fuel Locomotive Need for Refueling

Locomotive	C3				
Train no	**Start Loc**	**Start Time**	**End Time**	**End Loc**	**Mileage**
2121	CUS	2:35p	4:13p	Fox Lake	53
2146	Fox Lake	4:26p	5:55p	CUS	49.5
2145	CUS	6:05p	6:56p	Deerfield	24.2
2154	Deerfield	7:06p	8:00p	CUS	24.2
2153	CUS	8:35P	10:09p	Fox Lake	49.5
2160	Fox Lake	10:23p	12:04a	CUS	49.5
2159	CUS	12:25a	1:59a	Fox Lake	49.5
Fox Lake Overnight					299.4
2110	Fox Lake	6:14a	7:48a	CUS	49.5
2207	CUS	7:58a	9:23a	Big Timber	39.8
2230	Big Timber	9:36a	10:58a	CUS	43.3
				Total Morning:	132.6
				Total:	432

Likelihood of completing daily runs without refueling: Poor
Assuming 300 DGE CNG and 1,000 gal diesel total on-board capacity
Would require 2x refueling per day due to mileage

Approx. 3 hr window mid-day refueling; 4 hr window overnight refueling

Locomotive	C4				
Train no	**Start Loc**	**Start Time**	**End Time**	**End Loc**	**Mileage**
2147	CUS	6:25p	7:38p	Grayslake	41
2158	Grayslake	8:15p	9:34p	CUS	41
2155	CUS	9:45p	11:19p	Fox Lake	49.5
Fox Lake Overnight					131.5
2114	Fox Lake	6:38a	8:12a	CUS	53
				Total Morning:	53
				Total:	184.5

Likelihood of completing daily runs without refueling: Good
Assuming 300 DGE CNG and 1,000 gal diesel total on-board capacity

Approx. 7 hr window overnight for refueling; 4 hr mid-day window for refueling

Locomotive	C5				
Train no	**Start Loc**	**Start Time**	**End Time**	**End Loc**	**Mileage**
2133	CUS	4:48p	5:43p	Deerfield	27.7
2150	Deerfield	5:50p	6:44p	CUS	24.2
2149	CUS	6:55p	8:36p	Fox Lake	49.5
Fox Lake Overnight				Total Evening:	101.4
2122	Fox Lake	7:16a	8:49a	CUS	49.5
2211	CUS	9:30a	10:50a	Big Timber	39.8
2234	Big Timber	11:22a	12:43p	CUS	43.3
				Total Morning:	132.6
				Total:	234

Likelihood of completing daily runs without refueling: Good
Assuming 300 DGE CNG and 1,000 gal diesel total on-board capacity
Approx. 10 hr window for overnight refueling; 4 hr window mid-day for refueling

Weekend Schedules

Metra does not typically refuel locomotives on weekends, relying on the 2,500 gallon diesel fuel capacity of the MP36. As shown in Table 19, the three sample weekend locomotives shown, C13, C17 and C18 all run from 330.6 to 449 miles from Saturday through Monday. All three have an overnight layover at Fox Lake at some point, so weekend CNG refueling could be implemented if Metra desires.

It should be noted that the recently acquired SD70MAC locomotives, with their large 5,000 gallon fuel tanks, could easily accommodate the 550 DGE/2,000 gal diesel dual fuel tank concept developed by CNG Motive which would enable them to run through the weekend without diesel or CNG refueling.

Table 19 - Assessment of Sampling of MDN Weekend Dual Fuel Locomotive Need for Refueling

Locomotive	C13				
Train no	**Start Loc.**	**Start Time**	**End Time**	**End Loc.**	**Mileage**
Fox Lake Overnight -Saturday (all day)*					
2602	Fox Lake	6:45a	8:22a	CUS	49.5
2603	CUS	10:35a	12:12p	Fox Lake	49.5
2612	Fox Lake	12:45p	2:22p	CUS	49.5
2611	CUS	2:35p	4:12p	Fox Lake	49.5
2616	Fox Lake	4:45p	6:22p	CUS	49.5
2623	CUS	8:35p	10:12p	Fox Lake	49.5
2622	Fox Lake	10:25p	11:58p	CUS	49.5
2627	CUS	12:25a	1:57a	Fox Lake	49.5
Fox Lake Overnight -Sunday				Total Sunday:	396
2114	Fox Lake	6:38a	8:12a	CUS	53
				Total Weekend:	449

*Per Metra Equipment Cycles, C13 finishes Friday with 183.4 miles
Not possible to make all of Sunday runs without refueling; requires additional locomotive

Approx. 4 hr window for refueling Sunday night

Locomotive	C18				
Train no	**Start Loc.**	**Start Time**	**End Time**	**End Loc.**	**Mileage**
Fox Lake Overnight - Friday*					
2604	Fox Lake	8:45a	10:22a	CUS	49.5
2607	CUS	12:35p	2:12p	Fox Lake	49.5
2614	Fox Lake	2:45p	4:22p	CUS	49.5
2615	CUS	4:35p	6:12p	Fox Lake	49.5
Fox Lake Overnight - Sunday (all day)					198
2104	Fox Lake	5:13a	6:51a	CUS	49.5
2103	CUS	7:01a	8:36a	Fox Lake	49.5
2128	Fox Lake	8:45a	10:22a	CUS	49.5
2113	CUS	10:35a	12;12p	Fox Lake	49.5
2136	Fox Lake	12:45p	2:22p	CUS	53
				Total Sunday:	251
				Total Weekend:	449

*Per Metra Equipment Cycles, C18 finishes Friday with135 miles
Weekend runs possible with overnight refueling at Fox Lake
No Sunday runs, available all day for refueling

Locomotive	C17				
Train no	**Start Loc.**	**Start Time**	**End Time**	**End Loc.**	**Mileage**
Fox Lake Overnight - Friday*					
2604	Fox Lake	8:45a	10:22a	CUS	49.5
2607	CUS	12:35p	2:12p	Fox Lake	49.5
2614	Fox Lake	2:45p	4:22p	CUS	49.5
2615	CUS	4:35p	6:12p	Fox Lake	49.5
Fox Lake Overnight - Sunday				Total Sunday:	198
2110	Fox Lake	6:14a	7:48a	CUS	49.5
2207	CUS	7:58a	9:23a	Big Timber	39.8
2230	Big Timber	9:36a	10:58a	CUS	43.3
				Total Sunday:	132.6
				Total Weekend:	330.6

* Per Metra Equipment Cycles, C17 finishes Friday with 299.4 miles
Weekend runs possible with overnight refueling at Fox Lake
No Saturday runs, available all day for refueling

Assessment of Other Districts

The above assessment is specific to the Milwaukee District, in terms of potential refueling station locations and rough sizing of equipment; and dual fuel locomotive range relative to weekday and weekend operating schedules. What follows is an overview of Metra's other main fueling districts included for information to assist Metra in making an assessment of the feasibility of expanding the refueling infrastructure to the other districts to aid in fleet flexibility. These other district assessments only cover rough sizing and possible locations and limitations for installation of mid-day and overnight refueling equipment and do not evaluate train operation.

Rock Island District

The Rock Island lines were not assessed in as much detail as the Milwaukee District; however, this line would lend itself well to a pilot dual fuel conversion project, owing to the smaller quantity of locomotives (18) and the fewer lines. Two overnight CNG refueling stations and a mid-day refueling station would be needed. The initial cost of CNG refueling at all three locations would be on the order of $7.5M less NRE, site preparation and permitting. Again, coordination would be needed with local gas suppliers to provide the required incoming NG capacity and pressure

Table 20 - Rock Island District Pump Stations/Storage and Costs

Location	Compressors	Dispensing Stations	Storage	Fill Rate	Cost
51st Street Yard	2 (800 hp)	2	5,000 DGE	Fast	$3.5M
Joliet Yard	3 (200 hp)	2	4,000 DGE	Slow	$2.5M
Blue Island Yard	2 (200 hp)	1	2,500 DGE	Slow	$1.5M

Rock Island – Joliet Overnight Layover and Refueling

- 11 trains overnight
- Trains are CNG fueled overnight using CNG slow fill
- Three compressor station and two storage tanks ($2.5M)
- Assume 250 DGE per locomotive or 3,000 DGE of CNG is required, worst case

- Due to space constraints, it appears that alternative options may need to be considered such as the acquisition of additional space.

Figure 58 - Joliet Overnight Layover Location

Rock Island – Blue Island Overnight Layover and Refueling

- 5 trains overnight
- Trains are CNG fueled overnight using CNG slow fill
- Two compressor station and one storage tank ($1.5M)
- Assume 250 DGE per locomotive or 1,500 DGE of CNG is required, worst case

Figure 59 - Blue Island Overnight Layover Location

Rock Island – 51st Street Mid-Day Refueling

For mid-day refueling, a fast fuel CNG refueling station of one half of the size and capacity (2-800 hp compressor stations and 5,000 DGE storage at $3.5M) of the Milwaukee District would be needed. It is understood that Metra is currently undergoing a renovation of this location and an evaluation of equipment placement will need to be performed after modifications are complete.

Figure 60 - Rock Island Mid-Day Refueling Location

UP and BNSF Districts

The Milwaukee and Rock Island Districts combined use nearly 9 million gallons of diesel fuel annually so there is a potential to reduce diesel fuel usage by up to 6 million gallons and potentially save $8M. However, the UP and BNSF districts consume over 16 million gallons of diesel fuel annually. Their combined locomotive fleet also makes up over 2/3 of Metra's fleet and consists of Metra's oldest locomotives, the majority of which are at the end of their life. It is expected that Metra will prioritize these locomotives for replacement with either new or substantially overhauled and upgraded locomotives.

It is unclear what Metra's overall plan is for replacement or upgrading of their F40 fleet. The scenario created for the Milwaukee District utilizes 38 of Metra's newest locomotives for dual fuel conversions which still have at least half of their usable life. For the remainder of their locomotive fleet of over 100 F40's, Metra may choose to procure new Tier 4 diesel powered locomotives which would result in substantially lower exhaust emissions and reduced fuel consumption, due to exhaust after treatment and the more efficient high-speed Cummins and Caterpillar prime mover engines. Dual fuel conversion may not be an option for these newer generation locomotives as the leading manufacturers (namely Siemens and Progress Rail) do not offer this option for their prime mover engines. Suitable used locomotives from other sources may be difficult to acquire for dual fuel conversion and would also likely require a major overhaul in order for Metra to obtain 15 – 20 years of usable life, adding $2.5-$3M per unit to the cost of acquisition and CNG conversion. The potential benefit of full dual fuel conversion to Metra is a reduction in diesel fuel usage of approximately 16 million gallons CNG substitution at a potential annual savings of over $20M.

Table 21 - UP District Pump Stations/Storage and Costs

Location	Compressors	Dispensing Stations	Storage	Fill Rate	Cost
OTC	2 (800 hp)	2	10,000 DGE	Fast	$4.5M
M19A	2 (800 hp)	2	10,000 DGE	Fast	$4.5M
Elburn	3 (200 hp)	2	4,000 DGE	Slow	$2.5M
Barrington	2 (200 hp)	1	2,500 DGE	Slow	$1.5M
Crystal Lake	2 (200 hp)	1	2,500 DGE	Slow	$1.5M
McHenry	2 (200 hp)	1	2,500 DGE	Slow	$1.5M
Harvard	2 (200 hp)	1	2,500 DGE	Slow	$1.5M
Waukegan	2 (200 hp)	1	2,500 DGE	Slow	$1.5M
Kenosha	2 (200 hp)	1	2,500 DGE	Slow	$1.5M

Table 22 - BNSF District Pump Stations/Storage and Costs

Location	Compressors	Dispensing Stations	Storage	Fill Rate	Cost
14th Street	3 (800 hp)	2	10,000 DGE	Fast	$6M
Orland Park	2 (200 hp)	1	2,500 DGE	Slow	$1.5M
Manhattan	2 (200 hp)	1	2,500 DGE	Slow	$1.5M
Aurora	3 (200 hp)	2	4,000 DGE	Slow	$2.5M

UP – OTC Mid-Day and Overnight Refueling

- 5 trains overnight
- Trains are CNG fueled during the day and overnight using CNG fast fill
- Two compressor station and four storage tanks ($1.5M)
- Due to space constraints, it appears that alternative options may need to be considered such as the purchase of additional space or the use of street level space.
- Assume 250 DGE per locomotive or 10,000 DGE of CNG is required, worst case

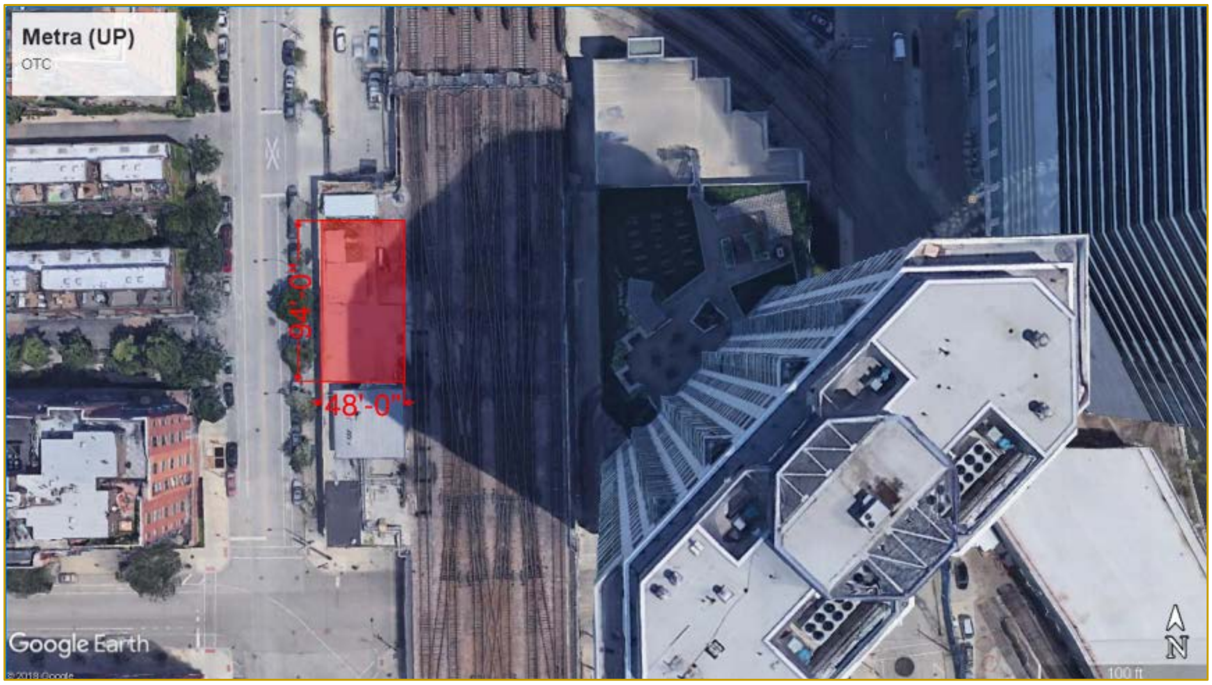


Figure 61 - UP OTC Refueling Location

UP – M19A Mid-Day Refueling

- Trains are CNG fueled during the day using CNG fast fill
- Two compressor station and four storage tanks ($4.5M)
- Assume 250 DGE per locomotive or 10,000 DGE of CNG is required, worst case.

Figure 62 - M19A Refueling Location

UP – Elburn overnight layover and refueling

- 11 trains overnight
- Trains are CNG fueled overnight using CNG slow fill
- Three compressor station and two storage tanks ($2.5M)
- Assume 250 DGE per locomotive or 3,000 DGE of CNG is required, worst case

Figure 63 - Elburn Overnight Layover and Refueling Location

UP – Barrington Overnight Layover and Refueling

- 4 trains overnight
- Trains are CNG fueled overnight using CNG slow fill
- Two compressor station and one storage tank ($1.5M)
- Assume 250 DGE per locomotive or 1,500 DGE of CNG is required, worst case

Figure 64 - Barrington Overnight Layover and Refueling Location

UP – Crystal Lake Overnight Layover and Refueling

- 6 trains overnight
- Trains are CNG fueled overnight using CNG slow fill
- Two compressor station and one storage tank ($1.5M)
- Assume 250 DGE per locomotive or 2,000 DGE of CNG is required, worst case.

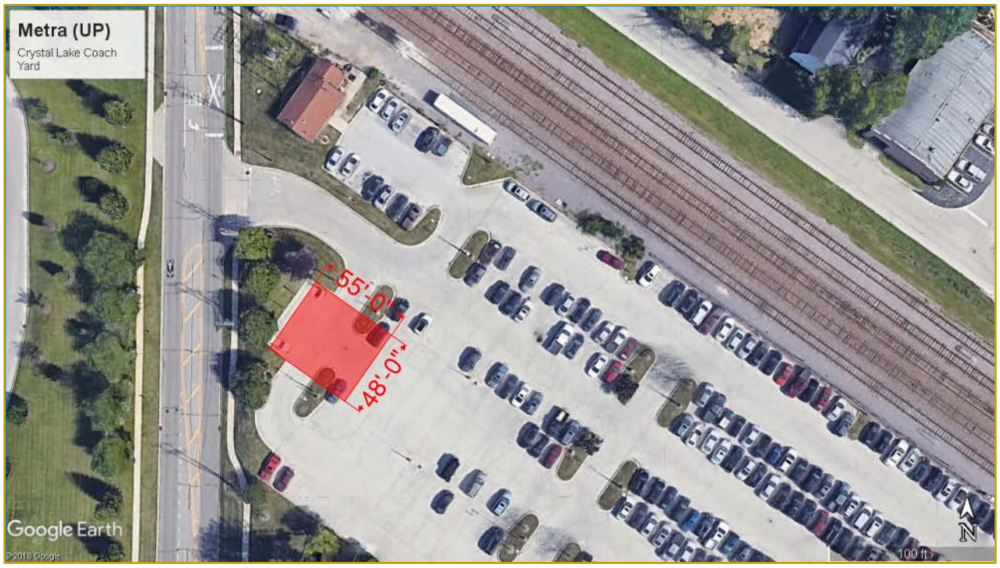


Figure 65 - Crystal Lake Overnight Layover and Refueling Location

UP – McHenry Overnight Layover and Refueling

- 2 trains overnight
- Trains are CNG fueled overnight using CNG slow fill
- Two compressor station and one storage tank ($1.5M)
- Assume 250 DGE per locomotive or 1,000 DGE of CNG is required, worst case

Figure 66 - McHenry Overnight Layover and Refueling Location

UP – Harvard Overnight Layover and Refueling

- 4 trains overnight
- Trains are CNG fueled overnight using CNG slow fill
- Two compressor station and one storage tank ($1.5M)
- Assume 250 DGE per locomotive or 1,500 DGE of CNG is required, worst case

Figure 67 - Harvard Overnight Layover and Refueling Location

UP – Waukegan Overnight Layover and Refueling

- 7 trains overnight
- Trains are CNG fueled overnight using CNG slow fill
- Assume 250 DGE per locomotive or 2,500 DGE of CNG is required, worst case.
- Two compressor station and one storage tank ($1.5M)

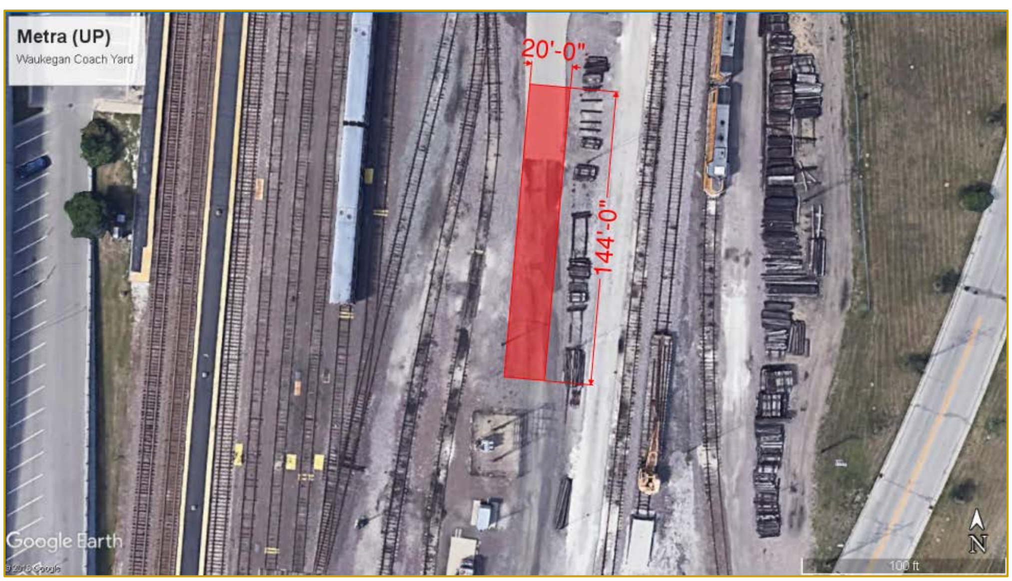


Figure 68 - Waukegan Overnight Layover and Refueling Location

UP – Kenosha Overnight Layover and Refueling

- 5 trains overnight
- Trains are CNG fueled overnight using CNG slow fill
- Assume 250 DGE per locomotive or 2,000 DGE of CNG is required, worst case.
- Two compressor station and one storage tank ($1.5M)

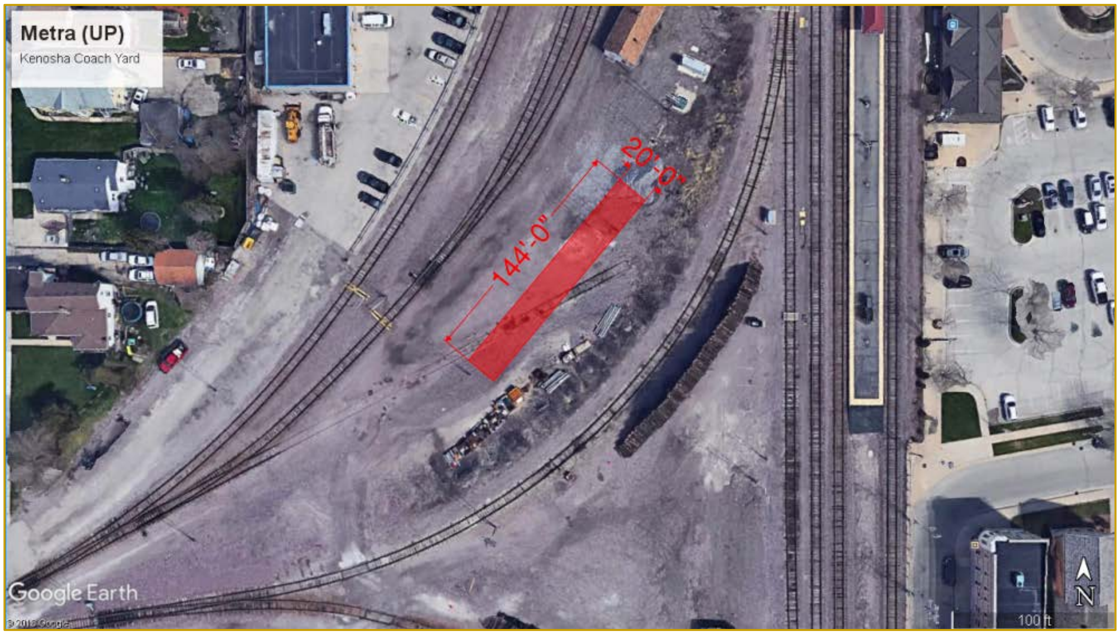


Figure 69 - Kenosha Overnight Layover and Refueling Location

BNSF – 14th Street Mid-Day Refueling

- Trains are CNG fueled during the day using CNG fast fill
- Three compressor station and four storage tanks ($6M)
- Assume 250 DGE per locomotive or 10,000 DGE of CNG is required, worst case

Figure 70 - 14th Street Refueling Location

BNSF – Orland Park Overnight Layover and Refueling

- 3 trains overnight
- Trains are CNG fueled overnight using CNG slow fill
- Two compressor station and one storage tank ($1.5M)
- Assume 250 DGE per locomotive or 1,500 DGE of CNG is required, worst case

Figure 71 - Orland Park Overnight Layover and Refueling Location

BNSF (SWS) – Manhattan Overnight Layover and Refueling

- 2 trains overnight
- Trains are CNG fueled overnight using CNG slow fill
- Assume 250 DGE per locomotive or 1,500 DGE of CNG is required, worst case.
- Two compressor station and one storage tank ($1.5M)

Figure 72 - Manhattan Overnight Layover and Refueling Location

BNSF – Aurora Overnight Layover and Refueling

- 19 trains overnight
- Trains are CNG fueled overnight using CNG slow fill
- Assume 250 DGE per locomotive or 5,000 DGE of CNG is required, worst case.
- Three compressor station and two storage tanks ($2.5M)

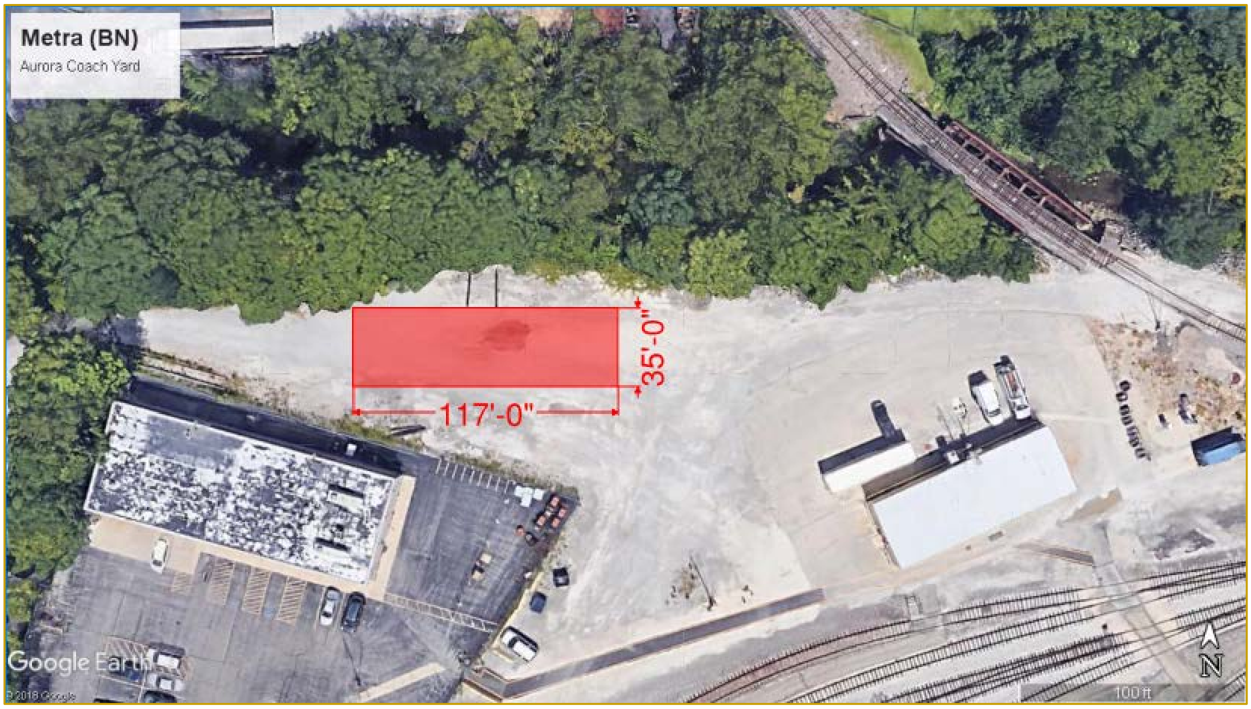


Figure 73 - Aurora Overnight Layover and Refueling Location

Metra Maintenance Facility Evaluation for CNG Operation

Introduction

The following section provides preliminary observations and recommendations for adaptation of the Metra Milwaukee District (Western Avenue) shop and Rock Island (47th Street) shop to a future fleet of CNG locomotives. This is not meant to be an exhaustive list of design criteria and that the next step would require a specific programming of each facility by architectural, structural, mechanical, electrical, and life safety designers as part of a future detailed design effort for facility upgrades.

The recommendations provided for the two Metra facilities are analogous to the BNSF 14th Street and Union Pacific M-19-A facilities as well. It should be noted that fueling of CNG within M-19-A would not be recommended as the indoor fueling operation would require even more restrictive requirements than those for a maintenance facility; M-19-A CNG fueling would need to be outdoors.

The Metra maintenance facilities are located within the City of Chicago, as such the Authority Having Jurisdiction (AHJ) for permitting and approval is the City of Chicago Department of Buildings. Future design teams will need to compile a code compliance matrix (as part of the design effort) to verify the changes against the prevailing Chicago Building Code (including the Chicago Electrical Code), NFPA 30A (Motor Fuel Dispensing Facilities and Garages), and NFPA 52 (Vehicular Gaseous Fuel Systems Code). It is strongly recommended that the chosen design team establish communication with the permitting authority during the programming and design process to ensure proper treatment of specific areas within the facilities:

- **Class I, Division 1 – Electrical Hazard Zone:** expected to contain hazardous concentrations of gases (or vapors) in the event of a spill (or leak) which must be provided with ignition source protection.
- **Class I, Division 2 – Electrical Hazard Zone**: may contain hazardous concentrations of gases (or vapors) and must be protected. For compressed natural gas vehicle maintenance facilities, Class I, Division 2 classification is utilized for conditions in which methane releases could occur but are not expected. This would be the case for an unexpected on-board fuel line leak.

A maintenance facility which services CNG-powered vehicles requires particular safety measures and equipment. CNG is composed of mostly methane gas (CH_4) with other trace hydrocarbons. As CNG is lighter than air, leaked gas will rise to the ceiling of a facility and dissipate. However, if concentrations of 5%-15% by volume of natural gas meet with an ignition source (spark or high temperature surface), a point of combustion may occur, with serious consequences. It should be understood however, that natural gas does have a propensity to dissipate rapidly. Additionally, the Lower Flammability Limit of CNG is higher than other fuels. With those considerations, facilities which maintain CNG vehicles do require different considerations which may not be needed in a traditional diesel fueled vehicle maintenance facility. Further, placement and protection of building systems may differ.

Compound	Formula	Density (lb/ft³) Gases at STP	Auto-Ignition Temperature (°F)	Lower Flammability Limit (LFL) (%)	Upper Flammability Limit (UFL) (%)
CNG (Methane)	CH_4 (majority)	0.0447	1,004	5.3	15.0
Propane	C_3H_8	36.2	850–950	2.2	9.5
Gasoline	C_8H_{18}	46.4	495	1.4	7.6
Diesel	–	52.4	600	1.0	6.0
Hydrogen	H_2	0.0056	1,050–1,080	4.1	74.0
Air	–	0.0806	–	–	–

Figure 74 - Specific Properties of Fuels (from the CNG Vehicle Maintenance Facility Modification Handbook)

General Facility Requirements

Facility Use and Classification

The first step in determining the scope of facility modifications is to perform an assessment of the current and intended use. NFPA 30A (Section 3.3.12) provides the following definitions:

- **Major Repair Garage:** A building or portions of a building where major repairs, such as engine overhauls, painting, body and fender work, and repairs that require draining of the motor vehicle fuel tank are performed on motor vehicles, including associated floor space used for offices, parking, or showrooms.
- **Minor Repair Garage:** A building or portions of a building used for lubrication, inspection, and minor automotive maintenance work, such as tune-ups, replacement of parts, fluid changes (e.g., oil, antifreeze, transmission fluid, brake fluid, air conditioning refrigerants, etc.), brake system repairs, tire rotation, and similar routine maintenance work, including associated floor space used for offices, parking, or showrooms.

While the definitions provided above are primarily intended for automotive repair facilities, they are analogous to locomotive maintenance facilities as far as an AHJ is concerned. To further clarify, any work that involves service to a vehicle's fuel system is not permitted in a "minor" maintenance facility; if any work which would be classified as "major" will be performed within the facility or space, it must then be classified as a "major" repair facility regardless of the frequency and scale of the activity. The distinction between "major" and "minor" repair facilities become critical as they define the scope of building modifications.

The Metra locomotive facilities will need to be considered as "major" as each of the locomotive shops is capable to perform not only prime mover repair but specific fuel system repairs currently. It is not foreseen that this will change with a CNG locomotive fleet as the logistics to shuttle locomotives between districts to reach a heavy maintenance facility will become burdensome. Within the locomotive shop, as the space is open between bays and tracks and due to facility flexibility, the major repairs are assumed to be performed on any track requiring the entire shop area to be considered as "major".

Location Classification

Within the maintenance facility specific areas shall be designated according to the Class 1, Division 2 or unclassified requirements of NFPA 30A and National Electrical Code (NEC) 2017 Table 511.3(D):

- **Class I, Division 2** - **Repair garage, major** (where lighter-than-air gaseous fielded vehicle are repair or stored): Within 450 mm (18 in.) of ceiling (except as noted below)
- **Unclassified locations** – **Repair Garage major** (as described above): Within 450 mm (18 in.) of ceiling where ventilation of at least 0.3 $m^3/min/m^2$ (1 $ft^3/min/ft^2$) of floor area, with suction taken from a point within 450 mm (18 in.) in the ceiling
- **Unclassified locations – specific areas adjacent to classified locations:** Areas adjacent to classified locations where flammable vapors are not likely to be released such as stock rooms, switchboard rooms, and other similar locations, where mechanically ventilated at a rate of four or more air changes per hour or designed with positive air pressure, or where effectively cut off by walls or partitions

The location classifications are critical to determining the type and location of electrical equipment and ventilation treatment required. It is suggested that Metra require a thorough inspection of each facility during the programming phases of design in order to properly designate each applicable location.

Paths of Migration

As CNG is composed of methane (CH_4) with trace hydrocarbons and is lighter-than-air, escaped CNG will rise rapidly to the ceiling of an enclosed space upon leak/release from a pressurized tank or pipeline. When this release occurs, the CNG accumulates at the ceiling before dissipation throughout the building, losing concentration. This evacuation through the building is called the "path of migration." At the ceiling level, gas may accumulate to above 5% (Lower Flammability Limit – LFL) concentration by volume. The first line of defense is to design/modify the maintenance facility to properly ensure that the ventilation system exhausts the gas as quickly as possible to prevent concentrations in the combustible range and that ignition sources are not present within the Class I, Division 2 locations.

However, even with suitable ventilation and mitigation of ignition sources, dissipated gas may travel and accumulate in unintended spaces. For example, gas may accumulate in unsealed pipe and conduit penetrations in walls and ceilings or openings for structural members such as joists and beams. These penetrations need to be protected either by means of a sealant, barriers, or pressurization (from the adjacent space), see Figure 75 for an example of sealed penetrations through a masonry wall.

Figure 75 - Example of Sealed Penetrations

Paths of migration are not limited to small openings; doors with louvers, low walls, stairways and passageways to upper levels may also serve as a path of migration. Mitigation means which may need to be considered are doors equipped with automatic closing mechanisms as well as documented protocols and signage for building occupants to follow.

Ventilation Considerations

Adequate air exchanges with the major repair area(s) of maintenance facility are critical for mitigation of the hazard presented by accumulated gas at the ceiling level. Mechanical ventilation is necessary to provide the required air flow within the facility area. Ventilation also plays a key role in directing escaped gas to detection systems, which in-turn trigger alarms and lock-out of other systems.

It should be noted that the approach discussed with this document are prescribed by NFPA (National Fire Protection Association) through related code documents such as NFPA 30A. There is a supplemental, or alternate, guidance document – the International Fire Code which covers the design of vehicle maintenance facilities. NFPA 30A and the IFC do differ on the requirements for ventilation. The ventilation requirements will need to be verified with the AHJ during the design process. Figure 76 shows some examples of blowers and fans which may be considered.

Figure 76 - Sample Catalog for Blower Fans

International Fire Code (IFC) Ventilation

The IFC stipulates that major repair facilities require a ventilation rate of one cubic foot-per-minute (cfm) for every 12 cubic feet of structure space which is equivalent to approximately five air exchanges per hour (ACH). IFC provides the following options for ventilation control:

- Continuously
- Continuously, while the space is occupied via interconnection with the lighting system
- Upon demand for air dilution, which is triggered by the gas detection system

For the purposes of a major CNG vehicle repair facility, the owner may choose the third option in order to reduce energy costs. However, Metra may consider that diesel locomotive repair facilities already have a prescribed amount of air exchanges per hour for engine exhaust. Agreement with the AHJ is critical during the design process.

National Fire Protection Association (NFPA) 30A Ventilation

The NFPA 30A approach is toward sources of gas ignition in the 450 mm (18 in.) below the ceiling line as this area is classified as a Class I, Division 2 location. This area may be designated as “unclassified” if the structure space has an effective continuous ventilation rate of at least 4 ACH. The electrical devices and appliances within a Class I, Division 2 location will need to be relocated or replaced with ones rated for that location type service. If the air exchanges can be accomplished, with a suction taken within 450 mm (18 in.) from the highest point in the ceiling, then electrical devices and appliances not rated for Class I, Division 2 may be allowed (with AHJ approval).

It should be noted that NFPA 30A does not address ventilation control like the IFC does. Accordingly, the AHJ may reference IFC and require a specific control requirement for ventilation. Further, it should be noted that if the third option of IFC is selected (gas detection system triggering), then the electrical devices within the 450 mm (18 in.) ceiling location will need to be removed, relocated, or replaced with ones rated for Class I, Division 2.

It should be further noted that an AHJ may require a building owner to meet the most stringent requirements of both IFC and NFPA 30A, requiring the ventilation system to be sized for 5 ACH. This will need to be determined during the design programming process.

Ventilation Means

The means of ventilation may be achieved through various methods. These will need to be determined specifically for each facility. It may be possible that additional roof-top upblast fans are required to augment the existing ventilation system. Existing upblast fans, if equipped, and new fans will need to be rated for Class I, Division 2 locations (for example, as described in NFPA 70E (NEC), Article 501.125 – Motors and Generators).

The ventilation system control may depend on existing or needed additional provisions for make-up air. The specific make-up air requirement will need to be determined for each facility.

Specific strategies for structure ventilation will need to be reviewed between the design engineer, Metra, and the AHJ. For example, for reduced energy costs Metra may elect to operate the ventilation system only when triggered by the gas detection system; however, as stated above, non-rated electrical equipment within the Class I, Division 2 zone needs to be relocated, removed, or replaced. Otherwise the ventilation system will need to be active at all times when the CNG locomotives are in the facility – which may increase energy and heating costs.

Heating Considerations

The heating system within the maintenance facility, particularly within the CNG locomotive maintenance area needs to be carefully reviewed for compliance. NFPA 30A (Section 7.6.6) clearly identifies that open flames or heating equipment with exposed surfaces having a temperature in excess of 399°C (750°F) shall not be permitted in areas subject to ignitable gas concentrations. It should be noted that all heating devices within the space (regardless of distance from ceiling) would be subject to this restriction and separate space heaters would not be allowed.

Typical heaters found within locomotive maintenance facilities which would require review are gas-fired infrared tube heaters running throughout the building, gas-fired fan blowers at bay doors, and electric infrared radiant heaters above walkways. These types of heaters would be prohibited within a CNG locomotive maintenance facility. An example of typical heaters seen within a non-CNG maintenance facility (and typical to locomotive facilities) is shown in Figure 77.

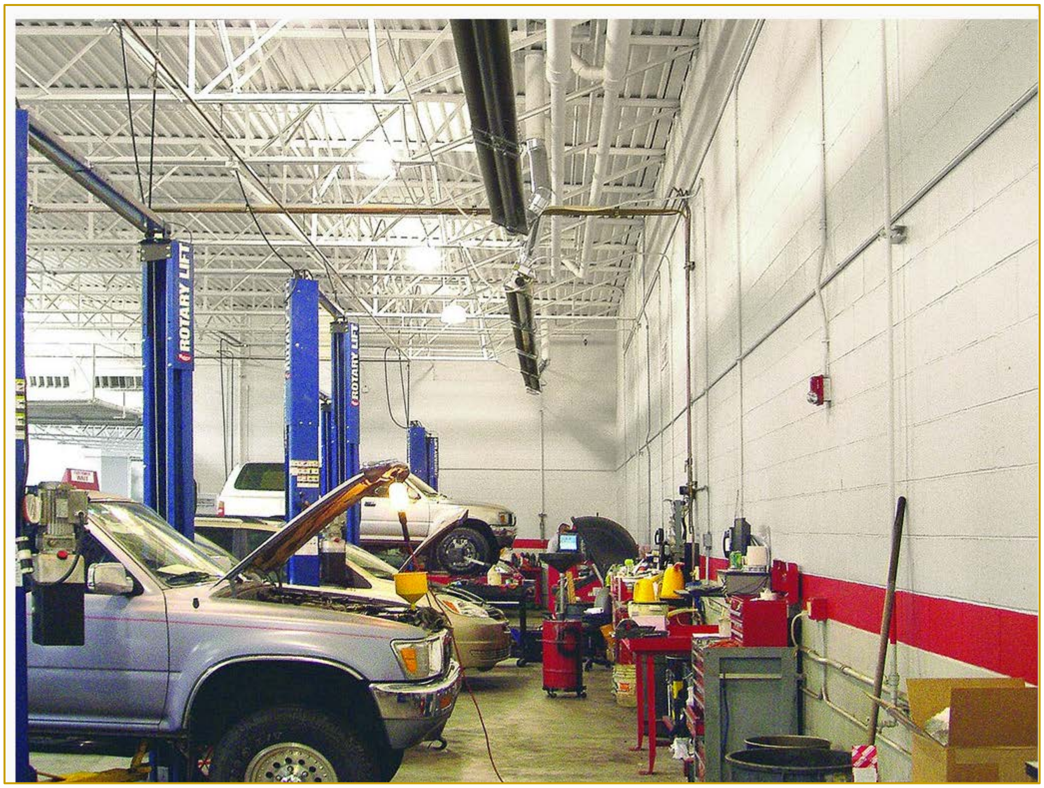


Figure 77 - Example of Infrared Tube Heaters

Gas-fired infrared tube heaters would need to ensure that any flames are enclosed and that the surface temperature is maintained below 399°C (750°F). For facilities with steam heat, review of blower-type heaters would be needed to ensure motors are rated for Class I, Division 2 service. An example of a heater designed for specialty fuel (CNG/LNG) vehicle repair shops is shown in Figure 78.

Figure 78 - Example of Compatible Infrared Tube Heater (Roberts Gordon Corayvac™)

Electrical and Installation Considerations

Electrical luminaires and appliances may present a risk of ignition in the presence of methane within the combustion range. Fault sparks as well as expected sparks may serve as the ignition point.

Conduits

Conduits may present a hazard as a fault (short) within a conduit may serve as a spark. Further, conduits present a risk of allowing gas to migrate from one area of a facility to another and therefore must be sealed.

As NFPA 30A designates the space of 450 mm (18 in.) from the top of the ceiling as Class I, Division 2, the electrical appliances within that space shall need to be rated accordingly or relocated. Conduits and junction boxes shall need to be explosion-proof and sealed. Investigation will be needed to determine if existing conduits may be sealed to prevent methane gas migration within – however NFPA 70E (NEC) Article 501.15(B) defines conduit seals for Class I, Division 2 locations. Specifically, seals are required within 3.05 m (10 ft.) of the Class I, Division 2 location boundary. Further, rigid metal conduit or intermediate threaded conduit shall be used between the sealing fitting and the point at which the conduit leaves the Class I, Division 2 location, and a threaded connection shall be used at the sealing fitting. The conduit run between the conduit seal and the point at which the conduit leaves the Class I, Division 2 location shall contain no union, coupling, box, or other fitting except for a listed explosion-proof reducer installed at the conduit seal.

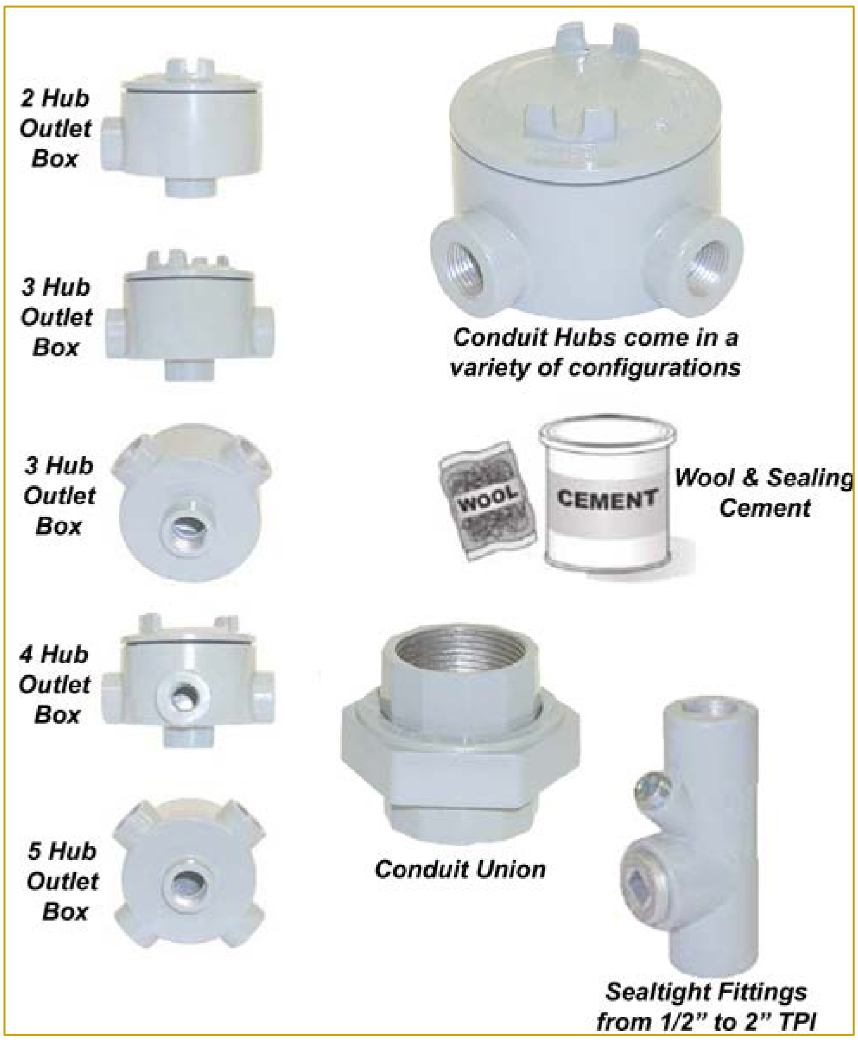


Figure 79 - Example of Conduit Fittings and Sealing Required for Class 1 Locations

Non-Insulated / Exposed Parts

NFPA 70E (NEC) Article 501.25 stipulates that there shall be no un-insulated or exposed parts such as conductors, terminals, buses, etc. that operate at more than 30V and shall need to be protected by a design scheme which renders the circuit as intrinsically safe (as defined in NEC Article 504), nonincendive circuit, or nonincendive system. For a locomotive maintenance facility, this will particularly apply for overhead crane exposed contact rails. Verification of the contact rails to the ceiling height will be critical for each facility by the design team in order to determine the best mitigation means.

Grounding

NFPA 70E (NEC) Article 501.30 provides some additional guidelines for equipment grounding within a Class I, Division 2 location. Specifically, bonding jumpers are required for raceways, fittings, boxes, and enclosures.

Surge Protection

NFPA 70E (NEC) Article 501.35 (B) provides requirements for surge arrestors allowed in Class I, Division 2 locations. Non-arcing devices shall be permitted.

Switches, Circuit Breakers, Motor Controllers, and Fuses

NFPA 70E (NEC) Article 501.115 (B) provides the requirements for switches, circuit breakers, motor controllers, and fuses which may be located in Class I, Division 2 locations. The article requires that these devices be installed within enclosures rated for Class I, Division 1 locations; however, general purpose enclosures may be allowed if any of the following conditions are met:

- Interruption of current occurs in a chamber that is hermetically sealed against the entrance of gasses or vapors
- Current make/break contacts are oil immersed
- Interruption of current occurs within an enclosure identified for the location and marked as “Factory Sealed”, “Seal Not Required”, etc.
- Solid state switching devices are used and the surface temperature of the device does not exceed 80% of the auto-ignition temperature of the gas involved

Specific to fuses, standard fuses are permitted if located within an enclosure rated for the location, otherwise hermetically sealed types must be used.

In a locomotive maintenance facility, it may not be usual to expect contactor and fuse enclosures at the ceiling level, however specific site surveys shall be needed to capture any of these devices by a design engineer.

Rotating Equipment

NFPA 70E (NEC) Article 501.125 (B) provides the requirements for motors, generators, and other rotating electrical machinery rated for Class I, Division 2 locations. Rotating equipment is allowed in the location if any of the following conditions are met:

- Identified for Class I, Division 2 locations
- Identified for Class I, Division 1 where sliding contacts, centrifugal switching mechanisms, or integral resistance devices (while starting or running are employed)

- Be open or non-explosion proof motors such as squirrel-cage motors without brushes, switching mechanisms, or other arc-producing components that are not listed for Class I, Division 2 locations

Figure 80 - Example of Class I, Division 2 Rated Motor Nameplate

These devices shall also comply with both of the following (as applicable):

- Exposed surface of space heaters used to prevent condensation of moisture shall not exceed 80% of the auto-ignition temperature of the gas involved
- Sliding contact shaft bonding device used for the purpose of grounding the rotor shall be permitted where the potential discharge energy is considered nonincendive for the application

NFPA 70E (NEC) Article 501.125 (B) also provides an informational note with reference to *IEEE 1349-2001, IEEE Guide for the Application of Electric Motors in Class I, Division 2 and Class I, Zone 2 Hazardous (Classified) Locations*. It should be further noted that the design of a motor for the location is critical. The design considers that the enclosure shall need to be explosion-proof, the internal fan is a non-sparking material type, and cable terminal housings are rated for the location.

Luminaires

NFPA 70E (NEC) Article 501.130 (B) provides guidance for the selection of luminaires rated for Class I, Division 2 locations. NFPA 30A also stipulates that luminaires must be explosion-proof. It is recommended that luminaires be moved away (lowering) from the ceiling, out of the Class I, Division 2 location as the simplest solution. If the luminaires cannot be moved, then they will need to comply with the following:

- Sealed and gasketed explosion-proof enclosure
- Be of a type tested to ensure that the external temperatures shall not exceed 80% of the auto-ignition temperature of the gas involved
- Protected from physical damage by suitable guards or location
- Pendant luminaires are required to be suspended by threaded rigid metal (or threaded intermediate metal) conduit stems
- Stems longer than 300 mm (12 in.) shall require lateral bracing

Locomotive maintenance facilities typically are equipped with high-bay pendant luminaires. As stated above the primary strategy should be to lower the fixtures; this approach should be checked with the AHJ during the design programming process. An example of a luminaire rated for Class I, Division 2 locations is shown in Figure 81.

Figure 81 – Example of Class I, Division 2 Rated Luminaire – Hubbell CLH

Signaling, Alarm, Remote-Control, and Communications Systems

NFPA 30A designates that low-voltage wiring, containing conduits (although still required to be sealed to prevent migration of gas to other locations) may be exempt from the requirements of Class I, Division 2 locations if non-sparking; however, this will require specific approval by the AHJ. NFPA 70E (NEC) Article 501.150 (B) provides guidelines for the selection of low voltage equipment that may be used within the Class I, Division 2 location. The simplest option may be to relocate low voltage equipment not rated for Class I, Division 2 locations away (lowering) from the ceiling level.

Interlocking and Other Considerations

While the main focus of a maintenance facility may be in the Class I, Division 2 location, an AHJ may require some additional modifications external to that location and within the structure. The following are examples which may be followed by a design engineer during the programming stages:

- Interlocking of bay doors to a methane detection system – automatically open all bay doors if considerable levels of methane are detected
- Interlocking (shunt-tripping) of overhead cranes to a methane detection system – automatically remove crane power if considerable levels of methane are detected
- Interlocking (shunt-tripping) of other building loads to a methane detection system
- Electrical devices outside of the Class I, Division 2 location may require modification – explosion-proof enclosures may be required

Gas Detection and Warning Systems

NFPA 30A specifically describes that "repair garages used for the repair of vehicle engine systems fueled by <u>non-odorized</u> gases shall be provided with an approved flammable gas detection system." [underline added for emphasis]. While this may indicate that a gas detector may not be necessary for CNG-powered vehicle maintenance facilities, an AHJ may require the detectors regardless. For the purposes of planning, a gas detection system should be assumed in the basis for design for locomotive maintenance facility modifications.

NFPA 30A provides requirements for the design of the gas detection system – activate when the level of flammable gas exceeds 25% of the lower flammable limit (LFL). Upon detection of the gas level, the detection and warning system (associated with the sensors) shall perform all of the following actions:

- Initiate distinct audible and visual alarm signals in the facility
- Deactivate the heating systems in the facility
- Activate the mechanical ventilation system, interlocked with the detection system

NFPA 30A further describes the steps required if there is a failure of the gas detection system:

- Deactivate the heating systems in the facility
- Activate the mechanical ventilation system
- Where the ventilation system is interlocked with the gas detection system, generate a fault signal to be generated in an approved location

As can be seen, these requirements provide significant leeway for an AHJ to provide further guidance. Design and interlocking of the gas detection system should be thoroughly reviewed with an AHJ during the design programming phase. As noted above, NFPA 30A doesn't strictly require this type of system for a CNG facility (assuming the natural gas used contains Mercaptan, odorizing agent); however, it is strongly recommended for safety reasons, and may be required by not only the AHJ but other external stakeholders such as insurance underwriters, neighboring communities, etc.

Detector Types and Considerations

The Compressed Natural Gas Vehicle Maintenance Facility Modification Handbook (United State Department of Energy, 2017) provides some guidance toward integration of gas detection sensors within a maintenance facility. The sensors are typically installed at the highest point of the ceiling level. Two types of detectors are primarily utilized:

- Catalytic bead: these types of detectors require periodic replacement of internal components and more frequent calibration cycles; this may prove challenging within a high bay locomotive maintenance facility
- Infrared: these types of detectors are available in two varieties:
    - Point monitoring: where a specific location, point, in the ceiling is monitored for methane gas levels
    - Beam monitoring: where a specific path, beam, is monitored for the presence of methane gas

It should be noted that there is no "standard" approach for the layout and selection of sensors within a facility – the exact layout will need to be determined during the design programming stages with input from the AHJ. One important consideration is calibration of the sensors. Exact calibration schedules are dependent on individual equipment suppliers, but it may be as frequent as every 12 months. For this reason, a separate tube is suggested for calibration gas to be provided. An example from the Emerson SC311 Infrared Combustible Gas Sensors manual is provided below in Figure 82.

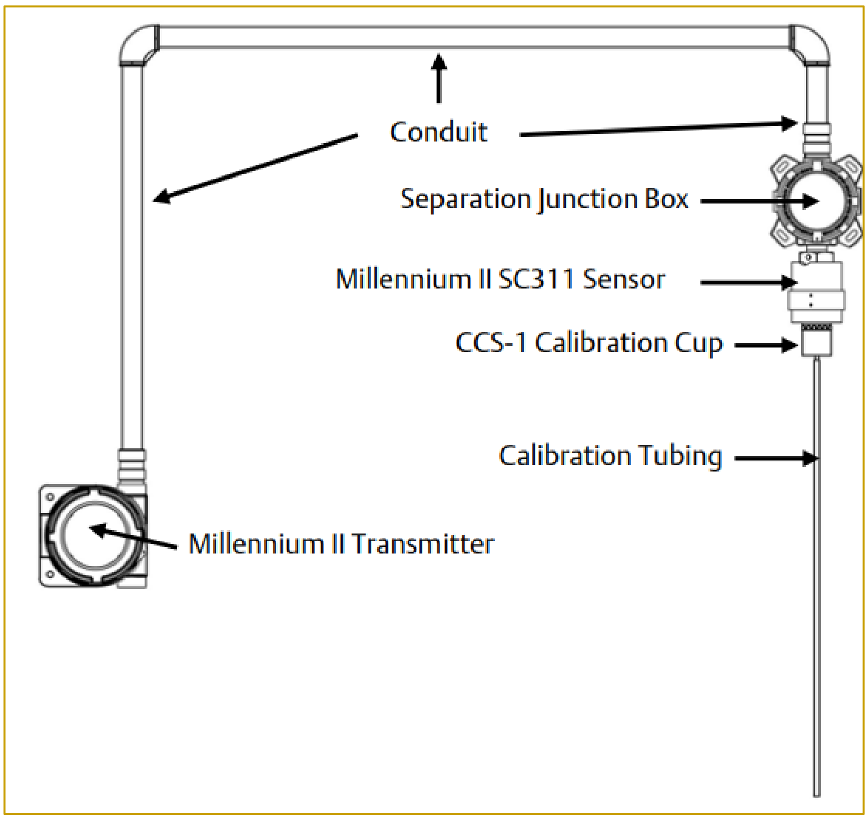


Figure 82 - Example of Infrared Gas Detector Installation Diagram – Emerson Millennium II

Sensor Calibration

Calibration is performed via a pressurized handheld vessel connected to the calibration tube, allowing pre-mixed trace methane levels to be sent to be piped to the sensor. Careful consideration of the calibration tubing length will be needed for the tubing length to account for gas flow rates. The calibration must be performed in order to determine the accuracy of the 25% reading of the LFL, as recommended by NFPA 30A.

In addition to the yearly calibration, manufacturers may recommend an even more stringent "bump test" schedule (e.g. quarterly). This will include a visual inspection, and application of a known gas concentration to simulate an alarm condition. If the bump test does not provide the alarm response, then a calibration may need to be performed, followed by another bump test for verification.

For a locomotive maintenance facility with high bay ceilings quarterly bump tests and annual calibrations may pose a real challenge based on the calibration tube length. These activities may still require the use of a lift or bucket truck – as well as replacement of sensor elements.

Further, deposits of dirt, soot, and other particulates may present challenges for sensors – reaffirming the need for bump tests and calibrations.

Warning Systems

The building warning / control system which the sensors are integrated with may be required to facilitate specific actions such as visible and audible alarms, triggering of ventilation systems, and shunt trip of heating systems as noted in this document. The Compressed Natural Gas Vehicle Maintenance Facility Modification Handbook (United State Department of Energy, 2017) provides an example table of conditions and LFL levels for two stages of detection, as shown in Figure 83 below.

	Methane Gas Concentration Level		
Condition	**Normal**	**20% LFL**	**40% LFL**
Operation Lights – Green	On	Off	Off
Operation Lights – Amber	Off	On	Off
Operation Lights – Red	Off	Off	On
Warning Horns	Off	On – Level 1	On – Level 2
Strobe Alarms	On	On – Level 1	On – Level 2
Supervisory Advisory	No	Yes	Yes
Fire Department Callout	No	No	Yes
Ventilation Fans	Manual	On	On
Roll-Up Doors/Louvers	Manual	Open	Open
Automatic Gas Valve	Open	Open	Closed
Shunt Trip Building Loads	No	No	Yes
Automatic Reset of System if Fault Clears	N/A	Yes	No – Manual Reset Required

Figure 83 - Example of Two Stage Methane LFL* Detection Scheme (CNG Vehicle Maintenance Facility Modification Handbook)

* "20% LFL" represents 20% of the LFL for methane (LFL is 5% of methane to air mixture); a 20% LFL reading would amount to 1% of overall methane to air mixture.

Specific Observations / Suggestions for Metra Facilities

As NFPA 30A, NFPA 52, and NEC provide code requirements and guidelines for installation, specific considerations are needed for the Metra locomotive maintenance facilities. The following section is not meant to be exhaustive but rather to give initial observations which will serve as a basis for future design work. Specific and complete requirements, recommendations, and design criteria will need to be established in the design programming phase of a facility modification design effort. This work will require the assistance of licensed mechanical, electrical, and fire protection system engineers as well as an architect for possible envelope modifications.

Each of the locomotive maintenance facilities will need to be considered as well as other facilities where locomotives may be expected such as heavy repair facilities (e.g. KYD and 49th St Shop). One consideration for other facilities may be procedural solutions which prevent any locomotive from entering the facility without prior evacuation (defueling) of the CNG within the onboard storage tanks.

Metra Rock Island District – 47th Street Locomotive Shop

The 47th Street locomotive shop is a stand-alone locomotive maintenance facility within the 47th-49th-51st Street complex. The 47th Street locomotive shop is the daily inspection shop for Rock Island District locomotives as well as a heavy maintenance facility for Metra locomotives in general (capital improvements and component replacement activities). The facility is designed as a "dead-end" shop, with space for two locomotives in each bay. The shop has six bays with ramps for daily service and periodic inspections and two bays for heavy maintenance and overhaul activities (although only one is used for locomotive parking). The heavy maintenance bay is equipped with an overhead crane and truck drop table.

Class I, Division 2 Locations

Within the 47th Street locomotive shop, according to the definitions provided by NFPA 30A, the Class I, Division 2 location would be 450 mm (18 in.) from the ceiling levels. It should be noted that this facility has two ceiling levels: high bay ceiling in the heavy maintenance (crane and drop table) area and low bay ceiling for the running maintenance tracks. The high bay ceiling is predominantly one level with glass block windows on the east and west sides. The low bay ceiling has two levels: low ceiling and high ceiling for skylights. As the high ceiling represents the highest points in the ceiling, ventilation and sensor considerations will need to be considered there. However, it may be required to have some sensor capabilities within the low ceiling areas as the change between high and low ceiling is abrupt and pockets of trapped gas may be within the low ceiling in the case of an un-planned release within the facility or dependent on locomotive location along the tracks.

Unclassified Locations

The unclassified locations within the facility, will be the area outside of the 450 mm (18 in.) from the ceiling and adjacent rooms. It should be noted that even in the area below 450 mm (18 in.) from the ceiling, heating considerations as described in this report will need to be considered (no space heaters, no exposed flames, or sparks) and may require the replacement of existing blower motors and overhead door motors.

The adjacent storehouse and train washer bay walls will need to be checked for penetrations into the shop (conduits, pipes, etc.) and sealed accordingly. The electric and machine shop to the west of the heavy maintenance area may require fixed doors. The foremen's office is already physically separated from the maintenance area via a closed door. The lunchroom and lower level doors will need to be verified to ensure physical separation from the maintenance area.

Heating System

The heating system within the facility is steam piping to circular blowers. These blowers are located throughout the building including above the bay doors. The heaters and steam piping are shown in Figure 84. While steam heat itself should not pose a danger for methane, as surface temperature should be at the steam condensing point of 100°C (212°F), the particular blower motor within the assembly will need to be verified if the AHJ deems this to be a risk, particularly in the service bays where the heater is closer to the ceiling level than the heavy maintenance bays. It should be noted that the steam pressure at the boiler outlet was not checked; accordingly, the pressure at the steam trap (in-line with each heater) has not been verified. This is important as the steam pipe may be at a higher temperature than the condensing point at the steam trap. It would not be reasonable to expect this to be in excess of 399°C (750°F) however.

Figure 84 - 47th Street Shop Heaters – Steam Heat / Blowers

Ventilation System

As the facility is currently equipped with only a partial ventilation system for the locomotive exhaust in specific maintenance bays, an entire ventilation system for the facility will need to be developed to accomplish up to 4 ACH, if the design calls for triggering by the methane detection system. The ventilation requirement may need to be met not only with upblast blowers but with forced air from outside.

Lighting

The facility is equipped with traditional pendant high-bay luminaires at the ceiling level. These are of the most interest with regard to the Class I, Division 2 location classification. An example from the heavy maintenance bay is shown in Figure 85. These luminaires may be able to be lowered from the Class I, Division 2 boundary of 450mm (18 in.), however their associated conduits will need to meet the requirements of Class I, Division 2 as described in this report. If the scope of modification requires replacement of conduits, then it may be prudent to replace the luminaires with ones rated for the location and upgrade to modern Light Emitting Diode (LED) type.

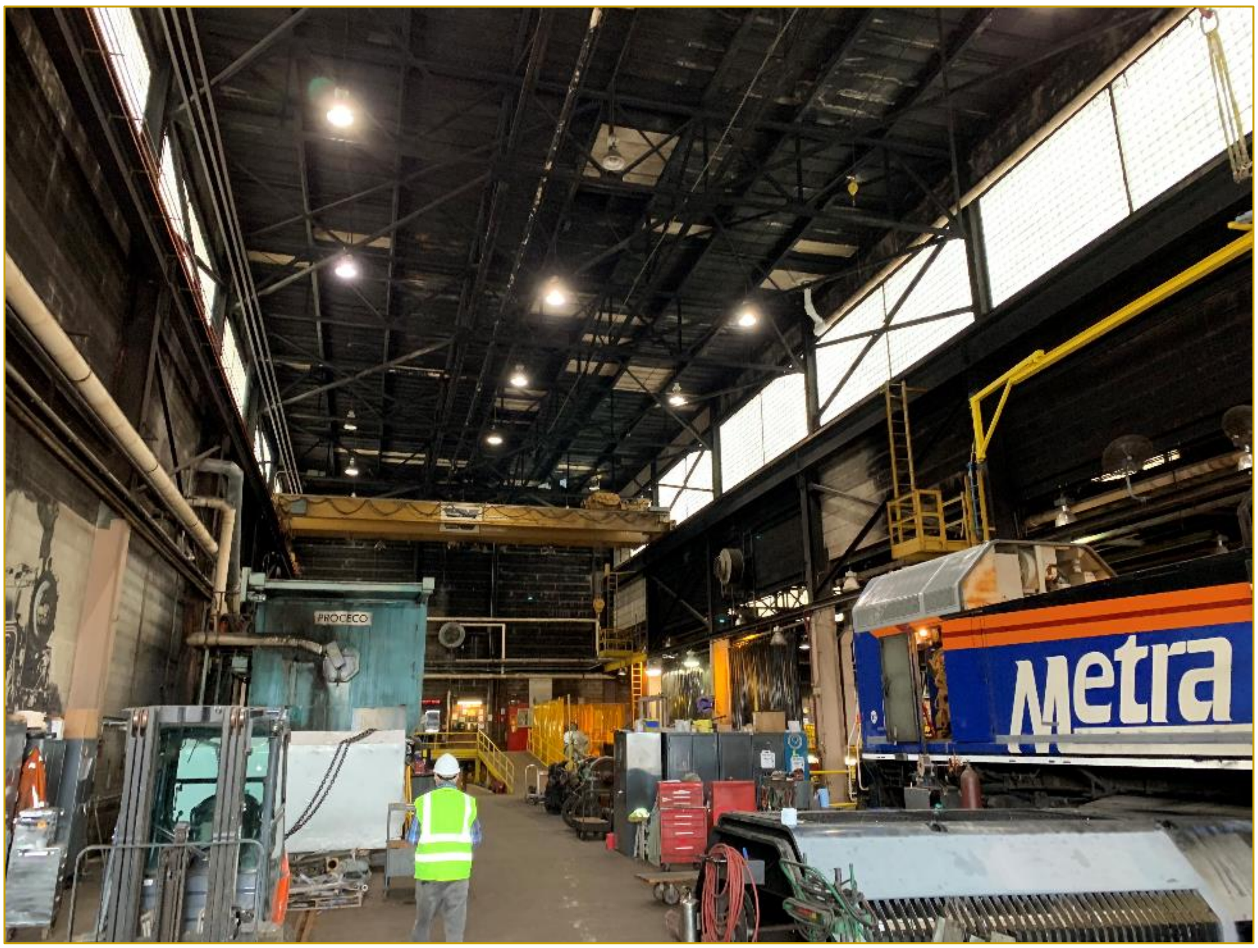


Figure 85 - 47th Street Heavy Repair Bay - High Bay Luminaires

Ceiling Electrical and Conduits

As the lighting in the 47th Street Locomotive shop will need to be lowered outside of the Class I, Division 2 location or replaced with ones listed accordingly, light circuit conduits will need to be replaced with sealed, threaded metallic (intermediate or rigid) type. Conduits for blower fans will also need to be evaluated for specific runs and sealing for conformance to the location requirements.

Other Observations

As described in this report, additional ventilation to meet the required air exchanges will be needed. The 47th Street Locomotive shop does have elevated ceiling sections with windows for natural lighting. These sections can be used for the installation of exhaust fans to facilitate the required air exchanges. As described in this report, interlocking of a methane detection system with bay doors may be required. The bay doors within the 47th Street Locomotive shop are electrified and will require tie-in to the sensor control system.

It should be noted that calibration and inspection of the methane detectors may be a challenge due to the ceiling height, particularly in the high ceiling area. Calibration tube lengths (if used) will need to be verified and coordinated with pressure vessel capacities which may be used for calibration purposes.

Metra Milwaukee District – Western Avenue Locomotive Shop

The Western Avenue Locomotive shop is part of a combined facility, with three bays for coaches and three bays for locomotives. The two portions of the shop are divided by a full partition wall. The facility is designed as "run-through"; fueled locomotives enter the building from the north end for daily service and exit the south end of the shop. The locomotive shop consists of three tracks, two of which are accessible by a ramp and are used for daily and other periodic inspections or running repairs; the other track is used for heavy repairs. One track is used as a heavy-repair and is equipped with a truck drop table. An overhead crane has access to the three tracks within the locomotive facility.

Each bay door is equipped with an overhead gas-forced air blower. The main heat source for the building is a network of ceiling-suspended gas infrared tube heaters with reflective shields. The building is equipped with an exhaust system to evacuate diesel locomotive emissions.

Class I, Division 2 Locations

Within the Western Avenue Locomotive shop, according to the definitions provided by NFPA 30A, the Class I, Division 2 location would be 450 mm (18 in.) from the ceiling level. The locomotive maintenance portion of the facility has only one ceiling level – high bay. The ceiling supports ducting which is currently used to remove diesel exhaust from the building. The ducts and luminaires are below the highest level of the ceiling. As the high ceiling represents the highest points in the ceiling, ventilation and sensor considerations will need to be considered there.

Figure 86 - Western Avenue Locomotive Shop Ceiling View

Unclassified Locations

The unclassified locations within the facility will be the area outside of the 450 mm (18 in.) from the ceiling and coach shop. It should be noted that even in the area below 450 mm (18 in.) from the ceiling, heating considerations as described in this report will need to be considered (no space heaters, no exposed flames, or sparks) and may require modification of the existing gas-fired infrared tube heater system.

The adjacent coach shop will need to be checked for penetrations into the shop (conduits, pipes, etc.) and sealed accordingly.

Heating System

The heating system within the facility is gas-fired infrared tube heaters. This heating system would need to be modified to ensure that any flames are enclosed and that the surface temperature is maintained below 399°C (750°F).

Gas-fired hot air blowers are used for directional heat at each bay door. These types heaters would need to be removed and replaced with ones that do not have exposed flames, with blower motors rated for Class I, Division 2 locations.

Figure 87 - Bay Door Heater Blowers

Ventilation System

The existing ventilation system is composed of the exhaust removal ducts and upblast fans at the ceiling level. There may need to be additional upblast fans considered in addition to evaluation of the existing exhaust system's capability for air exchanges.

Lighting

The existing lighting system consists of high-bay pendant luminaires, suspended from the ceiling. The pendants appear to be outside of the Class I, Division 2 boundary, 450mm (18 in.), from the highest point of the ceiling. However, the electrical conduit for these pendants will need to be evaluated.

Ceiling Electrical and Conduits

As noted above, the lighting in the Western Avenue Locomotive shop appears to be outside of the Class I, Division 2 location; however light circuit conduits may need to be replaced with sealed, threaded metallic (intermediate or rigid) type. Conduits for blower fans will also need to be evaluated for specific runs and sealing for conformance to the location requirements.

Other Observations

As described in this report, ventilation to meet the required air exchanges may be needed. The bay doors within the Western Avenue Locomotive shop are electrified and will require tie-in to the sensor control system. Interlocking with the overhead crane may be necessary to remove crane power if methane levels are detected. Location and spacing between methane sensors will need to be determined for the facility, with consideration of ceiling obstructions like the ventilation system ducts and overall large area of the ceiling.

It should be noted that calibration and inspection of the methane detectors may be a challenge due to the ceiling height. Calibration tube lengths (if used) will need to be verified and coordinated with pressure vessel capacities which may be used for calibration purposes.

BNSF – 14th Street Shop

The BNSF 14th Street facility is nearly identical to the Metra Milwaukee District Western Avenue facility. The modifications would be very similar as the buildings have the same type of features and amenities.

Union Pacific – M-19-A Shop

The Union Pacific M-19-A facility is unique compared to the other locomotive maintenance facilities as it is configured for fueling within the building (two dedicated fueling bays) in addition to typical exterior fueling. In order to accommodate interior fueling of CNG (to match similar operations for diesel), the bays would be classified as Class I, Division 1. This classification would require replacement of the electrical equipment within the bays with equipment rated for the location. It is suggested to consider CNG fueling exterior to the facility. The maintenance and diesel fueling bays would then fall under the Class I, Division 2 requirements as described in this report – considerations for lighting, conduit, and heat sources.

Repair/Modification Activities within Locomotive Shops

It should be noted that heavy repairs to the locomotive fueling system, welding, and torch-cutting likely will necessitate procedural changes to de-fuel (evacuate) the CNG storage tanks. Further, these repairs may need to be performed in an open area of the shop, away from locomotives undergoing running maintenance and non-fuel evacuated repairs. This will need to be evaluated by Metra's Mechanical and Safety departments to determine the appropriate procedures.

Metra Locomotive Modifications

Introduction

The Metra locomotives all have a 2-cycle engine built by EMD. The locomotive engine is suitable for a dual fuel configuration. The engine is reconfigured with bolt on components to optimize the use of natural gas ignited during combustion. The engine models METRA uses are the following:

- 16-645E3B
- 16-645F3B
- 12-710G3A

Figure 88 below represents a typical EMD engine.

Figure 88 - Typical Two Stroke Turbocharged EMD Engine

The engine models have different horsepower and cubic inch displacement but operate in a similar fashion. The engine is either mechanically injected or is equipped with electronic unit injection responding to a corresponding discrete engine rpm request. They are a series of 8 “throttle” speed requests that results in an rpm to drive the main alternator. The dual fuel system will not alter the rpm request.

Table 23 - CNG Substitution Notch Schedule

CNG Substitution by Notch provided by EE

Throttle	Diesel	CNG
Dynamic Brake	100%	0
Idle	100%	0
Notch 1	100%	0
Notch 2	100%	0
Notch 3	30%	70%
Notch 4	30%	70%
Notch 5	20%	80%
Notch 6	20%	80%
Notch 7	10%	90%
Notch 8	10%	90%

General Locomotive Requirements

The work scope for the locomotive dual fuel is similar to a light overhaul. The radiator and engine hatches will need to be removed to install a separate aftercooling radiator and there will need to be access to the underside to install CNG tanks and relocate the air piping and reservoirs, and possibly the battery box.

The typical dual fuel system will use:

- New pistons
- New cylinder heads
- Gas regulator
- Injectors
- Gas plumbing lines
- Aftercoolers
- CNG tank ~ 300 DGE (may be integral with diesel fuel tank)
- Diesel fuel tank
- ISO standard filling nozzles
- Flow valves
- Radiators and water pump for separate aftercooling, if not equipped

The diesel engine control will be from a governor or electronic engine control but will have the gas injection timed to coincide with the combustion of the diesel fuel. The system will require control wiring for the engine throttle inputs and monitoring equipment. An example of CNG equipment on an 8-cylinder EMD engine is shown in Figure 89. The CNG supply in the figure is provided by the manifold running along the top deck.

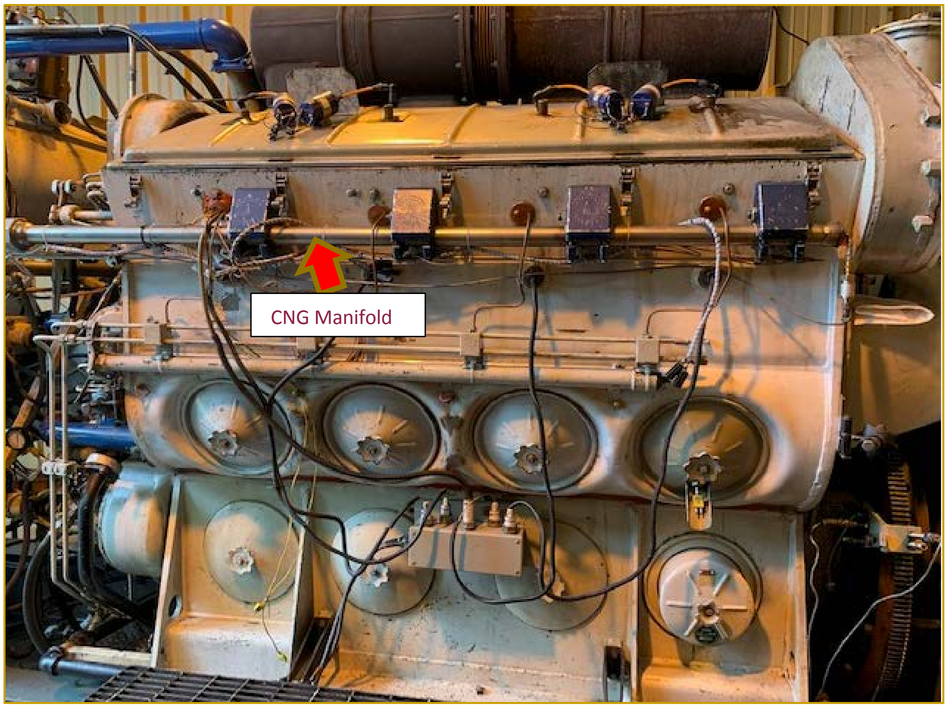


Figure 89 - CNG Dual Fuel Adapted on a Two Stroke EMD Engine

The piston is modified to lower the compression ratio which is substituted by the gas volume. The gas is injected as compression begins. The figure below shows the typical cylinder head as installed, on a mechanically injected 16-645 engine.

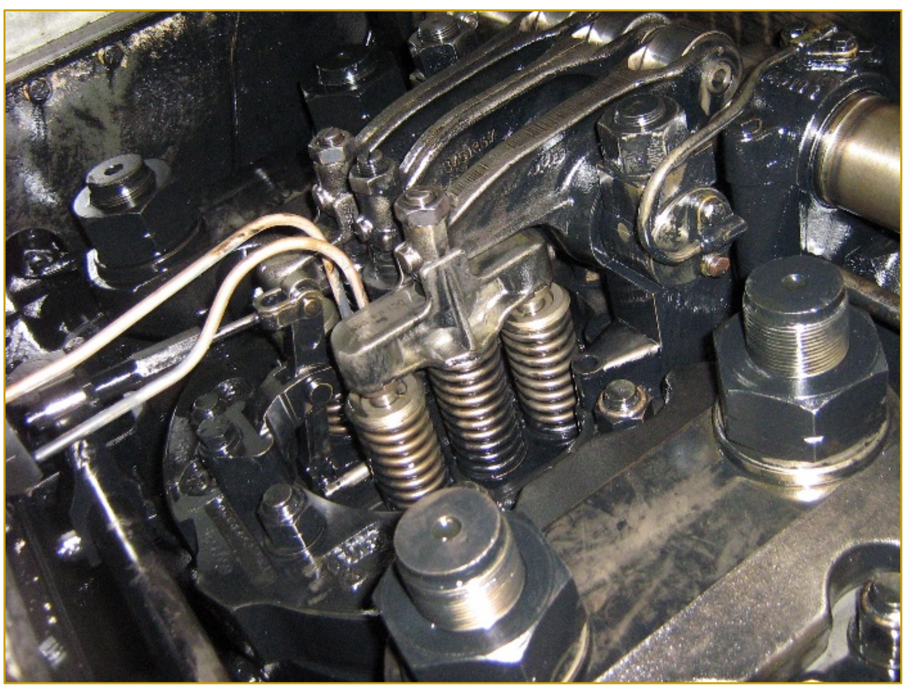


Figure 90 - Typical 645 Engine Head as Installed (Diesel Fuel Only)

Figure 91 - Cylinder Head with Gas Injector

The CNG cylinder head shown in figure 91 has been modified to accept a gas injector, (diesel fuel lines are not shown). The dual fuel head can be bolted directly to the existing liner in this example. The Dual Fuel head can be bolted directly to the existing liner. This in-carbody work would not require removing the hatches since only the head would be removed.

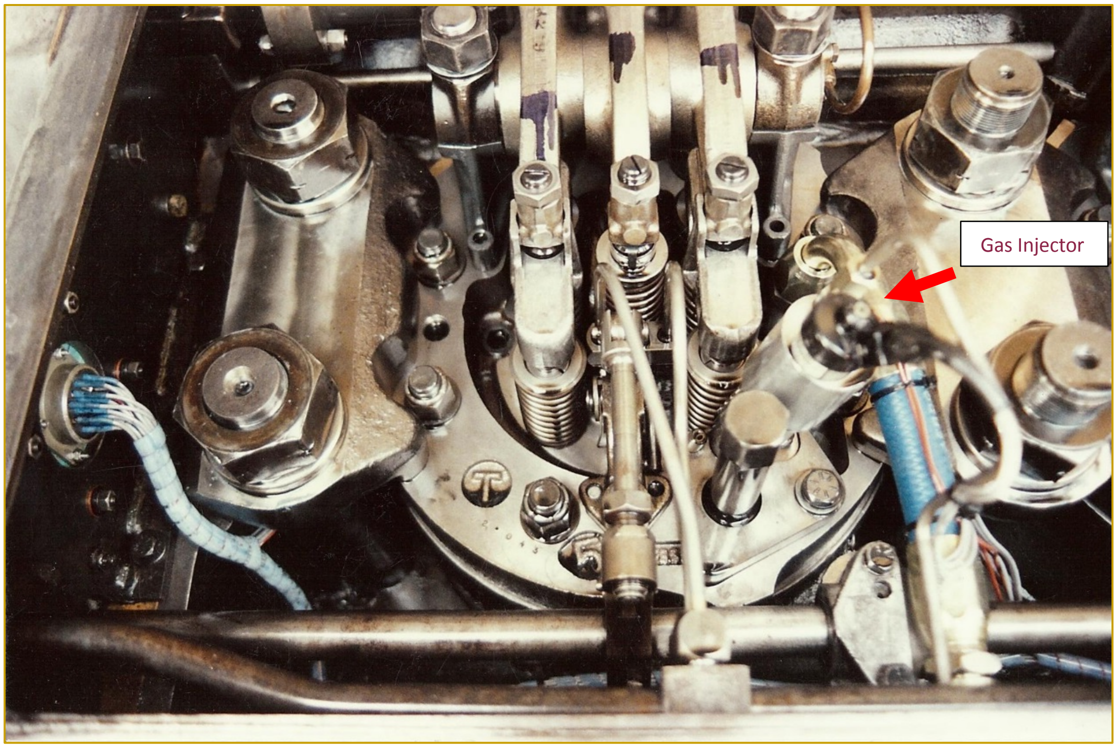


Figure 92 - Cylinder Head with Gas Injector as Installed (Dual Fuel)

In addition to the equipment required for a CNG dual fuel, there will be modifications to the in-carbody and underframe equipment. At a minimum some of the air piping such as the air dryer will require relocation to accommodate the additional CNG equipment. The piping may be routed above or around the new CNG equipment. The system would require mapping to limit number of elbows added. The existing fuel tank has two options. The first would be to leave the tank in place and add several CNG cylinders. The second option will be to remove the existing diesel fuel tank and replace with a new design to remain in the same location. The new design of the tank would have the CNG cylinders integrated with the diesel fuel tank. With either design the underframe will need to have brackets designed and fabricated to hold the fuel tanks.

As previously discussed, there are two manufacturers of the CNG dual fuel equipment for METRA locomotives applicable to the EMD 16-645 and the 12-710 engines. The EMD 12-710 powering the F59PH would require electronic fuel injection as a pre-requisite for dual fuel installation.

Progress Rail Services (formerly Electro-Motive) was the builder of the F59PH and F59PHI and the F40PH. They have worked with the class I railroads in the development of dual fuel use on the 16-710 engine and have the capability to apply the same engineering on the 12-cylinder 710 engine. Progress Rail can supply equipment to install dual fuel CNG/diesel equipment on the locomotive. The control equipment would be compatible with EM2000 and EMDEC locomotive control systems. The gas injection system is through the scavenged air system in the air box. The natural gas is directly injected while the piston is at the bottom of stroke.

Peaker Rail Services through acquisition of Energy Conversion Inc. (ECI) has developed the equipment for the 16-645 engine and have completed some development on the EMD 710 engine. The system for the 16-645 engine had been developed and tested on the BNSF and CN. That particular system would need to be further developed to use electronic fuel injection and further improve diesel exhaust emissions. In a recent interview with ECI/EE it was learned that they are working closely with Woodward on a new controller.

When performing the dual fuel conversion, a good practice would be to replace the lower connecting rod bearings when replacing the piston. To get the most benefit Metra should select a locomotive certified to Tier 0+ for the CNG dual fuel conversion. It is the lowest emissions level besides an unregulated engine. The CNG will provide an improvement of the emissions and would be validated with testing and emissions certificate.

OptiFuel has developed a CNG/diesel system for a multi engine Caterpillar C18 engine retrofit which is currently used on switch engines. Optifuel has provided some multi-engine conceptual designs using a combination of a Tier 4 diesel prime mover and CNG powered auxiliary engines that could be adapted to Metra, but requiring an extended (approximately 70 ft.) frame. These will be provided in the proprietary appendix.

On-Board Safety Equipment

It is suggested to evaluate locations within the main engine compartment for a methane detection system. In the case of a leak during running, the methane detection system can shut down the engine and associated rotating equipment loads. The equipment suppliers provide methane detection and NG shutoff systems as part of the onboard fuel control systems, the same as can be found on other NG powered vehicles. Natural gas-powered locomotives must meet the stringent safety requirements applicable to any NG powered vehicle per the requirements of the National Fire Protection Agency (NFPA) and are also subject to the approval of the Federal Railroad Administration (FRA) as noted in the Required Safety Studies section of this report.

Locomotive Modification Costs

The cost will vary by locomotive by engine model and respective control system. Each locomotive will require a separate loop aftercooling system installed. Budgetary estimates for the 645 engine are on the order of $475,000 for the engine equipment. Budgetary estimates for the 710 engine would be approximately $500,000. It is estimated that each kit installation would require approximately $150,000 of labor. It is expected that the cost would decrease after the pilot installation. The locomotive engine will require emissions testing and certificate upon completion. The cost of the emissions testing and certification will be approximately in a range of $200,000-$300,000 in addition to the modifications. This will be a one-time cost and may be borne by the engine conversion equipment supplier but is included in estimating. The locomotives may need 3 different engine family certificates; However, the 710 engines can likely be equipped the same and may need a single emissions certificate covering both locomotives.

CNG Conversion Project Timeline

A high-level project timeline was developed for full implementation of the dual fuel conversion for the Milwaukee District. Figure 93 provides the project timeline with major tasks and milestones identified. The timeline is shown to provide an estimated overall duration for the project starting with the project planning phase including the initiation of submittal for approval by the FRA. Engaging the FRA as early as possible in the conversion process is critical. This can be done by providing the test plan and related information previously identified which follows the guidelines that they have set for plan approval.

The project planning phase is followed by the detailed Engineering phase for the locomotives, facility conversion and fuel station design, estimated at a 12-month duration. It is anticipated that following the engineering phase there would be requests for proposals from Metra for the construction of the fueling facilities and the shop facilities modifications. It was assumed that the Metra crafts personnel (electricians, machinists and sheet metal/structural fabricators) would perform the locomotive conversion work. The conversion materials (engine conversion kits, fuel tanks and ancillary equipment) would need to be procured before the work could commence.

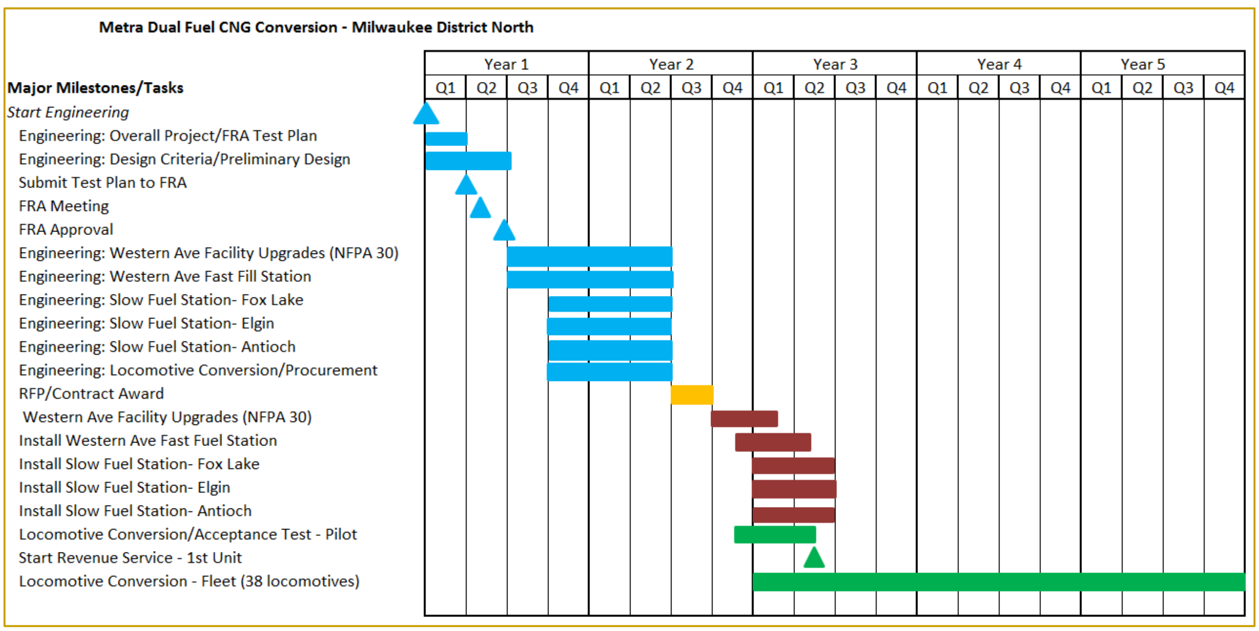


Figure 93 - Metra Dual Fuel Conversion Timeline - Milwaukee District

Figure 94 details the anticipated pilot locomotive build, test and acceptance timeline leading to revenue service, estimated as a 6-month process. Time estimates were based on information provided by the conversion equipment supplier from past experience. It is anticipated that the equipment supplier would provide an onsite resource for technical assistance and testing throughout the pilot phase. As a minimum, the Western Avenue fueling station must be completed prior to start of testing. Training of the operations and maintenance personnel on both the technical and safety aspects of using CNG on a locomotive would occur during this timeframe as well as training for the Metra personnel involved in refueling and other yard support activities. Four weeks of static testing are assumed, followed by a 10-week track test and evaluation phase, conservatively estimated to provide ample time to work through unanticipated issues and to obtain FRA acceptance for revenue service.

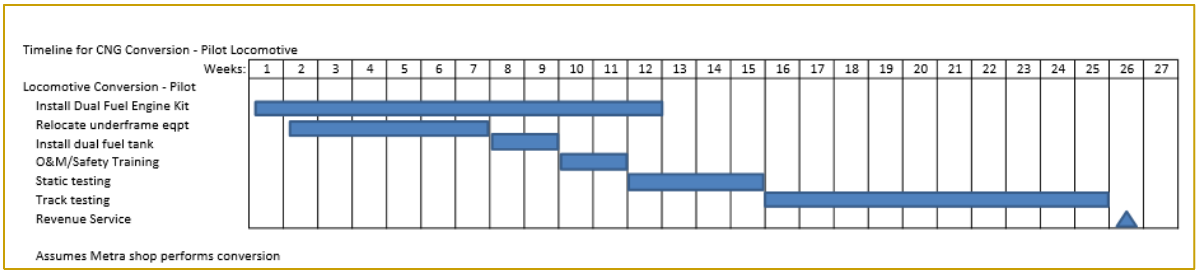


Figure 94 - Pilot Locomotive CNG Conversion Timeline

Figure 95 illustrates a timeline for full Milwaukee District locomotive fleet conversion for all 38 locomotives. Again, the assumption is that the work would occur in Metra's shops using their craft labor. It is assumed that each locomotive conversion and test phase would encompass three months and the conversions would be staggered to complete at a rate of one conversion per month. As shown, at this rate the conversion of the 38 locomotives would take about three years. This could be improved if Metra wished to take a more aggressive approach by removing a greater number of locomotives from service, conversion activities could be outsourced to a locomotive repair facility. One of the locomotive engine conversion equipment suppliers, Progress Rail, has this capability.

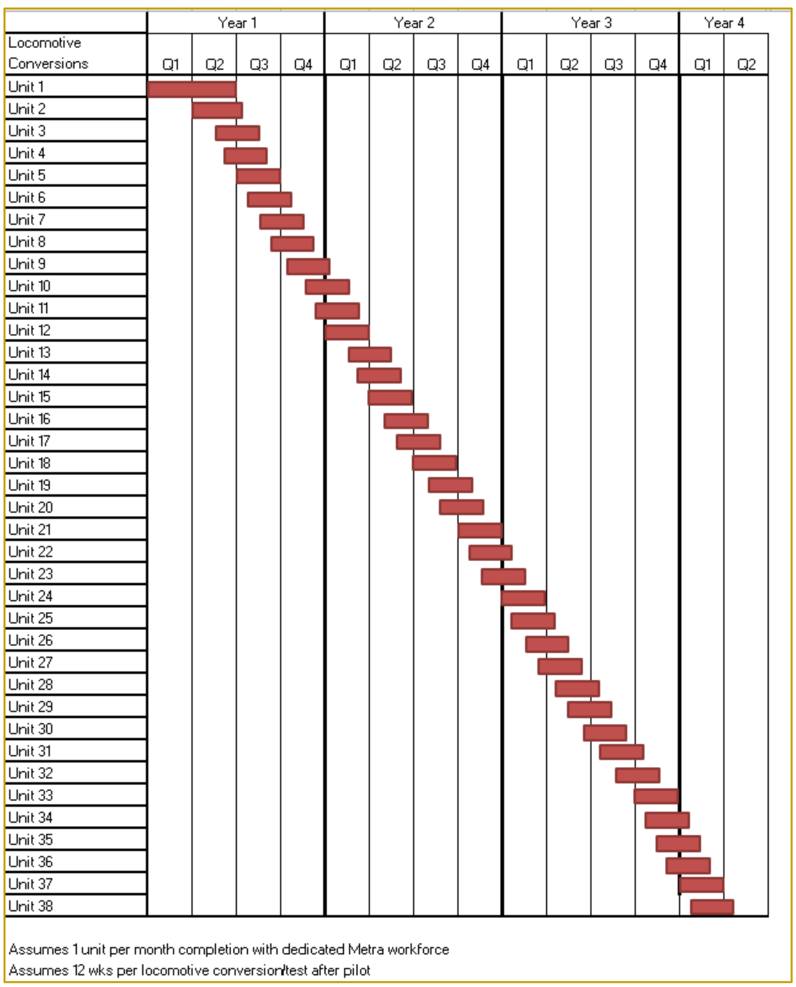


Figure 95 - Locomotive Fleet Conversion Timeline

Required Safety Studies

Safety of CNG

CNG primarily consists of methane. Because methane is an odorless gas it is odorized with Mercaptan to make it detectable at a concentration as low as 0.3% by volume in air, about 16 times lower than the level which will support combustion.

As discussed in the Facilities Modification section, CNG has a high ignition temperature, about 1,000 degrees Fahrenheit, compared with about 410 degrees Fahrenheit for diesel. It also has a narrow range of flammability; in concentrations in air below about 5 percent and above about 15 percent, natural gas will not combust. The high ignition temperature and limited flammability range reduce the likelihood of accidental ignition or combustion of CNG. Per the CNG Safety Data Sheet, there are no known toxic effects when exposed to moderate concentrations and it is noncorrosive. Since CNG is lighter than air, in the event of an outside leak, the gas disperses upwards and dissipates into the atmosphere. Methane leak detectors will also readily detect a leak and can provide an alert, or if part of a locomotive CNG injection control system can quickly interrupt flow to isolate the leak.

Indoor leaks can be dissipated with sufficient ventilation as discussed previously. Its primary hazard stems from the high pressure (3,600 to 4,500 psi) when stored in pressurized gas cylinders. Thus the gas storage cylinders must be periodically inspected and maintained. NFPA 52, the Vehicular Gaseous Fuel Systems Code sets requirements for tank manufacturing, inspection, marking, and testing. There are also end-of-life requirements for each tank, with an expiration date marked on the tanks, for removal from service.

FRA Requirements for NG Locomotives

On August 26, 2013, the Acting Associate Administrator for Railroad Safety/Chief Safety Officer of the Federal Railroad Administration (FRA), published a letter to the AAR, ASLRRA and APTA outlining their guidelines for any railroad entity wishing to evaluate NG as a fuel source for their fleet. The letter provides an overview of FRA authority to regulate LNG and CNG locomotives and tenders. The letter also summarizes the key elements of information necessary to facilitate timely evaluation and approval by the FRA of testing programs to evaluate the efficiency, feasibility, and reliability of LNG and CNG powered locomotives and fuel tenders. The guidelines are written to cover both on-board fuel storage and a separate fuel tender. The intent of this letter is to clarify to the major rail industry organizations the specific items to present to the FRA to gain approval for testing of a NG powered locomotive in railroad service. This letter clarifies the steps for a rail authority to take to gain FRA approval for an LNG or CNG pilot or "test" program. Although prepared primarily for the freight rail industry, it is also applicable to passenger transit. The letter can be found referenced in the report appendix. Two sets of guidelines were provided.

The first set consists of information to be submitted to the FRA prior to a meeting on the use of either LNG or CNG in railroad service, which must be submitted two weeks prior to the meeting. The list of information as enumerated in the letter is as follows:

1) Statement of the objective of the meeting and the benefit to the vendor from such a meeting (what is the expected outcome of the meeting?).

2) Clear description of the system to be tested, summary of the overall test plan, goals to be achieved in the test, and the principal elements that will be evaluated.
3) List of the project team members and their respective duties. Include specific statements on whether the team includes representatives from labor unions. If not, please explain why.
4) Details of the project plan for the tests. This should include, but not be limited to, the following items:
   a) Test plan.
   b) Schedule and milestones.
   c) Location of tests.
   d) Coordination with other stakeholders (vendors, subcontractors, emergency response institutions, etc.).
   e) Alternative approaches, if any.
   f) Physical layout, operational descriptions, flow diagrams, etc.
   g) Equipment design information (marked as confidential, proprietary, not for distribution).
5) Evaluations of personnel and public safety issues during both the test phase and the operational phase.
6) Types of data that will be collected, including an explanation of why and how these may be used in the design of the operations.
7) Issues that can be resolved by the railroad or vendor, and those which are external (and uncontrollable).
8) List of all regulations directly or indirectly applicable, indicating how compliance with the regulations will be achieved. Prepare a list of items for which a waiver from the requirements of the Federal regulations will be required for the purpose of testing.
9) Request for waiver from the requirements of the applicable Federal regulations for execution of the test plan, if compliance is not achievable.
10) List of potential benefits from the proposed plan to the industry and the public.
11) Set of specific questions that require a response from FRA.

The letter also states that "… any vehicle that carries natural gas or any other material being used to fuel attending locomotives is subject to FRA's statutory authority under 49 U.S.C. Chapter 207, Locomotives (formerly known as the Locomotive Inspection Act (LIA)), as well as other regulations applicable to locomotives and locomotive tenders." As addressed in the Best Practices report, all applicable railroad locomotive and passenger equipment safety standards must be met.

The second set of guidelines pertains to submittal of the test plan to the FRA for approval to test the use of CNG or LNG in railroad service which must include:
1) All items identified above when a meeting with FRA is requested.
2) Detailed structural analysis documentation and any relevant test data to support the safe operation and crashworthiness of the equipment and fuel storage elements (note: additional analysis or validation tests may be required by FRA).
3) Procedures for equipment maintenance and testing.
4) Risk analyses addressing, at a minimum, the following items, where applicable:

a) Fueling operations.
b) Leak detection and response.
c) Locomotive and tender separation (protection of crew).
   i) Survivability of tender, appurtenances, and connections in rail environment.
   ii) Crashworthiness (in such scenarios as derailment, collision, sideswipe, etc.)
   iii) Fatigue life
   iv) Excessive in-train forces
   v) Fuel tank penetration protection

5) Details of communication plans with employees, first responders, and public organizations.
6) Other relevant data or information that will expedite processing an approval of the proposed test plan and application for a waiver.

The above represents a substantial amount of documentation and planning that must be prepared and submitted to the FRA in order gain approval of the use of NG as a locomotive fuel. This effort would need to be one of the first tasks to be accomplished once a decision is made to move forward with a dual fuel plan. It would be expected at numerous meetings would be held with all relevant participants involved in the decision to move forward with the conversion process. It can also be expected that multiple meetings with the FRA will be needed before compliance will be granted. When recently requested, the FRA replied that they have a Natural Gas Safety Review team that works with the railroads that are planning to utilize natural gas or other alternative fuels. Contact information for the Supervisory Railroad Safety Specialist can be found in the References section of this report.

Safety Plans

In addition, the FRA requires a comprehensive safety analysis before the initiation of alternative locomotive fuel projects. The FRA has commissioned several studies to review relevant standards related to system safety for NG powered locomotives. The Sandia National Laboratory was commissioned to prepare a report, entitled LNG Safety Assessment Evaluation Methods to evaluate published safety assessment methods across a variety of industries utilizing LNG. This study was developed for the FRA's use in evaluating NG on-board and tender storage and refueling operations from a safety standpoint. A Safety Plan Checklist was formulated for evaluating safety plans submitted by the railroad industry. The checklist shown below in Table 24 is directed at dual fuel locomotives and LNG locomotive tenders; the approach is consistent with rail vehicle safety and hazard analyses required for new vehicle procurements. This checklist should form the basis of the safety assessment to be submitted to the FRA.

Table 24 - LNG Safety Assessment Checklist for FRA

Element	Description
Safety Assessment Description	• Purpose of the safety assessment • Boundary conditions and assumptions • The methodology applied to this project • Safety assessment team and reviewers • Safety plan review and approval process
System and Scope of Work	• Define system and components, their functions, and relationships • Describe site and facility characteristics • Nature of the work being performed
Information and Data Sources	• Previous LNG experience • Organizational policies and procedures • Operating policies and procedures • Safety policies and procedures
Identification of Safety Vulnerabilities (ISV)	• Hazards and consequences associated with storage, handling, and use of LNG • Risk and accident scenarios identified • Significant vulnerabilities identified • Safety critical equipment identified
Risk Management Plan	• Prevention and mitigation measures for significant vulnerabilities
Use of the Safety Assessment Results	• Process for implementing the results of the safety assessment • Equipment and mechanical Integrity • Employee training • Self-audits
Safety Events and Lessons Learned	• The reporting procedure within the organization and to the FRA • The system and procedure used to investigate events • How corrective measures will be implemented • How lessons learned from incidents and near-misses are documented and disseminated
Emergency Response	• The plan or procedures for responses to emergencies • Communication and interaction with local emergency response officials
Management of the Safety Assessment	• Process for periodic review and updating • Process for verifying continued implementation of safety recommendation throughout life of the system
Other Comments or Concerns	• Any information on topics not covered above • Issues that may require assistance from FRA

The typical Vehicle Safety Plan submitted by a locomotive or car builder consists of a System Safety Plan which encompasses:

- A hazard analysis performed in accordance with MIL-STD-882E, System Safety, which defines a rail industry accepted, disciplined systems safety management methodology and hazard tracking and mitigation strategy.
- Fire and life safety compliance in accordance with all applicable codes and regulations, such as NFPA 130 for the vehicle in particular those relating to NG operations and facilities, such as NFPA 52.

As CNG is a flammable, highly compressed gas, it requires a Safety Data Sheet identifying all known health and safety hazards and handling precautions first aid and firefighting measures, and other pertinent information. The CNG Safety Data Sheet must be made available to Metra's workers who will be in proximity to CNG. The first page of a typical CNG Safety Data Sheet shown in Figure 96. A training program for safe handling training on safe handling, storage, fueling, disposal and emergency procedures in the event of leak or fire will be required.

IRVING

SAFETY DATA SHEET

1. Product and Company Identification

Product identifier	Compressed Natural Gas (CNG)
Other means of identification	Not available
Recommended use	Fuel
Recommended restrictions	None known.
Manufacturer information	Irving Oil Refining G.P. Box 1260 Saint John, NB E2L 4H6 CA Phone: (506) 202-2000 Refinery: (506) 202-3000 Emergency Phone: 1-800-424-9300 (CHEMTREC)
Supplier	See above.

2. Hazards Identification

Physical hazards	Flammable gases	Category 1
	Gases under pressure	Compressed gas
Health hazards	Not classified.	
Environmental hazards	Not classified.	
WHMIS 2015 defined hazards	Not classified	
Label elements		
Signal word	Danger	
Hazard statement	Extremely flammable gas. Contains gas under pressure; may explode if heated.	
Precautionary statement		
Prevention	Keep away from heat/sparks/open flames/hot surfaces. - No smoking.	
Response	Leaking gas fire: Do not extinguish, unless leak can be stopped safely. Eliminate all ignition sources if safe to do so.	
Storage	Store in a well-ventilated place. Protect from sunlight. Store in a well-ventilated place.	
Disposal	Dispose of waste and residues in accordance with local authority requirements.	
WHMIS 2015: Health Hazard(s) not otherwise classified (HHNOC)	None known	
WHMIS 2015: Physical Hazard(s) not otherwise classified (PHNOC)	None known	
Hazard(s) not otherwise classified (HNOC)	None known.	
Supplemental information	None.	

3. Composition/Information on Ingredients

Mixture

Chemical name	Common name and synonyms	CAS number	%
Natural Gas, Dried		68410-63-9	100

All concentrations are in percent by weight unless ingredient is a gas. Gas concentrations are in percent by volume.

4. First Aid Measures

Inhalation	If symptoms develop move victim to fresh air. If symptoms persist, obtain medical attention.
Skin contact	Flush with cool water. Remove contact lenses, if applicable, and continue flushing. Obtain medical attention if irritation persists.

#23647 Page: 1 of 7 Issue date 11-October-2018

Compressed Natural Gas (CNG) (03085) (US-CAN SDS)

Figure 96 - Typical CNG Safety Data Sheet

Per 49 CFR Part 659, any authority receiving FTA funding requires that rail authorities develop and maintain vehicle and operations safety and security certification plans. If applicable, the Metra Safety and Security Certification Plan process would need to be applied to the dual fuel CNG conversion process. There are likely other internal safety procedures which would need to be developed or revised to govern the safe storage, handling and use of CNG in locomotive operations and maintenance.

The System Safety Process

The MIL-STD-882E approach developed by the Department of Defense (DoD) is a proactive methodology to identify and mitigate hazards as a project evolves through its lifecycle from design, manufacture, test and operational phases and is suitable for a major effort such as a locomotive dual fuel conversion program. The process is well understood and has been used successfully on numerous rail vehicle projects. Figure 97 illustrates the eight major elements of the process.

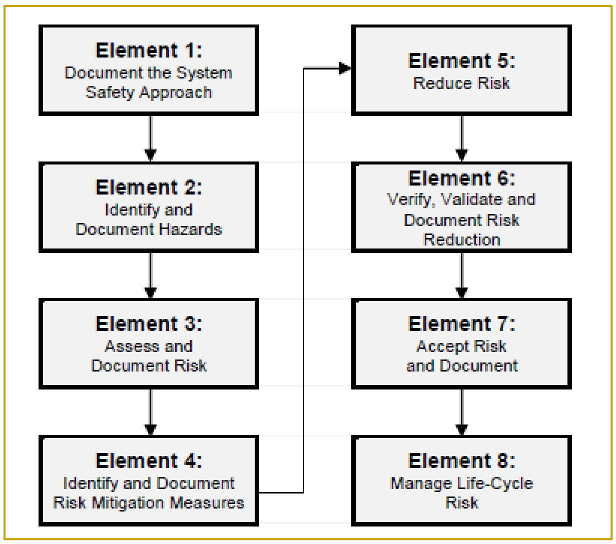


Figure 97 - 8 Major Elements of the MIL-STD-882 System Safety Process

To summarize the process, elements 2 through 7 are developed into a risk assessment matrix based on defined severity categories and probabilities levels (see Tables 98, 99 and 100). Items identified as High or Serious risks must be mitigated into a more acceptable category or if possible, eliminated. The hazard mitigation process is typically overseen by a qualified System Safety Engineer, either from the rail agency or from a third-party engineering firm, as the process is exhaustive and requires frequent review and updating as potential hazards are identified and mitigated. The hazard identification process should start at the beginning of the engineering phase and continue through testing and the pilot phase so that the startup and on-going operation and maintenance risks are alleviated.

SEVERITY CATEGORIES		
Description	**Severity Category**	**Mishap Result Criteria**
Catastrophic	1	Could result in one or more of the following: death, permanent total disability, irreversible significant environmental impact, or monetary loss equal to or exceeding $10M.
Critical	2	Could result in one or more of the following: permanent partial disability,injuries or occupational illness that may result in hospitalization of at least three personnel, reversible significant environmental impact, or monetary loss equal to or exceeding $1M but less than $10M.
Marginal	3	Could result in one or more of the following: injury or occupational illness resulting in one or more lost work day(s), reversible moderate environmental impact, or monetary loss equal to or exceeding $100K but less than $1M.
Negligible	4	Could result in one or more of the following: injury or occupational illness not resulting in a lost work day, minimal environmental impact, or monetary loss less than $100K.

Figure 98 - Severity Categories

PROBABILITY LEVELS			
Description	**Level**	**Specific Individual Item**	**Fleet or Inventory**
Frequent	A	Likely to occur often in the life of an item.	Continuously experienced.
Probable	B	Will occur several times in the life of an item.	Will occur frequently.
Occasional	C	Likely to occur sometime in the life of an item.	Will occur several times.
Remote	D	Unlikely, but possible to occur in the life of an item.	Unlikely, but can reasonably be expected to occur.
Improbable	E	So unlikely, it can be assumed occurrence may not be experienced in the life of an item.	Unlikely to occur, but possible.
Eliminated	F	Incapable of occurence. This level is used when potential hazards are identified and later eliminated.	Incapable of occurence. This level is used when potential hazards are identified and later eliminated.

Figure 99 - Probability Levels

RISK ASSESSMENT MATRIX				
SEVERITY / PROBABILITY	Catastrophic (1)	Critical (2)	Marginal (3)	Negligible (4)
Frequent (A)	High	High	Serious	Medium
Probable (B)	High	High	Serious	Medium
Occasional (C)	High	Serious	Medium	Low
Remote (D)	Serious	Medium	Medium	Low
Improbable (E)	Medium	Medium	Medium	Low
Eliminated (F)	Eliminated			

Figure 100 - Risk Assessment Index

Should Metra decide to move forward with dual fuel CNG conversion, it would be the first major passenger rail transit authority in the US to do so and can expect a greater level of scrutiny from the FRA as well as local and state authorities. In addition to the preparation of all of the above documentation, it would be expected that several review meetings would be required with the FRA to work through all of the potential issues in applying this technology to rail passenger transit. System safety engineers familiar with both rail system and CNG system safety should be consulted in developing the safety documentation deliverables.

Dual Fuel Financial Analysis

The financial assessment was conducted to investigate the financial viability of converting Metra's locomotive engines to dual fuel consumption, using both diesel and compressed natural gas (CNG) as fuel. In order to perform the analysis, the project team collaborated to create a multi-year financial model intended to calculate the capital and recurring costs of the conversion, as well as the potential fuel savings in converting from mainly diesel engines to a partial natural gas substitution. The analysis was limited to the Milwaukee District (encompassing the MDN, MDW, and NCS lines) which has 38 locomotives, as an initial test of the model. Certain operational assumptions were put in place to estimate costs for the conversion. Overall, given a range of fuel price forecast scenarios, the analysis produced a 15-year internal rate of return between 5.4% and 8.5%, which is greater than the assumed break-even hurdle rate for Metra of 5%. This 5% rate discounted cash flow of the scenarios had a 15-year net present value of between \$1.1MM and \$9.2MM. It is assumed that the conversion and overhaul of the locomotives in question would increase their service life an additional 15 years as a minimum.

Financial Model Assumptions

Construction of a financial model required the consultant team to make assumptions regarding the operating conditions and estimated costs of converting the Milwaukee District rail lines to partial natural gas usage. These assumptions fall into three categories: (1) non-recurring expenses (NRE), (2) operational expenses, and (3) general assumptions. NRE represent one-time expenses, which include the costs of engine conversion and installation, investment costs for establishing the filling stations necessary for natural gas usage, facility modification costs, and other miscellaneous costs. Operational expenses include assumptions that cover the cost of day-to-day operations, such as forecasts of fuel costs, and operational maintenance of locomotive units and filling stations. General assumptions include the discount rate of return (also referred to as cost of capital or investment hurdle rate), inflation rate for operating costs, diesel and CNG fuel price forecasts, locomotive conversion timeline, and financial horizon.

Non-Recurring Expenses (NRE)

There are three sub-categories of NRE:

1. Fueling Station Investment: This represents the capital expense for installing CNG fueling stations and is summarized in Table 26.
2. Locomotive Conversion Costs: This includes the cost of the kit and installation labor for the EMD 645 and EMD 710 engine conversion, as well as the cost of fabrication and installation of the fuel tanks. The locomotive conversion cost assumptions are outlined in Table 25.
3. Other NRE: Summarized in Table 27, this represents other miscellaneous one-time costs such as tier emissions certification, locomotive modification engineering, FRA CNG approval support, and training for Metra staff.
4. Facility Modifications: This includes construction and engineering costs to meet code requirements for modifying/upgrading facilities for dual fuel locomotive maintenance. This is currently estimated at \$3.2MM and applies only to the Western Avenue Locomotive Shop and the Fox Lake, Elgin, and Antioch Fueling stations (see Table 28).

Table 26 - CNG Fueling Station Investment

CNG Fueling Station Investment ($'000)
Milwaukee District

Location	Fill Rate	Capital Expense
Western Avenue (Mid Day)	Fast	$6,000
Fox Lake (Overnight)	Slow	$2,500
Elgin (Overnight)	Slow	$2,500
Antioch (Overnight)	Slow	$1,500
	Total	**$12,500**

Table 25 - Locomotive Conversion

Locomotive Conversion Unit Costs (Per Engine, $'000)
Milwaukee District

Item	MP36 (EMD 645)	F59PH/PHI (EMD 710)
Conversion Kit	$475	$500
Assembly Labor	$110	$110
Fuel Tank Fabrication	$125	$125
Fuel Tank Installation	$65	$65
Total	**$775**	**$800**
Nbr of Units MDN	**16**	**22**

Table 27 - Other Non-Recurring Expenses

Other Non-Recurring Expense ($'000)
Milwaukee District

Item	One-Time Expense
Tier Emissions Certification	$300
Locomotive Modif Engineering	$250
FRA CNG Approval Support	$95
Metra Staff Training*	$40
Total	**$685**

* 2 Trainers for 1 month ($125 x 20 x 8)

Table 28 - Facility Modification Capital Expense

Facility Modification Capital Expense ($'000)
Milwaukee District

Item	One-Time Expense
Facility Modification Capital Expense - Construction	$1,000
Facility Modification Capital Expense - Engineering	$2,200
Total Facility Modification Expense	$3,200

Operational Expenses

The operational expenses incorporated in the financial mode include:

1. Base Fuel Price (Diesel & CNG): Represents the assumed current cost per diesel gallon equivalent (DGE) of diesel and CNG. The assumptions are listed in Table 30, with the base fuel prices in Table 29.
2. Average Diesel Fuel Consumption per Locomotive: The data provided by Metra showed that the Milwaukee District consumed 6,235,935 diesel gallons across 38 locomotives, with an average diesel fuel consumption of 164,104 gallons per locomotive.
3. Diesel Substitution: This factor represents the percent of diesel replaced by CNG during operations. The factor used in the financial model is 65% and was derived from LTK trip simulations.
4. First Year Fuel Savings: During the implementation period, locomotives under conversion during a given year will not be able to fully operate under dual fuel conditions. Given the incremental conversion within the year, it is assumed that first year fuel savings will be equal to 25% of the full year fuel savings for the number of locomotives converted during that year.

5. Overnight Staffing of Fueling Stations: It is assumed that the Fox Lake, Elgin, and Antioch fueling stations will require overnight staffing. The staffing cost is estimated at $150,000 per station per year, or a total of $450,000 per year with an annual inflation rate of 2%.

Table 30 - CNG Cost Components

CNG Cost Components	
Component	**PACE $/DGE**
Natural Gas	$0.5206
Invoice	$0.1639
Electricity Cost	$0.0625
Operations & Maintenance	$0.0832
Total	**$0.8302**

Table 29 - Base Fuel Price

Base Fuel Price	
Fuel Type	**$/DGE**
Diesel*	$2.430
CNG**	$0.830

* Source: Metra

** Source: PACE

General Assumptions

The following general assumptions are made in the financial model:

1. Discount Rate of Return: This is the rate of return used to calculate the discounted cash flow and net present value of the cash flow over the investment period. Metra suggested a discount rate of return of 5%.
2. Inflation Rate: The inflation rate determines the rate of increase in general maintenance and operating costs (primarily overnight staffing) and is assumed to be 2% per year.
3. Diesel and CNG Fuel Price Forecasts: There are three scenarios of diesel and CNG fuel price forecasts used in the financial analysis:
    a. Constant Rate: Assumes a constant 1.7% year-over-year fuel price increase for both diesel and CNG. The rate is based on the 12-month rate increase of the fuel component of the April 2019 Consumer Price Index. The forecasted diesel and CNG cost per DGE is illustrated in Figure 101.
    b. Historical Volatility: Assumes that the individual historical price rate volatility for diesel and CNG will be reflected in future prices. The resulting diesel and CNG cost per DGE using this method is illustrated in Figure 102.
    c. Power Curve Regression: Diesel and CNG cost per DGE is forecasted based on fitting a statistical power curve (Y = a * X ^b) over historical pricing. The projected diesel and CNG cost per DGE using this method is illustrated in Figure 103.
4. Conversion Timeline: There are 38 locomotive units in the Milwaukee District fleet that are available for dual fuel conversion, with 22 units having F59/F59PHI engines while the remaining 16 having MP36 engines. It is assumed that the F59/F59PHI engines will be converted on the schedule of 6 units starting in the third year of the conversion timeline, with 7, 8, and 1 unit in the succeeding years. The MP36 engines are assumed to be converted on a schedule of 5 units starting in the third year of the conversion timeline, with 5, 5, and 1 units in the succeeding

years. The conversion timeline will show a total of 11 dual-fuel units converted and operational in the third year, with 12, 13, and 2 units converted and operational in the succeeding years. (Refer to Figure 93, Metra Dual Fuel Conversion Timeline, LTK Implementation Plan).

5. Financial Horizon: This is the timeframe under which the financial analysis is conducted and represents the investment period. We selected a 15-year and 20-year horizon, around the time when the first converted locomotive may be reaching its life expectancy. An implicit assumption is that all converted engines will remain in operation during the entire financial horizon (15 to 20 years)
6. The overhaul cycle of dual fuel engines is assumed to coincide with the same time or mileage-based cycle that a diesel only engine would require. The cost of performing a dual fuel locomotive engine mid-life overhaul was assumed to be the same as the cost to overhaul a diesel only engine.
7. The Western Avenue facility modification estimate is very high level, based on a per bay estimate of $160K per bay for all 6 bays; this is double the estimate provided in the Compressed Natural Gas Vehicle Maintenance Facility Modification Handbook which was developed with non-rail vehicles in mind.

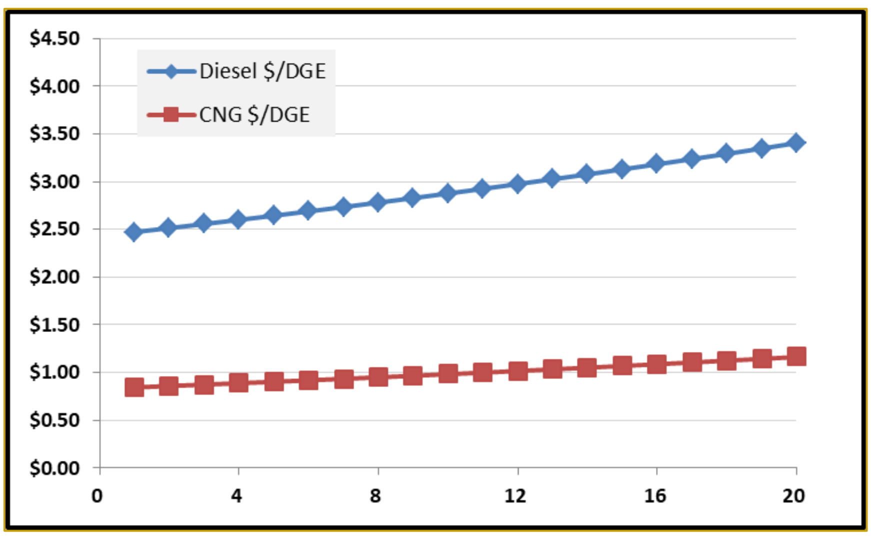


Figure 101 - Diesel and CNG Price Forecasts, Constant Rate

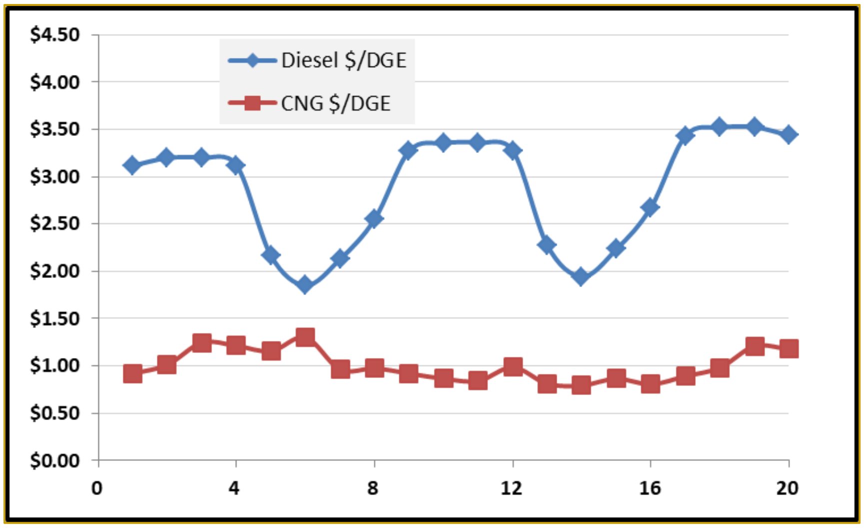


Figure 102 - Diesel and CNG Price Forecasts, Historical Volatility

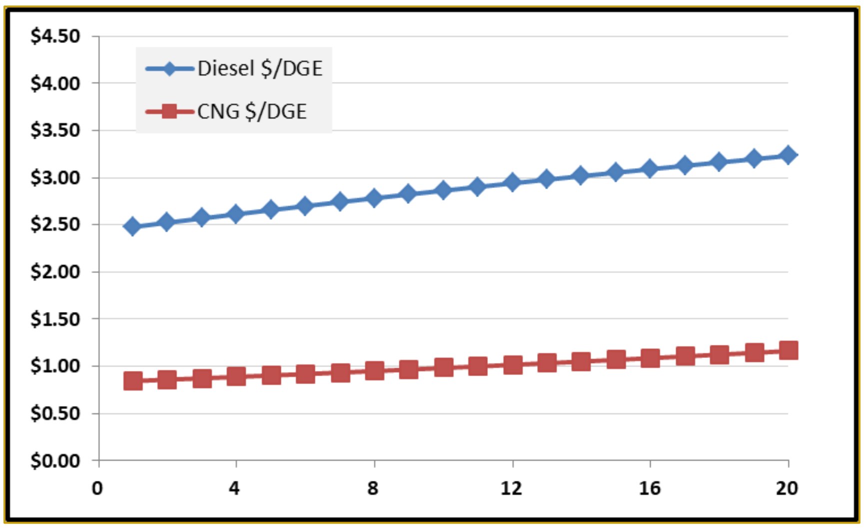


Figure 103 - Diesel and CNG Price Forecasts, Power Curve Regression

Financial Analysis Results

A financial model was developed for the Milwaukee District pilot conversion that calculated the annual cash flow (i.e., the sum for each year of capital expenditure, conversion costs, operating costs, and fuel cost savings) over a 15-year and 20-year financial horizon, using 3 diesel/CNG fuel price forecasting scenarios. We determined the following metrics to assess the financial viability of dual-fuel conversion initiative across the different scenarios:

1. Net Present Value (NPV): The current value of all the annual cash flow through the financial horizon, with each year's cash flow discounted using the assumed discount rate of return (DRR). The NPV of the cash flow for the horizon should be positive for a project to be financially viable.
2. Internal Rate of Return (IRR): The IRR is a discount rate that makes the net present value (NPV) of all future cash flows equal to zero. The IRR is compared to the DRR. The DRR is also referred

to as the hurdle rate because it is the minimum rate of return to justify investment in the initiative. The IRR should be greater than the DRR for a project to be financially viable.

3. Cumulative Discounted Cash Flow (CDCF): The CDCF is the year-by-year cumulative sum of the discounted cash flow. The chart of the CDCF is used to determine the break-even year of the initiative. The break-even year in the chart is where the CDCF line intersects with the X-axis, when the CDCF is zero (i.e., total discounted costs minus total discounted savings equal zero).

The diesel and CNG price forecast approaches serve as scenarios. The Constant Rate forecast is referred to as Scenario 01, the Historical Volatility forecast is referred to as Scenario 02, and the Power Curve Regression forecast is referred to as Scenario 03. The financial analysis results of the three scenarios are summarized in Table 31. From the analysis results, we can conclude that the dual fuel conversion initiative can be financially viable, with a 15-Year IRR between 5.4% and 8.5%, and a 15-Year NPV between $1.1MM and $9.2MM.

Table 31 - Financial Analysis Results

Financial Analysis: Results (in % and $MM)

Metric	Scenario 01	Scenario 02	Scenario 03
15-Year IRR	8.5%	5.4%	8.5%
20-Year IRR	11.9%	9.9%	11.8%
15-Year NPV @ 5% DR	$9.2	$1.1	$9.0
20-Year NPV @ 5% DR	$26.3	$19.7	$25.4

Figures 104, 105, and 106 illustrate the CDCF for each of the scenarios. The charts suggest that the break-even point occurs between 13 and 15 years into the initiative.

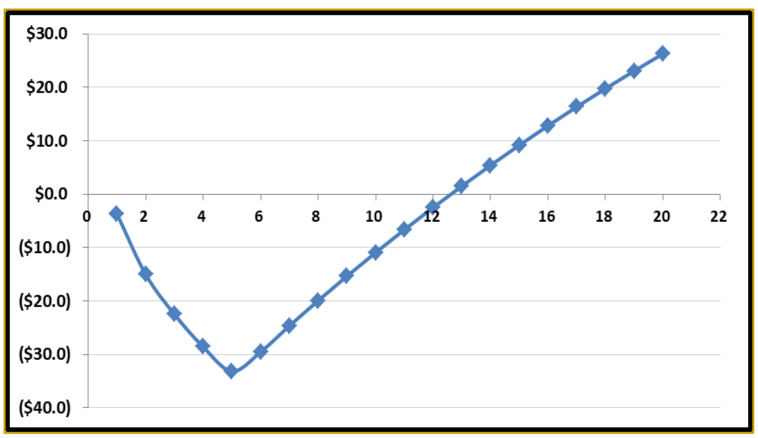


Figure 104 - CDCF for Scenario 01

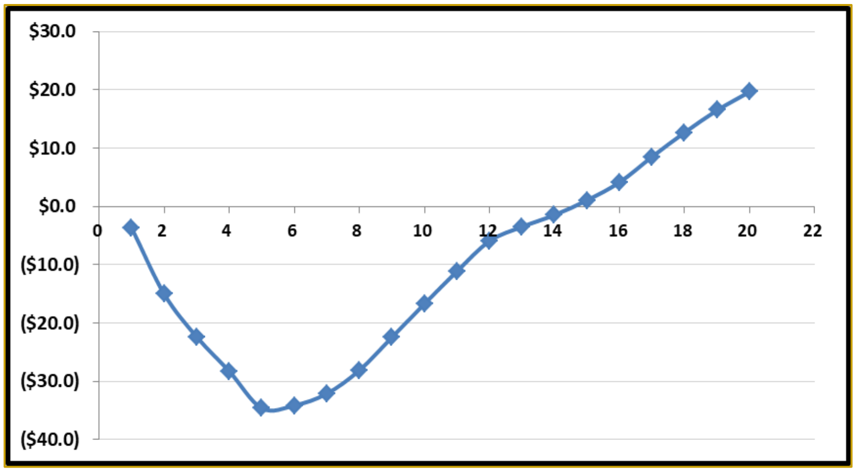


Figure 105 - CDCF for Scenario 02

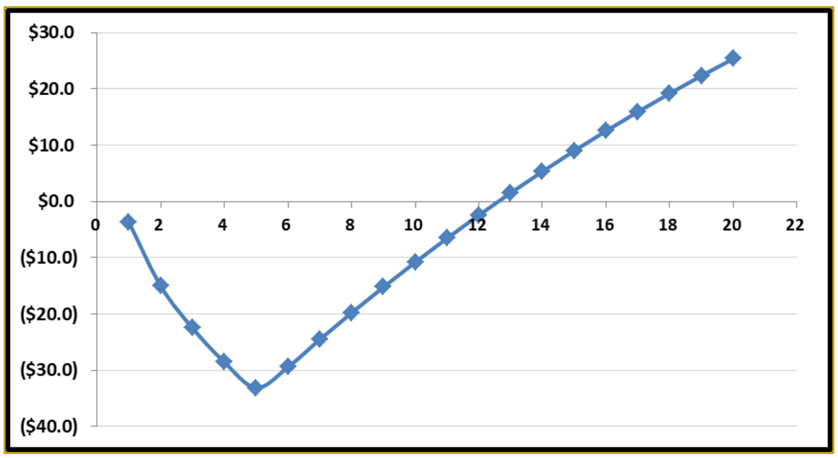


Figure 106 - CDCF for Scenario 03

The determination of financial viability will depend on Metra's internal standards on IRR and break-even years. Some organizations, such as private corporations, have very aggressive standards requiring an IRR of 20%+ and break-even point of one year. The decision to proceed with the dual fuel conversion initiative will be based on several metrics including financial viability, as well as Metra's tolerance for risk.

Potential for Exhaust Emissions Reductions

By converting 38 existing locomotives to dual-fuel capability, Metra may achieve significant reductions in emissions. By quantifying those reductions, Metra can improve its cost-benefit analysis activity. Quantification of emissions benefits may aid Metra in dealing with funding sources.

Using Metra mileage data and publicly available emissions test data, it is possible to estimate oxides of nitrogen (NO_X) and Particulate Matter (PM) reductions that would occur from substituting CNG for Diesel fuel. The estimate is limited by the data that exists for the candidate locomotives, but it is indicative of the scale of improvements that can be achieved by a CNG for diesel substitution program.

The proposed program plans on three different deployment strategies for the upgraded locomotives.

- Deployment One: upgrade sixteen MP36PH locomotives to dual-fuel units and operate them on the Milwaukee District North line.
- Deployment Two: Upgrade 22 F59PH locomotives to dual-fuel units. Nineteen of these units will replace F40PH-3 units. For this exercise we will assume that these also operate on the Milwaukee North District.
- Deployment Three: The remaining upgraded F59PH locomotives (three) will operate in revenue service. For this exercise we will assume that these also operate on the Milwaukee North District.

The total emissions benefits will be the sum of the emissions reductions associated with replacing the nineteen F40PH-3 units, and the improvements for three F59PH locomotives and sixteen MP36PH locomotives.

A methodology will be developed to estimate the annual emission benefits associated with each of the three Deployments. This methodology will employ the following:

- Performance data from the simulation runs made by LTK using the Milwaukee District North profiles and time tables.
- Two "notch schedules" for dual-fuel operation, specifying the diesel/CNG mixture by notch. These "notch schedules" were provided by a supplier of dual -fuel conversion equipment.
- Test data and emissions certification data for the emissions performance of the existing engines on the target locomotives, specifying the NOX and PM levels by notch.
- Mileage data from Metra indicating a typical year of operation.

After working through all three deployment strategies the expected emissions savings for the overall program can be calculated.

Table 32 - Emissions Savings Estimates

Annual Emissions Savings Total Deployment Program	50% CNG savings		90% CNG savings	
	NOx (tons/yr)	PM (tons/yr)	NOx (tons/yr)	PM (tons/yr)
Deployment 1- 16 MP36PHs upgraded	443	8	689	12
Deployment 2- 19 F40PH-3s replaced with 19 upgraded F59PHs	361	8	551	12
Deployment 3- 3 F59PHs upgraded	42	1	64	2
TOTAL EMISSIONS REDUCTIONS	**846**	**17**	**1304**	**26**

Methodology

This methodology will be followed for each of the three Deployment Strategies described in the Abstract.

General

It is necessary to calculate the reduction in the rate of emissions for NOx and PM that is associated with each of the two dual-fuel "notch schedules". This will be expressed as grams/hour. Then the Metra data will be analyzed to determine typical annual hours of operation, and the annual hours will be used to calculate the grams/year. This will be converted into tons/year for convenience

Since this document is calculating the reduction in emissions due to dual-fuel operation, it is only concerned with the circumstances when dual-fuel operation is employed. Dual-fuel operation is not used in Idle, Dynamic Brake, N1 or N2.

Two dual-fuel notch schedules have been provided by a supplier of dual-fuel retrofit kits. One notch schedule is titled 50% CNG. The other notch schedule is titled 90% CNG. The notch schedules are shown in the table below.

Table 33 - 50% and 90% CNG Substitution

CNG level		Notch
50% CNG	90% CNG	
0	0	1
0	0	2
0.65	0.7	3
0.8	0.7	4
0.75	0.8	5
0.7	0.8	6
0.6	0.9	7
0.5	0.9	8

The 50% and 90% titles come from the N8 mixture levels. The mixture levels or both notch schedules have very similar values for notches 3 through 6. (Note that the 50% notch schedule's CNG level is even higher than the 90% notch schedule's CNG level for Notch 4). Because of this notch schedule, a comparison of the reduction levels achieved with each notch schedule will not follow the ratio of 90/50. Another factor influences the comparison of the performance of the two notch schedules. The time spent in each notch is not equal. The LTK simulations showed substantial differences relative to the time in each notch. This is to be expected as speed limits force operation in lower notches. The different times in each notch for the Milwaukee District North simulations are shown below.

Table 34 - Data from MDN Simulation

Throttle Notch	BHP	Fuel Rate (gpm)	Time (hours)
Idle	22	3.3	
Notch 1	198	13.2	0.06
Notch 2	474	26.3	0.005
Notch 3	862	47.4	0.463
Notch 4	1090	57.9	0.027
Notch 5	1604	85.8	0.072
Notch 6	2232	116.5	0.065
Notch 7	3170	160.4	0.028
Notch 8	3735	194	0.548

The emissions that occur during the Milwaukee North District operations can be calculated. This will need to be done for each engine type involved in the three Deployment Strategies. To demonstrate the methodology the data from the 16·645F3B will be used. This engine is on the MP36PH locomotives. These results apply to “Deployment One”.

Initial Emissions Levels

From emissions test data, there are published g/BHP-hr levels for the NOx and PM that are created by this engine, when it is running in diesel only mode. This information is available for each notch. The simulation provides the information needed to calculate the BHP-hrs spent in each notch for the trip. It is possible to calculate the total grams of NOx and PM created by this engine in each notch during the trip. Then these notch values are summed to calculate the total grams of NOx and PM produced during the typical trip. Since the trip lasts 1.268 hours, the results can be scaled to represent the output for one hour of operation. This scaling factor will be useful when the data is used to calculate annual emissions values.

Here are the NO_x and PM levels per notch for diesel-only mode of operation for the 16·645F3B.

Table 35 - NOx and PM levels for 16-645F3B Engine

Notch	g/BHP-hr	
	NOX	pm
1	5.39	0.25
2	16.46	0.3
3	13.99	0.3
4	13.87	0.23
5	13	0.21
6	15.39	0.24
7	15.8	0.21
8	14.75	0.24

When these numbers are combined with the BHP-hr information from the simulation, the results are the NOx and PM emissions levels for the trip.

Table 36 - NOx and PM by trip (Fox Lake run)

	100% Diesel	
Notch	NOx (g/trip)	PM (g/trip)
1	66.297	3.075
2	39.0925	0.7125
3	6509.757	139.5945
4	506.685	8.40213
5	1755.936	28.36512
6	2766.968	43.1496
7	1528.05	20.30952
8	31248.88	508.4563
Sum	**44421.7**	**752.065**

Emissions Reductions

Using the notch schedule information, the resulting emissions levels for dual-fuel operation can be calculated. This assumes a linear relationship between the reduction in diesel fuel and the reduction in emissions.

Table 37 - NOx and PM Comparisons, Diesel Baseline and CNG 50%/90%

	100% Diesel		CNG Levels		50% CNG schedule		90% CNG schedule	
Notch	NOx (g/trip)	PM (g/trip)	50% CNG schedule	90% CNG schedule	NOx (g/trip)	PM (g/trip)	NOx (g/trip)	PM (g/trip)
1	66.297	3.075	0	0	66.297	3.075	66.297	3.075
2	39.0925	0.7125	0	0	39.0925	0.7125	39.0925	0.7125
3	6509.757	139.5945	0.65	0.7	2278.415	48.858075	1952.927	41.87835
4	506.685	8.40213	0.8	0.7	101.337	1.680426	152.0055	2.520639
5	1755.936	28.36512	0.75	0.8	438.984	7.09128	351.1872	5.673024
6	2766.968	43.1496	0.7	0.8	830.0904	12.94488	553.3936	8.62992
7	1528.05	20.30952	0.6	0.9	611.2198	8.123808	152.805	2.030952
8	31248.88	508.4563	0.5	0.9	15624.44	254.22816	3124.888	50.84563
Sum	**44421.7**	**752.065**			**19989.9**	**336.714129**	**6392.6**	**115.366**

Then by subtracting the value for each notch schedule from the diesel-only value, it is possible to calculate the emissions reductions.

Table 38 - Emissions Reductions for 50%/90% CNG

50% CNG savings		90% CNG savings		
NOx (g/trip)	PM (g/trip)	NOx (g/trip)	PM (g/trip)	Notch
0	0	0	0	1
0	0	0	0	2
4231.342	90.73643	4556.83	97.71615	3
405.348	6.721704	354.6795	5.881491	4
1316.952	21.27384	1404.749	22.6921	5
1936.878	30.20472	2213.574	34.51968	6
916.8298	12.18571	1375.245	18.27857	7
15624.44	254.2282	28123.99	457.6107	8
24431.8	**415.351**	**38029.1**	**636.699**	**Sum**

This is the savings for the entire trip. For extrapolation over a fleet, it would be more useful to show this as an hourly rate. This is done by dividing by the trip time, 1.268 hours.

Table 39 - Hourly Values for NOx and PM Reduction

50% CNG savings		90% CNG savings		
NOx (g/trip)	PM (g/trip)	NOx (g/trip)	PM (g/trip)	Notch
0	0	0	0	1
0	0	0	0	2
4231.342	90.73643	4556.83	97.71615	3
405.348	6.721704	354.6795	5.881491	4
1316.952	21.27384	1404.749	22.6921	5
1936.878	30.20472	2213.574	34.51968	6
916.8298	12.18571	1375.245	18.27857	7
15624.44	254.2282	28123.99	457.6107	8
24431.8	415.351	38029.1	636.699	**Sum**
19268	**327.56**	**29991**	**502.13**	**one-hour values**

The data in the bottom row is the emissions savings for NO_x and PM that is achieved for an hour of typical operation for these two notch schedules of dual-fuel operation.

Extrapolation to Annual Values for the Fleet

To convert the hourly values of emissions savings into annual savings, the hours of operation per year are needed. This can be derived from the total miles of operation over a year, divided by the average speed when operating.

Metra has provided a spreadsheet showing mileage data for its locomotive fleets by road number. The mileage data for 2016 reportedly represents the entire year of operation. Deployment Strategy One is focused on the MP36PH fleet. METRA's spreadsheet provides annual mileage information for 23 locomotives of the MP36PH fleet in 2016. The total mileage for those 23 units in 2016 was 1,046,052.

LTK TrainOps® simulations can provide the average speed achieved during the runs, and that average speed can be combined with the fleet mileage to determine the total hours of operation. The TrainOps® simulation of the Milwaukee District North provided values for the average speed over the line, noting the impact of station dwells and On-Time Performance rates.

Table 40 - LTK TrainOps® Average Speed Simulation Results – Milwaukee District North

Southbound:

	Trip-Weighted Average	Time-Weighted Average	Distance-Weighted Average
All Day Average Speed, mph (Including Dwells, 100% OTP)	31.34	31.33	31.62
All Day Average Speed, mph (Excluding Dwells, 100% OTP)	34.70	34.84	35.02
All Day Average Speed, mph (Including Dwells, Reported OTP)	31.18	31.19	31.48
All Day Average Speed, mph (Excluding Dwells, Reported OTP)	34.52	34.67	34.85

Northbound:

	Trip-Weighted Average	Time-Weighted Average	Distance-Weighted Average
All Day Average Speed, mph (Including Dwells, 100% OTP)	30.97	31.16	31.27
All Day Average Speed, mph (Excluding Dwells, 100% OTP)	34.73	34.96	35.03
All Day Average Speed, mph (Including Dwells, Reported OTP)	30.83	31.02	31.13
All Day Average Speed, mph (Excluding Dwells, Reported OTP)	34.55	34.79	34.87

Since emissions benefits only occur when running, it is appropriate to use the average speed that excludes dwell times at stations and turn points. However, the average speed will be reduced by slow orders, station delays, etc. The simulations were also run to reflect typical On-Time Performance, which is more representative of actual railroad operations.

Therefore, the average speed that was calculated by excluding dwell times but adjusted for On-Time Performance is appropriate for estimating emissions benefits.

The tables above show that three averaging techniques are provided for the southbound and northbound simulations. The values for all three techniques are essentially identical. Note that the highest average speed will result in the fewest hours of operation. And using the lowest hours of operation will be more conservative relative to estimating the emissions benefit. The rest of this exercise will use the highest speed shown. The average speed will be selected as 34.87 mph.

By dividing the total miles for these 23 locomotives by the average speed, we can calculate the hours of operation over the road:

Table 41 - Hours of Operation Calculation – MP36PH

MP36PH-3C locomotives in 2016	**23**
MP36PH-3C 2016 total mileage	1046052
Milwaukee District North Average Speed	34.87
2016 hours of operation- no dwell, OTP	29999

So these 23 locomotives saw 30,000 hours of operation over the road in 2016. As a sanity check, that amounts to just over 1300 hours of operation per year, or about 25 hours per week. This seems to be quite reasonable for a passenger railroad. And since more hours of operation would result in more emissions reductions, using this number is conservative.

Since 16 MP36PH locomotives are to be converted to dual fuel, it is reasonable to expect that those locomotives will see 30,000*16/23 = 20,870 hours annually. To calculate the savings in tons, take the grams/hour savings rate and multiply it by 20, 870 hours and the conversion factor of 1ton/(454g/lb*2000lb/ton). The results for these 16 locomotives are shown below:

Table 42 - NOx and PM Reductions for 16 MP36PH Locomotives

50% CNG savings		90% CNG savings	
NOx (tons/yr)	PM (tons/yr)	NOx (tons/yr)	PM (tons/yr)
442.9	**7.5**	**689.3**	**11.5**

Deployment Strategies

<u>Deployment One</u> is the installation of dual-fuel capability on sixteen MP36PH locomotives. The complete calculations for Deployment One was used above to demonstrate the methodology, and the emissions savings for Deployment One are shown in the table above.

<u>Deployment Two</u> is the replacement of 19 F40 locomotives with 19 FH59PHI locomotives that have been upgraded to dual-fuel capability. The F40 Locomotives use the 16-645E3B 3,000 hp engine. The F59PHI's use the 12-710G3 engine.

For Deployment Two, the emissions benefit will be the reduction of emissions achieved by comparing the emissions from a dual-fuel 12-710G3 engine to a diesel only 16-645E3B engine.

For a valid comparison, both calculations must use the same operating conditions. Deployment Two will use the trip notch duty cycle data that was created by the TrainOps® simulations (same as used for Deployment One). Deployment Two will use the mileage data used for Deployment One, since the mileage data provided by Metra for the FH59PH locomotives is very limited, so it might not be representative of true fleet behavior.

The first step is to establish the emissions levels of the 19 F40 locomotives that will be replaced. The table below shows the results. The data is taken from a passenger locomotive, except for the NOx data, which came from a freight locomotive of the same horsepower and engine type:

Table 43 - Emissions Results - Diesel Only

	Notch	BHP	Time in Notch (from sim)	BHP-HRS per notch	Diesel Only Operation NOX (g/BHP-HR)	PM (g/BHP-HR)	NOX (g/trip)	PM (g/trip)
	1	105	0.06	6.3	26.74	0.33	168.5	2.1
	2	363	0.005	1.815	15.29	0.34	27.8	0.6
	3	721	0.463	333.823	14.84	0.33	4953.9	110.2
	4	1030	0.027	27.81	14.9	0.25	414.4	7.0
	5	1438	0.072	103.536	14.3	0.23	1480.6	23.8
	6	1821	0.065	118.365	12.97	0.28	1535.2	33.1
	7	2492	0.028	69.776	11.72	0.24	817.8	16.7
	8	3070	0.548	1682.36	11.69	0.26	19666.8	437.4
						SUM	29064.8	630.9
				ONE HOUR VALUES			22921.8	497.6
HOURS/LOCO		1304		**ANNUAL G/LOCOMOTIVE**			29,897,995	649,011
FLEET SIZE		19		**ANNUAL GRAMS/FLEET**			568,061,907	12,331,215
CONVERT TO TONS		908000	G/TON	**ANNUAL TONS/FLEET**			**626**	**14**

The emissions rates of the 19 dual-fuel F59PHI locomotives is shown in the table below:

Table 44 - Emissions Results - Dual Fuel F59PHI, Scenario 2

				Diesel Only Operation				CNG level per notch		50% CNG schedule		90% CNG schedule	
Notch	BHP	Time in Notch	BHP-HRS per notch	NOX (g/BHP-HR)	PM (g/BHP-HR)	NOX (g/trip)	PM (g/trip)	50% CNG	90% CNG	NOx (g/trip)	PM (g/trip)	NOx (g/trip)	PM (g/trip)
1	197	0.06	11.82	14.82	0.17	175.2	2.0	0	0	175.2	2.0	175.2	2.0
2	356	0.005	1.78	14.04	0.31	25.0	0.6	0	0	25.0	0.6	25.0	0.6
3	684	0.463	316.692	12.66	0.3	4009.3	95.0	0.65	0.7	1403.3	33.3	1202.8	28.5
4	1025	0.027	27.675	10.95	0.23	303.0	6.4	0.8	0.7	60.6	1.3	90.9	1.9
5	1353	0.072	97.416	9.98	0.21	972.2	20.5	0.75	0.8	243.1	5.1	194.4	4.1
6	1719	0.065	111.735	8.99	0.25	1004.5	27.9	0.7	0.8	301.3	8.4	200.9	5.6
7	2568	0.028	71.904	9.4	0.21	675.9	15.1	0.6	0.9	270.4	6.0	67.6	1.5
8	3023	0.548	1656.604	9.15	0.23	15157.9	381.0	0.5	0.9	7579.0	190.5	1515.8	38.1
					SUM	22323.1	548.4			10057.8	247.1	3472.6	82.3
							ONE HOUR VALUES			**9672.9**	**237.6**	**2738.6**	**64.9**
			HOURS/LOCO		1304		**ANNUAL G/LOCOMOTIVE**			12,616,891	309,950	3,572,140	84,621
			FLEET SIZE		19		**ANNUAL GRAMS/FLEET**			239,720,932	5,889,058	67,870,662	1,607,804
			CONVERT TO TONS		908000	G/TON	**ANNUAL TONS/FLEET**			**264**	**6**	**75**	**2**

The emissions savings can be calculated by the difference between the values for the two locomotive classes:

Table 45 - Emissions Savings - F40 vs F59PHI (dual fuel), Scenario 2

Scenario TWO	F40's	F59 50% schedule		F59 90% schedule	
Pollutant	Emission Tons	Emission Tons	Tons Saved	Emission Tons	Tons Saved
NOX	626	265	**361**	75	**551**
PM	14	6	**8**	2	**12**

Deployment Three- Three FH59PH locomotives will be upgraded but they will not be replacing a F40 locomotive. The improvement in emissions associated with these locomotives is the difference between the emissions produced from the 12-710G3 engine before the dual-fuel conversion and the emission produced after the dual fuel conversion.

The table below shows the emissions calculations per the methodology described earlier:

Table 46 – Emissions Results - Dual Fuel F59PH, Scenario 3

				Diesel Only Operation				CNG level per notch		50% CNG schedule		90% CNG schedule	
Notch	BHP	Time in Notch	BHP-HRS per notch	NOX (g/BHP-HR)	PM (g/BHP-HR)	NOX (g/trip)	PM (g/trip)	50% CNG	90% CNG	NOx (g/trip)	PM (g/trip)	NOx (g/trip)	PM (g/trip)
1	197	0.06	11.82	14.82	0.17	175.2	2.0	0	0	175.2	2.0	175.2	2.0
2	356	0.005	1.78	14.04	0.31	25.0	0.6	0	0	25.0	0.6	25.0	0.6
3	684	0.463	316.692	12.66	0.3	4009.3	95.0	0.65	0.7	1403.3	33.3	1202.8	28.5
4	1025	0.027	27.675	10.95	0.23	303.0	6.4	0.8	0.7	60.6	1.3	90.9	1.9
5	1353	0.072	97.416	9.98	0.21	972.2	20.5	0.75	0.8	243.1	5.1	194.4	4.1
6	1719	0.065	111.735	8.99	0.25	1004.5	27.9	0.7	0.8	301.3	8.4	200.9	5.6
7	2568	0.028	71.904	9.4	0.21	675.9	15.1	0.6	0.9	270.4	6.0	67.6	1.5
8	3023	0.548	1656.604	9.15	0.23	15157.9	381.0	0.5	0.9	7579.0	190.5	1515.8	38.1
					SUM	22323.1	548.4			10057.8	247.1	3472.6	82.3

The savings associated with each notch schedule is shown below:

Table 47 - Emissions Savings - Dual Fuel F59PH, Scenario 3

50% CNG savings		90% CNG savings		
NOx (g/trip)	PM (g/trip)	NOx (g/trip)	PM (g/trip)	Notch
0.0	0.0	0.0	0.0	1
0.0	0.0	0.0	0.0	2
2606.1	61.8	2806.5	66.5	3
242.4	5.1	212.1	4.5	4
729.2	15.3	777.8	16.4	5
703.1	19.6	803.6	22.3	6
405.5	9.1	608.3	13.6	7
7579.0	190.5	13642.1	342.9	8
12265.3	301.3	18850.5	466.2	**SUM**

This can be converted into the savings for this three locomotive “fleet” by the same methods described earlier:

Table 48 - Emissions Savings - F59PH Fleet, Scenario 3

				50% CNG savings		90% CNG savings	
				NOx (g/trip)	PM (g/trip)	NOx (g/trip)	PM (g/trip)
			ONE HOUR VALUES	**9672.9**	**237.6**	**14866.3**	**367.7**
ANNUAL HOURS/LOCO	1304		**ANNUAL G/LOCOMOTIVE**	12,616,891	309,950	19,390,820	479,544
FLEET SIZE	3		**ANNUAL GRAMS/FLEET**	37,850,673	929,851	58,172,460	1,438,632
CONVERT TO TONS	908000	G/TON	**ANNUAL TONS/FLEET**	**42**	**1**	**64**	**2**

Conclusion

By combining the TrainOps® simulation results with published data regarding NOx and Particulate Matter emissions, it is possible to use Metra data for fleet usage to estimate the total NOx and PM reductions that can be achieved with conversion to CNG/diesel dual-fuel operation for the Milwaukee North District. The amount of savings is dependent on the amount of CNG substitution.

Table 49 - Estimated Emissions Reduction from CNG

Annual Emissions Savings Total Deployment Program	50% CNG savings		90% CNG savings	
	NOx (tons/yr)	PM (tons/yr)	NOx (tons/yr)	PM (tons/yr)
Deployment 1- 16 MP36PHs upgraded	443	8	689	12
Deployment 2- 19 F40PH-3s replaced with 19 upgraded F59PHs	361	8	551	12
Deployment 3- 3 F59PHs upgraded	42	1	64	2
TOTAL EMISSIONS REDUCTIONS	**846**	**17**	**1304**	**26**

This information can be used to support cost-benefit analysis activity associated with this opportunity. It may also be useful when applying for funding from outside agencies and government organizations.

Should Metra consider other opportunities involving different fleets or in different districts, this analysis would need to be repeated. The relevant information for those fleets or districts would need to be provided to enable the analysis. It should also be noted that this estimate is based on the time in throttle notch of a trip recorded on the CUS-Fox Lake run and that there will be variation in exhaust emissions based on individual train operation on different routes. In general, more time in higher throttle notches will yield lower emissions, due to the higher substitution rate of CNG.

Potential Funding Sources for Dual-Fuel Capability

Funding is available from various government agencies. The various agencies are part of the regional, state and federal governments. The agencies are chartered to use their funding to promote improvements relative to transportation or emissions.

The evaluation processes for these government agencies emphasizes emissions reduction. Since the EPA has a leadership role in this area, EPA metrics are generally used for evaluation.

A dual-fuel program at Metra will require funding for rolling stock and for infrastructure (fueling stations). Different agencies may need to be involved, since some may only fund one type of project.

State funding opportunities include:

- Illinois EPA Driving a Cleaner Illinois Program
- CMAP Transportation Programming

Federal funding opportunities include:

- US EPA Clean Diesel Program
- US DOT Better Utilizing Investments to Launch Development (BUILD)

State Funding Sources

Driving a Cleaner Illinois Program, Illinois EPA

The Illinois EPA established the Driving a Cleaner Illinois Program to allocate funding for various types of diesel emission reduction projects involving on-road vehicles, off-road equipment, and electric charging. The Driving a Cleaner Illinois Program receives funding from a variety of sources. These funding sources are summarized below, including a description of the types of projects, current funding amounts, and fund status.

Volkswagen (VW) Environmental Mitigation Trust Fund

The Illinois EPA has been is the lead agency responsible for distributing funds apportioned to Illinois from the VW Environmental Mitigation Trust. The VW Environmental Mitigation Trust was created as a result of the VW Settlement because of Clean Air Act violations relating to the installation of "defeat devices" in certain Volkswagen diesel vehicles. Illinois' initial portion of the funds is approximately $108 MM. The funds are to be spent on projects that decrease emissions of nitrogen oxides (NOx) in Illinois.

Illinois EPA submitted its plan for dispensing the funds to the Volkswagen Trustee. The plan provided for a range of projects and funding allocations, including up to approximately $32 MM for public transit projects, including cleaner diesel, alternate fueled and all-electric public transit buses and public passenger/commuter line haul locomotives.

The Driving a Cleaner Illinois Program recently completed a first round of funding involving VW Environmental Mitigation Trust Funds. The awards included the following public transit grants:

Table 50 - VW Environmental Mitigation Funds - Proposed Allocation for Chicago Area Transit

Pace Suburban Bus	Six new compressed natural gas public transit buses	$ 2,307,690	VW Round 1
Metra	Eight new Tier 4 diesel passenger/ commuter locomotives	$14,000,000	VW Round 1

Congestion Mitigation and Air Quality Improvement (CMAQ) Funds

CMAQ provides funding to state and local governments for transportation programs or projects that reduce congestion and improve air quality. The Federal Highway Administration grants this funding to State Departments of Transportation. The Illinois Department of Transportation (IDOT) has distributed funding to the Illinois EPA to grant awards to eligible applicants and projects.

Currently, the Illinois EPA has one CMAQ grant programs that can be a potential source of funding for the conversion of Metra locomotives to dual fuel engines as described below.

CMAQ Chicago Area Green Fleet Grant Program

The CMAQ Chicago Area Green Fleet Grant Program is designed to provide funding for either the purchase of new vehicles that are powered by natural gas or propane, or for converting conventionally-fueled vehicles to use natural gas or propane. The funds can also be used to purchase off-road equipment powered by natural gas, propane, or electricity. Currently, $800,000 is available for allocation through this program.

To be eligible for funding, entities must be located, and will operate the vehicles, in the counties of Cook, DuPage, Kane, Lake, McHenry, or Will or Aux Sable or Goose Lake townships in Grundy County, or Oswego Township in Kendall County.

Diesel Emission Reduction Act (DERA) Funds

The DERA State Clean Diesel Grant Program provides funding to participating states to support programs that significantly reduce diesel emissions. Through this grant program, states enter into Cooperative Agreements with the U.S. Environmental Protection Agency for overseeing the disbursement of their allocation of DERA funds for qualified projects. This funding is provided on a federal fiscal year basis.

Projects eligible for funding include the replacement of older diesel on-road vehicles, off-road equipment, or engines with new, cleaner diesel or alternate fueled vehicles, equipment, or engines. Funding is also available for the installation of certified emission control technologies on diesel vehicles or engines.

For the FY17-18, federal funding of $974,551 is currently available to Illinois EPA for grant awards.

Source: https://www2.illinois.gov/epa/topics/air-quality/driving-a-cleaner-illinois/Pages/default.aspx

The Chicago Metropolitan Agency for Planning (CMAP)

(CMAP) is the regional planning organization for the northeastern Illinois counties of Cook, DuPage, Kane, Kendall, Lake, McHenry, and Will, responsible for the development and implementation of regional plans. As part of its mandate, CMAP is also involved in Transportation Programming for the Chicago metropolitan area. CMAP helps direct the allocation of federal funds for transportation, including the Surface Transportation Program (STP), Transportation Alternatives Program (TAP), Transportation Improvement Program (TIP), and Congestion Mitigation and Air Quality Improvement Program (CMAQ).

The CMAP funding source most relevant to the RTA Alternative Fuel Study is the Congestion Mitigation and Air Quality Improvement (CMAQ) program, a federally-funded program of surface transportation improvements designed to improve air quality and mitigate congestion. CMAP oversees the program development and implementation of CMAQ-funded projects in northeastern Illinois. The Illinois Department of Transportation is responsible for distributing and administering the CMAQ funding to various eligible agencies such as CMAP and the Illinois EPA.

The CMAQ Program has identified four objectives in support of its goals of improving air quality and reducing congestion. They include: 1) Localized Congestion Relief; 2) Operational Improvements; 3) Mode Shift, and 4) Direct Emissions Reduction.

Currently, CMAP has designated the following types of projects as eligible for funding: transit improvements, traffic flow improvements, bicycle facility projects, and direct emissions reductions projects, among others. The Metra dual fuel locomotive conversion will most likely fall under the direct emissions reductions project type.

Direct Emissions Reduction Projects

According to CMAP's program description,

"*These projects reduce emissions through a variety of measures, including idle reduction, purchase of fuels that produce less emissions (beyond fuels required by law or regulation), retrofitting existing diesel engines with catalysts or filters, repowering vehicles with cleaner engines, or vehicle replacements with alternative fuel vehicles. For vehicle replacements, only vehicles types that provide a dominant transportation function are eligible for up to 80 percent funding. These types include transit buses, paratransit, freeway courtesy vans/tow trucks, incident management patrol vehicles and others. For general purpose public fleet vehicles, only the incremental cost difference between standard and alternative fuel vehicle is eligible for up to 80 percent funding*."

In December 2013, CMAP provided $34.25 million in grant funding to the Indiana Harbor Belt Railroad Co. (IHB) to convert 31 of its locomotives to operate on natural gas. The conversion of Metra locomotives to run on dual fuel energy would be similar in scope to the Indiana Harbor Belt project.

Federal Funding Sources

US Environmental Protection Agency Clean Diesel Program

The Clean Diesel Program provides grants and rebates funded by the Diesel Emissions Reduction Act. The program supports projects that improve air quality by reducing emissions from diesel engines.

The Clean Diesel Program provides different types of funding but the DERA specifies that:

1) Seventy percent of the DERA appropriation is to be used for national competitive grants and rebates to fund projects that use EPA or California Air Resources Board (CARB) verified or certified diesel emission reduction technologies.
2) Thirty percent of the DERA appropriation is allocated to the states and territories to fund programs for clean diesel projects. Base funding is distributed to states and territories using a formula based

on overall participation. (Please see the Illinois EPA Driving a Cleaner Illinois Program for details about this funding source).

Clean Diesel National Grants

Under the national grants program, the US EPA anticipates awarding approximately $40 million in competitive grant funding for the year 2019. The Program recently conducted a nationwide call for proposals for projects designed to reduce diesel emissions in terms of tons of pollution produced. Particular interest is given to fleets in areas that the Program Administrator views as poor air quality areas.

Eligible applicants for funding include regional, state, local or tribal agencies/consortia with jurisdiction over transportation or air quality. Funding can be used for diesel locomotive engines, school buses, Class 5 – Class 8 heavy-duty highway vehicles, marine engines, and other non-road engines, vehicles, and equipment.

The 2019 request for applications period closed on March 26, 2019. The 2020 request for applications is planned to open in December 2019.

Comparable grants awarded to Illinois from the DERA Clean Diesel Program include the following:

2017 National	Illinois	Chicago Transit Authority	$400,000	Replace 3 transit buses with electric buses	Transit Buses
2016 National	Illinois	Chicago Transit Authority	$1.8 million	Replace five transit buses with all-electric buses with en-route charging capabilities.	City/County Vehicle, Transit Bus
2009 ARRA National	Illinois	Illinois Environmental Protection Agency	$4.17 million	Retrofit 21 fleets (approximately 675 diesel vehicles and/or engines) with auxiliary power units, diesel oxidation catalysts, diesel multi-stage filters, direct-fired heaters and engine repowers (replace with cleaner engines).	All

US Department of Transportation BUILD Discretionary Grants

The Better Utilizing Investments to Launch Development (BUILD) program, formerly known as Transportation Investment Generating Economic Recovery (TIGER) is run under the US Department of Transportation. This program is a potential source of funding for building fueling infrastructure for dual fuel consumption locomotives, but funds from these grants are in high demand. In 2018, 851 eligible applications were received, which totaled to over $10.9 billion in requested funding, far more than the $195 million that was awarded.

Currently, $900 million is available for grants in 2019, with the maximum individual grant award of $25 million and $90 million per state. Of the available funds, up to 50% is to be granted specifically to rural projects that meet the selection criteria. It is currently not known how much funding will be available in 2020, as this is determined by the federal budget process.

The focus of the 2019 BUILD grants is on surface transportation infrastructure. Funding can be used for roads, bridges, transit, rail, ports, or intermodal transportation. Grants can also be awarded for projects that improve infrastructure condition, public health and safety, regional connectivity, economic growth or competitiveness, or energy independence. Projects are selected based on their safety, economic competitiveness, how they improve the quality of life, their state of good repair, innovation, and their partnerships with other stakeholders.

The deadline to submit an application for the FY 2019 BUILD Transportation Discretionary Grants program is July 15, 2019.

Comparable Grants Awarded in 2018 include the following project:

- BUILDing Brazos Transit District Bus Replacement Project
  - BUILD Grant Award: $14 MM
  - Project Description: Replacement of more than 30 buses with battery-electric buses.
  - Project Location: Brazos County, Texas

Other Potential Funding Sources

US Department of Energy Title XVII Innovative Energy Loan Guarantee Program

The Title XVII Innovative Energy Loan Guarantee Program provides loans, through the U.S. Department of Energy, to projects that promote the deployment of innovative energy. This includes advanced fossil fuel energy, advanced nuclear energy, renewable energy, or efficient energy. Loans can also be granted for deployment of infrastructure for alternative fueling. The RTA Alternative Fuel Study is eligible for its focus on the latter. Projects must also use technology that is new or significantly improved, reduce or avoid greenhouse gases, be located in the US, and have a reasonable prospect of repayment. This program has almost $22 billion available for loan grants, and loan guarantees can cover up to 100% of the amount of the loan granted. Loan guarantees over 80% must be issued and funded by the Treasury Department's Federal Financing Bank.

More information can be found at: https://www.energy.gov/lpo/loan-programs-office

Public Transportation Innovation Program

From the US DOT website, the description for this program states that it provides funding "to develop innovative products and services assisting transit agencies in better meeting the needs of their customers." While there are no grants currently active for this program, the status of Funding Availability can be monitored at http://www.grants.gov/ using the CFDA number 20.514.

More information can be found at: https://www.transit.dot.gov/funding/grants/public-transportation-innovation-5312

Alternative Fuel and Advanced Vehicle Technology Research and Demonstration Bonds

This funding source comes in the form of subsidized Qualified Energy Conservation Bonds issued by qualified state or local governments. The bonds are subsidized by the U.S. Department of Treasury. While the name of the program lists research and demonstration, such projects represent one example of an eligible activity for the bonds. Full eligibility criteria for this source of funding are uncertain, and further information will have to be obtained from the state or local governments.

Further information can be found at: https://afdc.energy.gov/laws/10612

Conclusion

Funding programs that provide the most opportunity for garnering the required capital for implementation of dual fuel technology include, the Illinois EPA's Volkswagen (VW) Environmental Mitigation Trust Fund ($32 MM), the CMAP CMAQ Funding Program, the US EPA Clean Diesel National Grants, the US DOT BUILD Program, and the US DOE Title XVII Innovative Energy Loan Guarantee Program.

Since most of these programs are aimed at supporting projects that significantly reduce emissions, the Metra dual fuel conversion project may not be as attractive as it needs to be if the deployment is limited to about 25% of the total fleet in the Milwaukee District. It may need to be presented as part of an overall strategy to modernize Metra's fleet and introduce 'green' initiatives, in a similar fashion to transit buses initiatives.

Conclusions

As determined from the Best Practices and Existing Conditions Report, a CNG/diesel dual fuel approach was identified as the most viable option as an alternative fuel for Metra's existing fleet, based on currently available, service proven technology. This report, the Feasibility Analysis and Conversion Details, investigated commercially available CNG storage and refueling equipment, determined possible operating ranges given the variables of fuel consumption rate, trip distances, locomotive daily range and available onboard storage capacity. Dual fuel equipment suppliers were queried with regard to locomotive conversion and fueling details. An operating scenario for the Milwaukee District was developed from a simulation model based on actual train performance data (i.e., event recorder data) for the Union Station to Fox Lake route. Potential refueling locations were surveyed for both mid-day refueling as well as overnight refueling which now becomes a requirement due to limited onboard CNG storage on the locomotives that were evaluated. Modifications to Metra's facilities were also investigated to meet NFPA requirements for servicing locomotives with onboard CNG. FRA mandated test planning and safety related documentation were studied and summarized. A financial break-even analysis was conducted based on estimated capital costs. Reduction in NOx and PM were estimated based on the operating simulation combined with the expected substitution rate for CNG. A number of potential state and federal sources were identified for funding a portion of the conversion costs; the primary aim of most of the funding sources is reduction of diesel exhaust emissions, which the CNG conversion would enable.

The Milwaukee District lent itself well to the feasibility study for the following reasons:

- The daily travel distances are typical of Metra's routes.
- The quantity of locomotives utilized on it (38) approximated the number of locomotives available in Metra's fleet that are all viable candidates for dual fuel conversion (at mid-life or less), namely the MP36PH-3C, the F59PH and the recently acquired F59PHI.
- This district is fully within Metra's control unlike the UP and BNSF districts, allowing greater flexibility in implementation.
- There is potential for a substitution of approximately 4MM gallons of diesel fuel with CNG and an annual fuel cost savings of $6.5MM annually, based on the diesel-CNG pricing differential of $1.60 used in this report.
- Good operational model data already existed for the CUS to Fox Lake route.
- The Milwaukee District (or one of its routes) could be used as a pilot program for evaluating CNG conversion before deploying on a larger scale. Also, a more limited scale than what was presented herein could also be executed as an evaluation project.

Feasibility for conversion of Metra's entire fleet in other operating districts was not evaluated due to uncertainty of what type of locomotive will replace the approximately 100 F40's that are nearing end of life. Metra may choose to replace these with new Tier 4 locomotives; dual fuel conversion has not been applied to any of the currently available Tier 4 commuter locomotives.

An evaluation was conducted of Metra's major locomotive maintenance facilities (Western Avenue and the 47th Street shops) for compliance to safely handle CNG equipped locomotives, and a preliminary survey of potential space envelopes for CNG refueling stations at all of Metra's mid-day and overnight layover facilities was also provided. From this study the following conclusions can be made:

- The Milwaukee District Operating Scenario demonstrates the feasibility of a dual fuel operation utilizing CNG; however, some operational challenges have been identified.
- The most impactful issue identified is that on-board CNG storage capacity is a limiting factor with Metra's current fleet of F59PH, F59PHI and MP36 locomotives due to limited space in the carbody and underframe areas. Initial capacity based on available onboard space was estimated to be on the order of 300 DGE of CNG and up to 1,000 gallons of diesel fuel, when utilizing a novel underframe combination storage tank concept proposed by one of the refueling station suppliers. Additional above-deck CNG storage may be possible but would require a major reconfiguration of the equipment in the car body.
    - At the estimated substitution rate of 65% CNG, these locomotives would be limited by the on-board CNG, which would be consumed at an average rate of 2.2 DGE per mile, based on the CUS-Fox Lake run simulation.
    - Because of the onboard CNG storage limitation, the MDN study identified a necessary overnight refueling scenario. This drives additional costs to install and maintain the overnight fueling stations and additional staff to perform the fueling. Weekend refueling would also be required. Metra currently has no need to refuel at remote sites and can typically operate some locomotives throughout the weekend without refueling.
    - Also because of the onboard CNG storage limitation, conversion of the separate diesel HEP engine was not considered. If more onboard CNG storage were available, the diesel HEP engines could be replaced with 100% CNG fueled engines allowing an even greater rate of diesel fuel substitution (another 20%) and additional reduction of exhaust emissions.
    - Although the CNG storage is limited, the larger volume of onboard diesel storage combined with its reduced usage, would ensure that even if all of the onboard CNG were consumed, the nature of the dual fuel engine allows it to run on diesel only.
    - It is noted that the recently acquired EMD SD70MAC (freight conversion to passenger) locomotives would have a greater CNG and diesel onboard storage capability (550 DGE of CNG and 2,000 gallons of diesel) and would be less limited in range than the smaller commuter locomotives (if converted). Per Metra, it is not planned to utilize these locomotives on the Milwaukee District.
- In the case of Metra's mid-day refueling locations, large buffer storage of CNG (up to 10,000 DGE) would be required to expedite the mid-day refueling which will require a large footprint. The site survey shows 3 of the 4 possible fueling locations on the Milwaukee District appears to have available space for installation of the CNG fueling and storage equipment with further assessment needed for the Western Avenue location. There are also several potential locations on the other districts presenting challenges.

- In the case of the Milwaukee District, if space is available, CNG refueling could be accomplished at the Western Avenue mid-day refueling site with fast fill fueling dispensers and a large buffer storage (10,000 DGE) of CNG. The proposed fueling facility presented was sized to refuel 40 locomotives in a two-hour window.
- The overhaul cycle of dual fuel engines is assumed to coincide with the same time or mileage based cycle that a diesel only engine would require. The cost of performing a dual fuel locomotive engine mid-life overhaul was assumed to be the same as a diesel only engine. Manufacturers do not have long historical data to validate life of engine components or overhaul requirements.
- Owing to the large installed base of CNG fueling stations for large vehicles such as passenger buses, commercial trucks, and other utility vehicles, the fueling equipment is readily available and largely well supported. The equipment is scalable to support the necessarily higher refueling rates and capacities for locomotives. Specific consideration will need to be given in future engineering efforts for space constraints at Metra's facilities.
- Special considerations will need to be made for Metra's locomotive maintenance facilities to ensure electrical and mechanical equipment (lights, heaters, fans, etc.) compatibility with CNG vehicle maintenance facility code requirements. An overview of necessary changes has been provided, but a more detailed assessment and equipment survey of each facility is recommended to determine design criteria before preliminary engineering work can commence.
- The proposed timeline indicated that the conversion process for the Milwaukee District is estimated to be a 4 to 5 year process once funding is available, based on the assumptions made. This is a conservative assumption based on Metra supporting the locomotive conversion with their craft labor and completing the conversions at the rate of one unit per month. The process could potentially be expedited by increasing the rate of conversions through outsourcing of the conversions.
- Accordingly, each facility and overnight fueling location design requirements will need to be thoroughly reviewed with the local Authority Having Jurisdiction (AHJ) for permit planning. This may also require community outreach and education. These efforts are hard to define and capture in this report.
- The two primary dual fuel conversion equipment suppliers, ECI/EE and Progress Rail have created the kits and they have been installed and operated in pilot projects throughout North and South America on freight railroads, however there is not a large base of installed systems on locomotives currently operating in North America, and none known to be in passenger rail service to date.
- The FRA will require a formal detailed plan to be submitted to demonstrate that locomotives utilizing CNG as a fuel can be safely operated in Metra's districts, including along specific alignments. Obtaining FRA approval is the first step in the process of dual fuel conversion. The FRA has created a Natural Gas Safety Review program for NG and alternative fuel locomotives.

- Based on the estimated capital cost assumptions shown and the diesel-CNG price forecast, payback for the investment in the CNG conversion for the Milwaukee District will take about 13 to 15 years as long as fuel prices remain somewhat predictable. If external funding is secured to cover a portion of the capital expenses, or if the price of diesel fuel rises dramatically, this would improve the payback timeframe.
- If Metra wished to perform an evaluation of CNG/diesel dual fuel on a smaller scale, one of the three lines (i.e., Fox Lake) in the Milwaukee Districct, and a limited number of locomotives could be converted along with the necessary CNG infrastructure for a pilot project. The Rock Island line may also be considered for a pilot project as it is a smaller operation than the Milwaukee District.
- It should be noted that once the investment is made in the dual fuel fleet conversion, the refueling infrastructure and other related activities, Metra would continue to benefit from the annual fuel savings indefinitely with the continued availability of dual fuel powered locomotives. To that end it is expected that this would become a requirement in the specifications for future locomotive procurements.
- Substitution of CNG for diesel fuel will have a positive effect on exhaust emissions for the converted locomotives. NO_x and PM will both decrease by proportional amounts of CNG substitution as NG burns 'clean'. It should be noted that CNG substitution begins at notch 3 in a dual fuel locomotive so exhaust emissions at idle will not change. Metra would gain the most emissions improvement by converting unregulated, Tier 0 or Tier 1 locomotives and take advantage of the immediate benefits.

It should be noted that this report was specifically prepared to review and make recommendations regarding available alternate fuels for Metra's locomotive fleet. It is beyond the scope of this report, but it is expected that Metra would also evaluate the pros and cons of dual fuel conversion against a Tier 4 diesel engine conversion. Although the fuel cost savings would not be as significant (Tier 4 engines are more fuel efficient than those in the current fleet), exhaust emissions reductions would be much greater.

Benefits of Dual Fuel Conversion

- Potential for up to 65% NG substitution for diesel, with corresponding fuel cost savings depending on degree of conversion. For the Milwaukee District, this would be on the order of 4MM gallons of diesel fuel replaced at an estimated savings of approximately $6.5MM annually at current CNG and diesel prices. If applied to all Metra districts, the annual fuel cost savings would be on the order of $26MM annually.
- Potential for PM and NOx exhaust emissions reductions as NG is a cleaner burning fuel. In addition to the fuel itself, diesel also contains dyes, and lubricants which also contribute to the particulate matter and soot.
- Significantly fewer diesel fuel deliveries (about 580 fewer diesel fuel deliveries to Western Ave. annually, for example), resulting in less traffic in and out of refueling

facilities and reduced spill potential. NG is supplied directly to each site by pipeline so no service disruptions due to weather or missed fuel deliveries.

- Dual fuel conversion allows backup operation on 100% diesel if onboard CNG is depleted.
- CNG refueling is simpler than diesel refueling as fuel stations automatically regulate and shutoff when fueling is complete.
- CNG fueling infrastructure is transit service proven, due to the large fleets of CNG powered buses (over 14,000 in operation) and other vehicles in operation for many years; fueling and NG compression equipment is readily available and scalable to Metra's fleet needs.
- The price of NG is historically more stable and not prone to the wild fluctuations of diesel fuel due to variations in supply.
- Dual fuel conversion kits are available for Metra's existing fleet (645 and 710 engine families) and conversions can be accomplished in Metra's shops by Metra personnel (with engineering support from the supplier).

Challenges for Dual Fuel Conversion

- There are very high capital costs and a multi-year timeline associated with the addition of CNG infrastructure, locomotive fleet and maintenance facility modifications to Metra's districts and a long payback period as illustrated in the provided financial analysis.
- Based on the financial model of Milwaukee District only, the break-even point may take up to 15 years, assuming no gross fluctuation in prices for either fuel. This may be near the usable life of the converted locomotives. A fifteen-year life was assumed for the locomotives after conversion and overhaul.
- There is some uncertainty about the availability of locomotives for dual fuel conversion; this study identified locomotives in Metra's fleet that are suitable for conversion, however it is unknown at this time if any of the current manufacturers would offer this option for a new locomotive.
- Additional refueling equipment will require an extensive multi-year project planning, engineering, coordination, construction, testing and acceptance planning.
- Limited on-board storage availability for CNG will drive additional refueling, impacting Metra's current operating scenarios.
- Addition of personnel at overnight refueling station locations to accomplish CNG refueling.
- Additional safety and operational training on the use of CNG will be required.
- Timely approval of all testing and conversion plans by the FRA.
- Hazard potential will require detailed hazard analyses and mitigation plans, coordination with municipalities (i.e., first responders along Metra's alignments) and extensive safety training.
- Potential noise nuisance issues with CNG pumping equipment at Metra's outlying overnight locations.

- Public perception of locomotives with CNG on board passing through multiple, densely populated communities – significant efforts for community outreach may be needed.
- Potential for additional maintenance and inspection of NG equipment on board locomotives.
- Exhaust emissions reductions, although much improved over Metra's existing diesel locomotive fleet, does not approach the reduction from EPA Tier 4 engines.
- Meeting higher emissions standards such as Tier 4 may requires more CNG and exhaust filtering apparatus.

Next Steps

The data in this report, and the Best Practices report is intended to aid the RTA and Metra in making an assessment in the feasibility of converting all or a portion of its diesel locomotive fleet to operate on an alternate fuel; the CNG/diesel dual fuel approach is proposed as it allows for a greater substitution of a lower cost and more cleaner burning fuel without compromising available horsepower and subsequently train performance. Per the equipment suppliers, the dual fuel approach does not in any way degrade locomotive operation.

These reports provide an initial assessment of the feasibility of the alternate fuel conversion and a roadmap to further investigations and studies to determine the impact to Metra, both positive and negative, on a dual fuel fleet conversion.

If Metra chooses to pursue a dual fuel approach as outlined in this report, the following recommendations are made:

- Engaging the FRA's Natural Gas Safety Review team is key to moving forward and gaining approval before any major investment is made. Contact information for the FRA Supervisory Railroad Safety Specialist is provided in the References section of this report.
- An experienced natural gas facilities engineering consultant should be brought on board who can guide Metra through the CNG conversion process, encompassing safety requirements, NG supply, pressurization, storage and fueling, local, state and federal regulations, etc. Pace used this approach to successfully launch their CNG bus project.
- Contact with the NG suppliers in proximity to each facility to determine available gas line pressure to discuss what is needed to provide the gas volumes required at each fueling location.
- A detailed site survey and engineering study of each fueling location to determine suitability of each site for the pumping, storage and dispensing stations.
- A detailed review of Metra's maintenance shops to determine the scope of changes required to be code compliant for handling CNG fuel locomotives.
- Contact with the equipment suppliers identified in this report to begin discussion on the conversion details and detailed cost estimates for the locomotive modifications and the fueling equipment. The cost estimates provided herein are rough order of magnitude.

- Contact with locomotive manufacturers to explore the option of providing dual fuel Tier 4 locomotives for future procurements; and the development of associated specification requirements for future locomotive procurements.
- Development of a more detailed break-even analysis to better evaluate the financial side of the project. The analysis presented makes many assumptions and is considered conservative. Receipt of public funding was not considered to offset the capital cost.
- Monitoring of new motive power technology. The CNG dual fuel approach was selected based on its availability and applicability to Metra's existing fleet. While there is limited development in North America, Europe has been more aggressive in mandating a path away from diesel engines in rail transportation.
- For a local perspective on a CNG based dual fuel conversion process currently underway, Metra may wish to reach out to the Indiana Harbor Beltway to learn more about their switcher conversion process. The supplier of the dual fuel engines, Optifuel, may be contacted to arrange this if Metra is interested.

Abbreviations

AESS	Automatic Engine Start Stop
AHJ	Authority Having Jurisdiction
ANSI	American National Standards Institute
ASLRRA	American Short Line and Regional Railroad Association
ASTM	American Society of Testing Materials
BTU	British Thermal Unit
CNG	Compressed Natural Gas
CO	Carbon Monoxide
CDCF	Cumulative Discounted Cash Flow
DBA	Doing business as
DGB	Dynamic Gas Blending
DGE	Diesel Gallon Equivalent
DRR	Discounted Rate of Return
DME	Dimethyl Ether
DMU	Diesel Multi Unit
DOC	Diesel Oxygen Catalyst
DOD	Department of Defense
DOE	Department of Energy
DOT	Department of Transportation
DPF	Diesel Particulate Filter
EFI	Electronic Fuel Injection
EMD	Electromotive Diesel
EPA	Environmental Protection Agency
FRA	Federal Railroad Administration
GE	General Electric
GNG	Gaseous natural gas
Gpd	Gallons per day
Gpm	Gallons per minute
HC	Hydrocarbon
HEP	Head End Power
HPDI	High Pressure Direct Injection
IFC	International Fire Code
IRR	Internal Rate of Return
LFL	Lower Flammable Limit
LNG	Liquid Natural Gas
LPG	Liquid Petroleum Gas
MCC	Motor Control Center
MUI	Multi-Unit Injection
NEC	National Electrical Code
NFPA	National Fire Protection Association
NG	Natural Gas
NGV	Natural Gas Vehicle

NO_x	Oxides of Nitrogen
NPV	Net Present Value
PLC	Programmable Logic Controller
PM	Particulate Matter
RNG	Renewable Natural Gas
RTA	Regional Transportation Authority
SCF	Standard Cubic Foot
VAC	Volts AC

References

Technical Reports

Coradia iLint Product Sheet, Alstom SA, 2016

Dr. A. Chris LaFleur, Dr. Katrina M. Groth, Dr. Huafei Liao, Carlos Lopez and Alice B. Muna, Sandia National Laboratories ; "LNG Safety Assessment Evaluation Methods", U.S. Department of Transportation Federal Railroad Administration, July 2016

Kay Kelly and Margo Melendez, National Renewable Energy Laboratory; "Compressed Natural Gas Vehicle Maintenance Facility Modification Handbook", United State Department of Energy, September 2017

Jason Schug, Vyom Neeraj, James Paul, and Marc Wiseman, Ricardo Strategic Consulting "Review of Codes, Standards, and Regulations for Natural Gas Locomotives", U.S. Department of Transportation Federal Railroad Administration, June 2014, This document is available to the public through the FRA Web site at http://www.fra.dot.gov

Robert Lauby, US Department of Transportation, Federal Railroad Administration August 26, 2013 to Messrs. Fronczak, AAR; Streicher, ASLRRA; and Sanders, APTA; letter providing information to be submitted to the FRA prior to a meeting on the use of natural gas in railroad service

Frey, H. C., & Hu, J. (2015) "Measurement of Locomotive Head End Power Engine Fuel and Emissions" North Carolina State University, Department of Civil, Construction and Environmental Engineering. Raleigh, NC: North Carolina Department of Transportation.

Michael J Logue, US Department of Transportation, Federal Railroad Administration May 13, 2013 to Mr. Patrick Brady, Assistant Director, Hazardous Materials, BNSF Railway, letter regarding the regulation of natural gas as locomotive fuel

Nott, Dennis and Ray Plaugher, Ray "Locomotive Update, MK1200G LNG Powered Switcher", Proceedings of the 59th Annual Meeting, Chicago, September 15-17, 1997, Locomotive Maintenance Officers Association

Optifuel Systems, LLC, "Dual-Fuel Systems for IHB CNG-Powered Switcher Locomotives Near Integration", NGV Global News, May 7, 2017

Schug Jason, Neeraj, Vyom, Paul, James, and Wiseman, Marc, Ricardo Strategic Consulting, Review of Codes, Standards, and Regulations for Natural Gas Locomotives" prepared for U.S. Department of Transportation, Federal Railroad Administration, June 2014

Semple, J David "Natural Gas Powered Locomotives", presented at the Conference on Railway Excellence, 5-7 May 2014, Adelaide, Australia

Stagl, Stagle"Liquefied natural gas could help railroads reap locomotive benefits if regulatory, technical issues are resolved", Progressive Railroading, March 2014

US Department of Energy, Clean Cities Alternative Fuel Price Report, July 2018

US Environmental Protection Agency 40 CFR §1033 Control of Emissions from Locomotives

University of California, Davis, University of California, Berkeley, "California Dimethyl Ether Multimedia Evaluation Tier I Final Draft", February 2015

Vantouno, William C.,"LNG Power, A history lesson" Railway Age, May 31, 2018

Vantouno, William C , "FEC Goes LNG", Railway Age, November 10, 2017

Spitfire Energy Advisors, Brad Williams "Liquefied Natural Gas to Displace Diesel Fuel an LNG Development Plan Outline", slide presentation, undated

Applicable Standards

Department of Defense, MIL-STD-882E, System Safety, May 11, 2012

NFPA (National Fire Protection Association) NFPA 30A

US Department of Transportation, Federal Railroad Administration, 49 U.S.C. Chapter 207, Locomotives

Chicago Electrical Code (American Legal Publishing Corporation) website, http://www.amlegal.com/codes/client/chicago_il/

Chicago Building Code (American Legal Publishing Corporation) website, http://www.amlegal.com/codes/client/chicago_il/

Locomotive Dual Fuel Conversion Equipment Websites

Engenious Engineering™ Website: http://www.energyconversions.com/index.html

CNG Motive Website: https://cngmotive.com/

Optifuel Systems Website: http://optifuelsystems.com/

Rail Propulsion Systems Website: http://railpropulsion.com/

US DOE Alternative Fuels Data Center website: https://afdc.energy.gov/fuels/

ANGI Energy Systems website, https://www.angienergy.com/

Facilities Equipment Suppliers

Fire Engineering, https://www.fireengineering.com/articles/2016/12/building-construction-penetrations.html

Industrial Fans Direct, https://www.industrialfansdirect.com/collections/explosion-proof-fans-and-blowers

Sunstar Heaters: https://sunstarheaters.com/tube-heaters/

C.J. Anderson and Co.: http://www.cjanderson.com/http/www.cjanderson.com/conduitoutletboxesfittingsandunions-2.aspx.aspx

World Wide Electric: https://www.worldwideelectric.net/resource/electric-motors-how-to-read-the-nameplate/

Hubbell: https://www.hubbell.com/hubbellindustriallighting/en/Products/Lighting-Controls/Harsh-Hazardous-Lighting/High-Bay---Low-Bay---Well-Glass/CLH-Series/p/1983146#prod-detail-section

Roberts Gordon: http://www.robertsgordon.com/corayvac-sf-infrared

Other

Compressed Natural Gas (CNG) Safety Data Sheet, Irving Oil Refining G.P. Box 1260 Saint John, NB E2L 4H6 CA, Issue date 11-October-2018

Contact Information

Federal Railroad Administration – Natural Gas Safety Review Team
Gary Fairbanks
Department of Transportation
Supervisory Railroad Safety Specialist
(202) 493-6322
gary.fairbanks@dot.gov

Illinois EPA Midwest Clean Diesel Initiative
Darwin Burkhart
Manager, Clean Air Programs
Illinois Environmental Protection Agency
Phone: (217) 524-5008
darwin.burkhart@illinois.gov

Appendix A

Appendix A Contents

C5284 Metra Alternative Fuels Study Simulation Results

LTK Engineering Services

Metra Alternative Fuels Study
Simulation Results

Prepared for:
Regional Transportation Authority

by:
LTK Engineering Services

Document Number: LTK.C5284.01

May 23, 2019

Metra Alternative Fuels Study Simulation Results

Table of Contents

0 Revision History

Revision No.	Date	Description of Revision
0	12/28/2018	Initial Release
1	05/23/2019	Updated calculation of fuel used by case trip. Added calculation of volumes of diesel fuel which can be replaced by CNG based on new data from a supplier.

1 Introduction

LTK Engineering Services has been commissioned to assess the viability of converting some portion of the Metra commuter rail system's diesel locomotive fleet to utilize alternative fuels. The goal of such a conversion is to reduce emissions, improving air quality for northeastern Illinois and locally within confined spaces of certain Metra stations.

In order to do so, a conventional diesel-powered and hypothetical alternative-fuel-powered locomotive have been modelled using TrainOps® rail network simulation software, based on vehicle performance characteristics provided by Metra and by rail equipment suppliers. This model is used to quantify the effect of locomotive alternative fuel conversion on travel times, fuel consumption, and emissions.

A preliminary modelling effort was undertaken to ensure the accuracy of the model, by calibrating travel times and fuel consumption outputs for the existing Metra MP36PH-3C locomotive to their present-day values, as measured or estimated from available performance data. The calibration process consists of first matching simulated travel times and speed profiles, then calculating fuel consumption for a matched trip, applying corrective factors as necessary and appropriate to match the source data. All simulations were performed on the Milwaukee District North Line, since the most complete source data on vehicle performance and fuel consumption was only available for this service.

The resulting baseline simulation model serves as a benchmark with respect to travel times, full consumption and emissions. Based on equipment performance data provided by a supplier, a future alternative-fuel scenario has been compared to this benchmark trip. The alternative fuel of choice is a "dual-fuel" mixture of conventional diesel and compressed natural gas (CNG). It is possible to modify existing diesel engines to accept such a mixture, with the ratio of the two fuels varying depending on the engine's power output in order to maximize the available tractive effort. The substitution of CNG for a substantial fraction of the diesel fuel which would otherwise be consumed by a standard revenue trip has implications for the type and quantity of emissions generated.

An additional potential benefit of incorporating CNG fuel may be reduced fuel cost and reduced exposure to fuel cost fluctuations. However, these benefits are not addressed within this memorandum, which is focused on the physical performance of Metra's fuel-powered locomotives.

2 Metra Performance Data

2.1 Vehicle Performance

Two sources of data were used as the basis for assessing real-world Metra performance. Both sources concern operations on the Metra Milwaukee District. One source is event recorder data from locomotive 422, an MP36PH-3C operating on the Milwaukee District North Line and hauling six gallery cars. The event recorder data which was analyzed spans from October 12, 2018 to October 14, 2018.

The second source calibration data consists of six Milwaukee District West Line trip speed profiles recorded by GPS receiver on May 11 and 12 of 2017, with three trips traveling in each direction. The Milwaukee District West Line diverges from the Milwaukee District North Line at the interlocking CP A-5, at Milepost 5.5. As such, the speed profiles of the Milwaukee District West Line trips are only a valid representation of the speed profiles of a Milwaukee District North Line trip between Chicago Union Station and Tower A-4, the signal approaching the diverging move. The trips recorded used a variety of locomotives and consists, so not all speed profiles are directly comparable to any individual simulated consist. The source trips for each of the data sources plotted for calibration are summarized in Table 1.

Table 1: Trips Recorded for Vehicle Performance Calibration

Trip	Locomotive Model	Number of Gallery Cars + Cab Cars	Data
2205	MP36PH-3C	7	GPS
2215	F40PH-3	6	GPS
2209	F40PH-3	6	GPS
2230	MP36PH-3C	6	GPS
2234	F40PH-3	5	GPS
2230	F40PH-3	6	GPS
2102	MP36PH-3C	6	Event Recorder
2601	MP36PH-3C	6	Event Recorder

Both sources of speed profile data are subject to certain types of error. The GPS data consists of a series of time-stamped geographic coordinates. Speed is derived as the distance between each time-adjacent pair of coordinates, divided by the time interval. There is some error in the measurement of each location, such that even at rest the location at sequential recorded data points is not constant. As a result, the total distance recorded along a path tends to exceed the actual distance travelled by the GPS device. Moreover, it is difficult to precisely identify the duration of a station stop using the speed profile alone. GPS location measurement precision is affected by many factors, including the built environment surrounding the receiver and the constellation of GPS satellites available at each recording time-step. The GPS signal becomes highly inaccurate within the last mile of track approaching Chicago Union Station for all trips, due to the surrounding structures which obstruct the satellite signals.

By contrast, the event recorder data records speed as a function of the rotational velocity of the train's axles, using the diameter of the wheel to calculate the linear distance travelled in each time-step. Distance travelled is computed as the integral of the speed signal. Any minor difference between the actual wheel diameter and the value used to compute distance travelled, or any rotation of the axle which does not advance the wheel (slippage), introduces error into both the speed measurement and the distance measurement on a linear basis. However, unlike GPS data, the event recorder data clearly delineates station stops.

Based on the track distance between stations shown on the Metra track charts, the distance travelled during each time-step in the event recorder data was re-scaled in order to sum to the correct total distance between Fox Lake Station and Chicago Union Station. The scaling factor was obtained by comparing a sample of five trips in each direction, which confirmed that event recorder distances are consistently 1.027% longer than track chart distances. This linear error is consistent with the hypothesis that the wheel diameter used to calculate distance travelled from rotational frequency is slightly inaccurate, though there may be other causes. The Event Recorder speed profiles shown in Figure 1 and Figure 2 reflect this re-scaling of the raw data, affecting both speed and distance travelled, which is the integral of the speed.

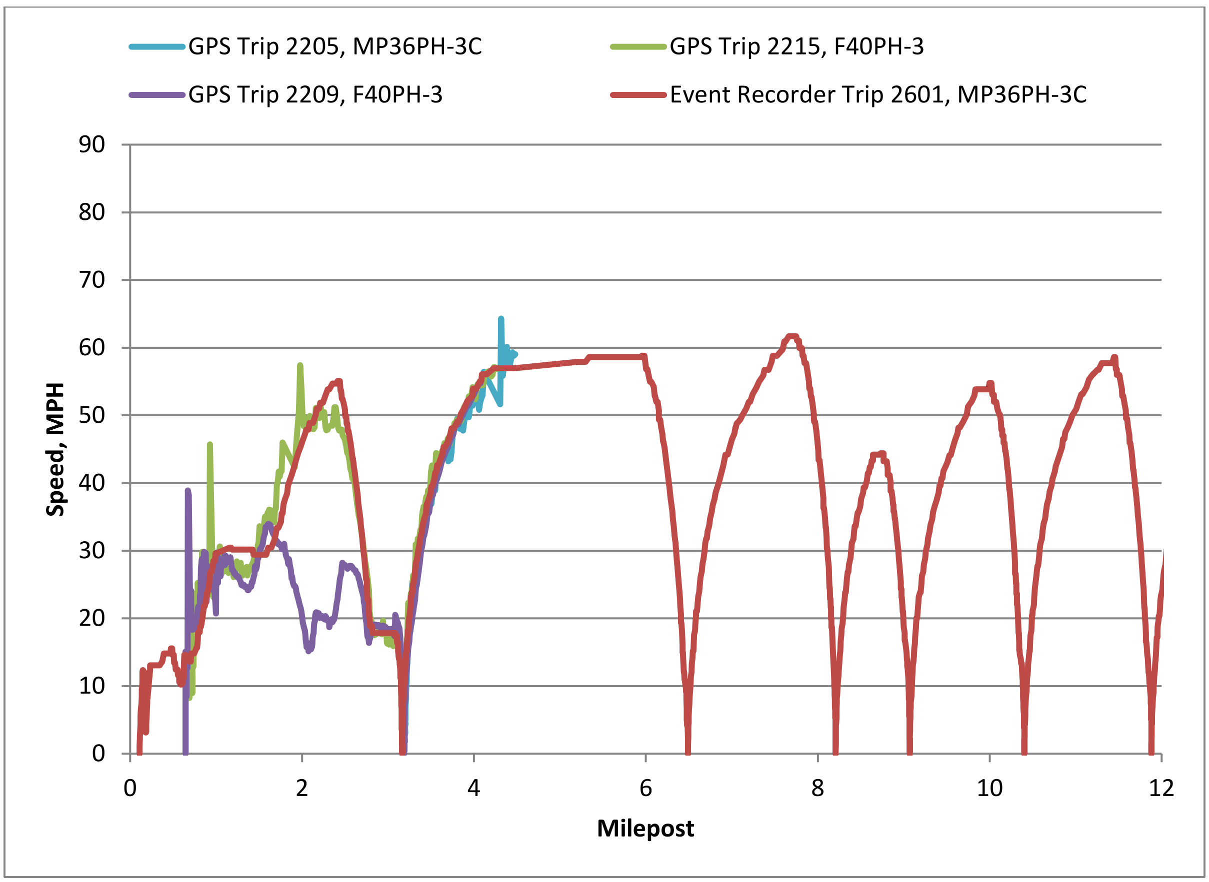


Figure 1: Northbound Speed Profiles (CUS on Left)

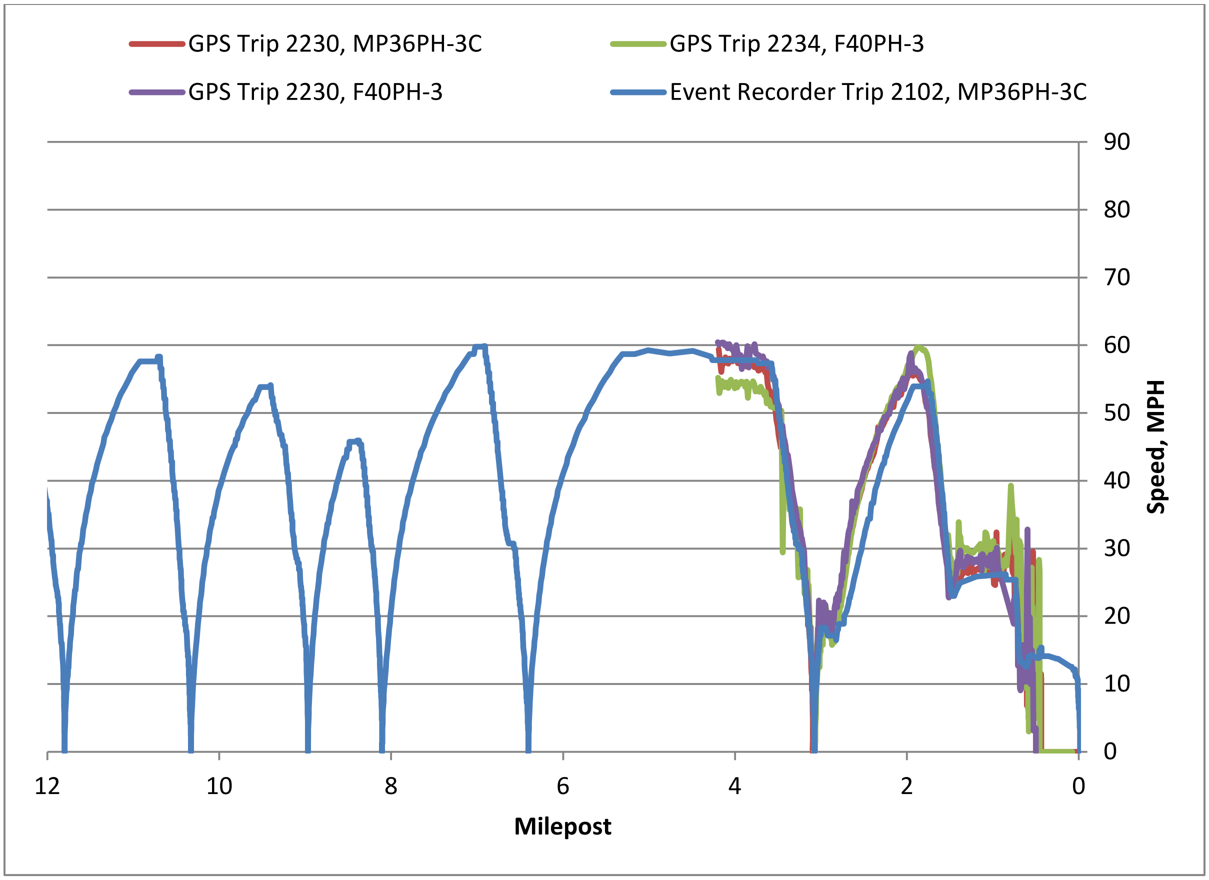


Figure 2: Southbound Speed Profiles (CUS on Right)

One important vehicle performance characteristic which cannot readily be derived from technical specifications is the practical service brake rate. While any vehicle will be limited in its ability to decelerate by the maximum brake force which can be applied, passenger comfort generally dictates that engineers brake into stations at a more gradual rate. To assess the range of standard practices for trips led by the MP36PH-3C, the event recorder data provided for locomotive 422 was sampled to identify station stops. An example speed and acceleration profile is presented in Figure 3.

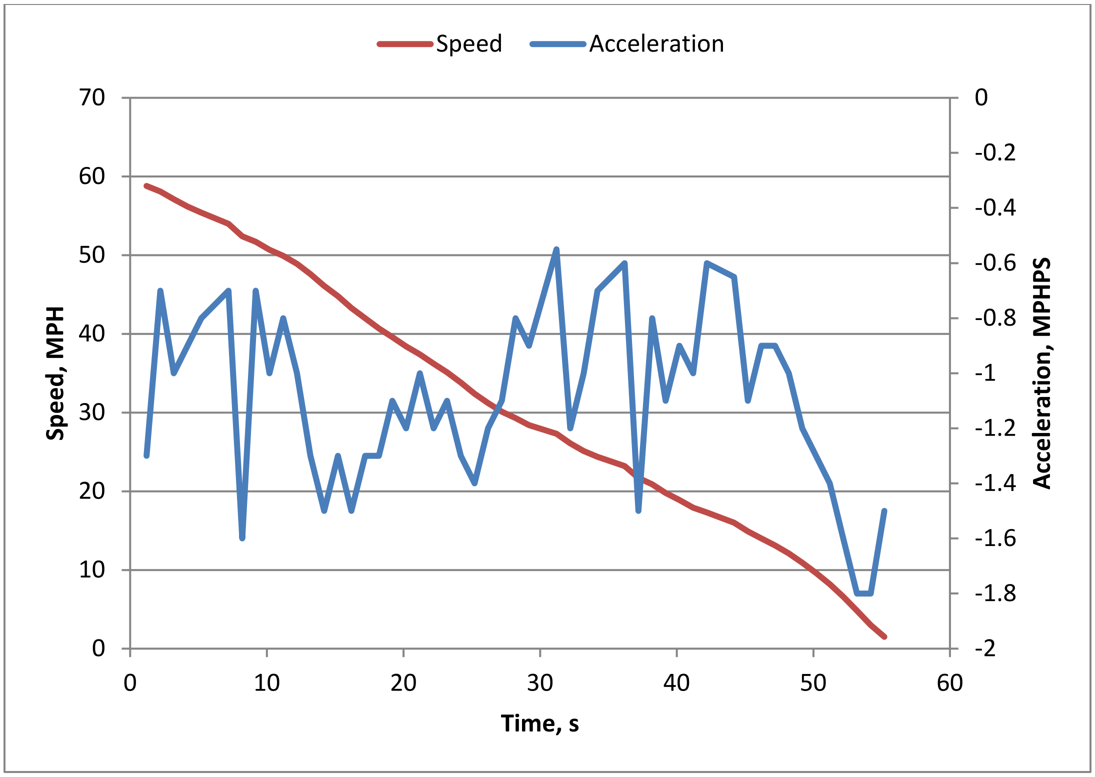


Figure 3: Acceleration Profile for Trip 2102 Braking into Morton Grove Station, MP36PH-3C + 5 x Nippon-Sharyo Gallery Cars + 1 x Nippon-Sharyo Cab Car

The range of observed brake rates across a sample of station stops identified as having similarly uniform braking profiles are summarized in Table 2.

Table 2: Typical Station-Stop Brake Rates for MP36PH-3C Consist

Station	Average Brake Rate, MPHPS
Morton Grove, Southbound	1.100
Forest Glen Station, Southbound	1.077
Edgebrook, Northbound	0.874
Mayfair, Southbound	0.989

Based on the largest value observed in this sample, the target brake rate in simulation has been limited to 1.1 MPHPS for consists led by an MP36PH-3C. This is significantly lower than the full service brake rate of the train but is reflective of practical train handling in daily operation.

2.2 Fuel Consumption

The primary source available for assessing present-day fuel consumption by Metra's diesel locomotives is a study performed during the fall of 2017. This study calculated fuel consumption for each of several variants of different diesel-powered locomotives, based on four days' worth of data from trip 2125 on the Milwaukee District North line. In addition to the locomotive, Trip 2125 is comprised by seven passenger cars, which are assumed to be six Nippon-Sharyo gallery cars and one Nippon-Sharyo cab car, based on the Equipment Cycle sheets for the Milwaukee District North. Fuel consumption for each trip was calculated based on approximate fuel gauge readings before and after each round trip, and, separately, based on the volume of fuel added after each round trip.

However, there are several variables which limit the applicability of the results to the Metra Alternative Fuels Study. These results provide only a rough estimate of fuel consumption to compare against more nuanced analysis. The precision of the fuel gauge readings in the 2017 data is low: on the order of +/- 50 gallons per trip. The volume of fuel added after each trip is recorded more precisely, to the single gallon. However, the volume of fuel consumed includes an inbound and outbound trip, as well as a layover at Chicago Union Station and one or more trips between the yard and Fox Lake Station. Without additional information regarding the duration of the dwell at Chicago Union Station, the power output of the locomotive during the dwell, and the duration and speed profile of both the inbound and outbound trip, and confirmation that all test trips included the same passenger vehicles, the resulting estimate of fuel consumption cannot be directly compared to the calculated fuel consumption during simulated trips discussed below in Section 3.2. However, these values do provide a check that any calculated fuel consumption value is within reason, with the understanding that the per-mile fuel consumption values are likely higher than in actual operation.

With these caveats, fuel consumption estimates provided in the Metra study are summarized in Table 3.

Table 3: Metra Fuel Study Consumption Estimates for a Southbound Trip by Locomotive

Locomotive Model	Fuel Per Mile, gal	
	By Gauge Reading	By Fuel Added
F40PH-3 with EFI	6.82	4.66
MP36PH with EFI and CAT Engine	4.29	3.88
F40PH-3 with MUI	4.04	4.72
MP36PH with CAT	3.03	3.53
MP36PH with Inverter	3.03	3.72
F59	N/A	3.58

The vehicle modeled for calibration corresponds to the MP36PH with EFI and CAT Engine, identified elsewhere as “MP36PH-3C.” Since this is the only locomotive for which data is available for both performance (speed profile) calibration and fuel consumption, this is the only vehicle for which full results have been computed.

3 Calibrating Simulated Performance

3.1 Matching Vehicle Performance

In order to correct for effects which limit trip performance in the real world, the initial simulation results based on ideal inputs were corrected using a schedule margin. Schedule margin is a performance limitation imposed on a simulated trip's theoretical acceleration, speed and dwell times, to account for such effects as variability in operator behavior, mechanical variability (not all traction motors operating at peak performance) and platform dwell variation. With 10% schedule margin, a simulated trip which takes 100s under ideal conditions (a so-called "golden run") will take 110s in simulation.

In order to compute the appropriate schedule margin, travel times between stations in an ideal "golden run" TrainOps simulation were compared to event recorder data for an all-stops local trip in each direction. These station-to-station travel times are presented in Table 4 and Table 5, which represent comparisons to northbound Trip 2601 and southbound Trip 2102, respectively. The appropriate schedule margin was assessed based on the average observed difference between the simulated and recorded travel time through each track segment between stations.

All trips were simulated with a dwell time at each inline station of 35 seconds, based on the average dwell time observed in a sample of the event recorder data for revenue trips.

Table 4: Northbound Station-to-Station Travel Time Comparison for Trip 2601

Track Segment	TrainOps, 0% Schedule Margin	Event Recorder for 10/7/2018	Recorded / Simulated Travel Times
Chicago Union Station – Western Avenue	07:45	08:21	1.078
Western Avenue – Healy Station	04:30	04:51	1.078
Healy Station – Grayland Station	02:54	03:00	1.034
Grayland Station – Mayfair Station	01:56	02:11	1.129
Mayfair Station – Forest Glen Station	02:33	02:38	1.036
Forest Glen Station – Edgebrook Station	02:34	02:47	1.083
Edgebrook Station – Morton Grove Station	03:54	03:50	0.983
Morton Grove Station – Golf Station	02:53	03:09	1.093
Golf Station – Glenview Station	02:21	02:26	1.035
Glenview Station – North Glenview Station	02:45	02:52	1.039
North Glenview Station – Northbrook Station	03:23	03:27	1.021
Northbrook Station –	02:57	03:06	1.050

Track Segment	TrainOps, 0% Schedule Margin	Event Recorder for 10/7/2018	Recorded / Simulated Travel Times
Lake-Cook Road Station			
Lake-Cook Road Station – Deerfield Station	02:27	02:25	0.983
Deerfield Station – Lake Forest Station	04:52	05:02	1.033
Lake Forest Station – Libertyville Station	09:01	10:11	1.130
Libertyville Station – Prairie Crossing	04:59	05:47	1.161
Prairie Crossing – Grayslake Station	02:45	02:53	1.048
Grayslake Station – Round Lake Station	04:15	06:11	1.456
Round Lake Station – Long Lake Station	03:02	03:38	1.199
Long Lake Station – Ingleside Station	02:55	03:23	1.162
Ingleside Station – Fox Lake Station	03:14	04:29	1.388
Average			**1.106**

Table 5: Southbound Station-to-Station Travel Time Comparison for Trip 2102

Track Segment	TrainOps, 0% Schedule Margin	Event Recorder for 10/8/2018	Recorded / Simulated Travel Times
Fox Lake Station - Ingleside Station	03:11	03:23	1.064
Ingleside Station – Long Lake Station	02:57	02:59	1.013
Long Lake Station – Round Lake Station	03:09	03:13	1.023
Round Lake Station – Grayslake Station	04:15	05:34	1.311
Grayslake Station – Prairie Crossing	02:50	03:05	1.088
Prairie Crossing – Libertyville Station	04:49	05:07	1.063
Libertyville Station – Lake Forest Station	08:56	09:58	1.116
Lake Forest Station – Deerfield Station	04:53	04:56	1.011
Deerfield Station – Lake-Cook Road Station	02:23	02:35	1.080
Lake-Cook Road Station – Northbrook Station	02:57	03:15	1.103

Track Segment	TrainOps, 0% Schedule Margin	Event Recorder for 10/8/2018	Recorded / Simulated Travel Times
Northbrook Station – North Glenview Station	03:19	03:28	1.046
North Glenview Station – Glenview Station	02:47	03:04	1.099
Glenview Station – Golf Station	02:19	02:35	1.115
Golf Station – Morton Grove Station	02:51	03:00	1.054
Morton Grove Station – Edgebrook Station	03:52	03:55	1.014
Edgebrook Station – Forest Glen Station	02:32	03:11	1.259
Forest Glen Station – Mayfair Station	02:34	02:42	1.049
Mayfair Station – Grayland Station	01:56	02:05	1.079
Grayland Station – Healy Station	02:52	03:24	1.184
Healy Station – Western Avenue	04:29	04:59	1.110
Western Avenue – Chicago Union Station	07:47	08:35	1.103
Average			**1.095**

Based on the average difference observed between the northbound and southbound trip, a schedule margin of 10.0% was applied to all simulations. The simulated travel times for a local trip with this calibration factor applied are compared to the equivalent event recorder data in Table 6.

Table 6: Simulated vs. Recorded End-to-End Travel Time Only (No Station Dwells)

Trip	TrainOps Simulation, 10% Schedule Margin	Event Recorder Data	Recorded / Simulated
2102 (Northbound)	1:24:51	1:26:38	1.021
2601 (Southbound)	1:24:39	1:25:04	1.005

The speed profiles of TrainOps simulated trips with and without the calculated 10% schedule margin are presented in Figure 4 and Figure 5. Note that without schedule margin, the simulated trips achieve a top speed between each station similar to that of the trips recorded by both the GPS and the Event Recorder. However, with schedule margin the simulated trips do not reach the same top speed as in the observed trips. The reason the lower top speed does cause the simulated trip time to exceed the observed trip time is that simulated trips are more aggressive in accelerating out of and decelerating into station stops than actual engineers. While it is not readily visible in the speed profiles indexed against distance shown in Figure 4 and Figure 5, much of the disparity between simulated and observed travel times is due to more aggressive acceleration and deceleration into and out of each station stop. This discrepancy exists because the simulation program always commands the maximum theoretically possible performance from the vehicle, unlike a real operator, who is likely to "feather" braking and acceleration for passenger comfort and flexibility in final train position.

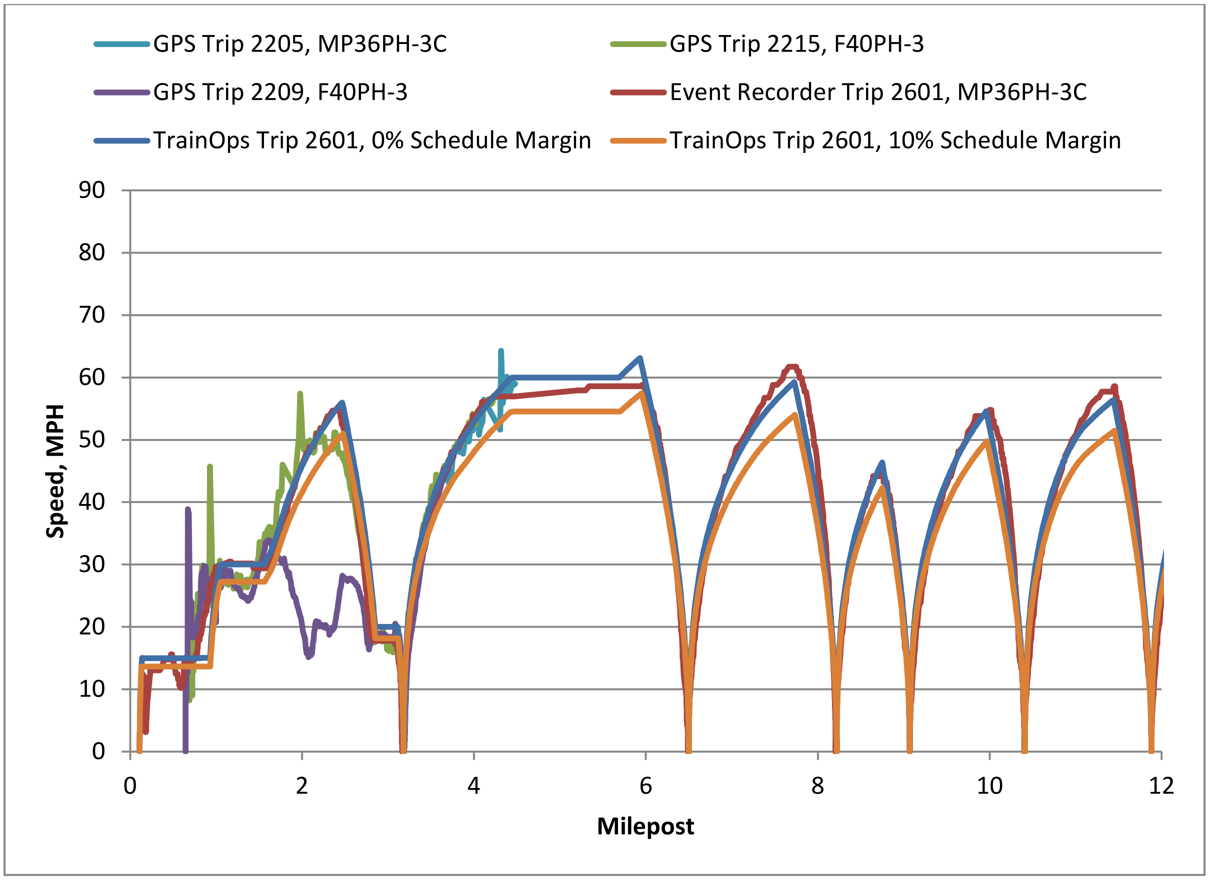


Figure 4: Simulated Northbound Speed Profiles

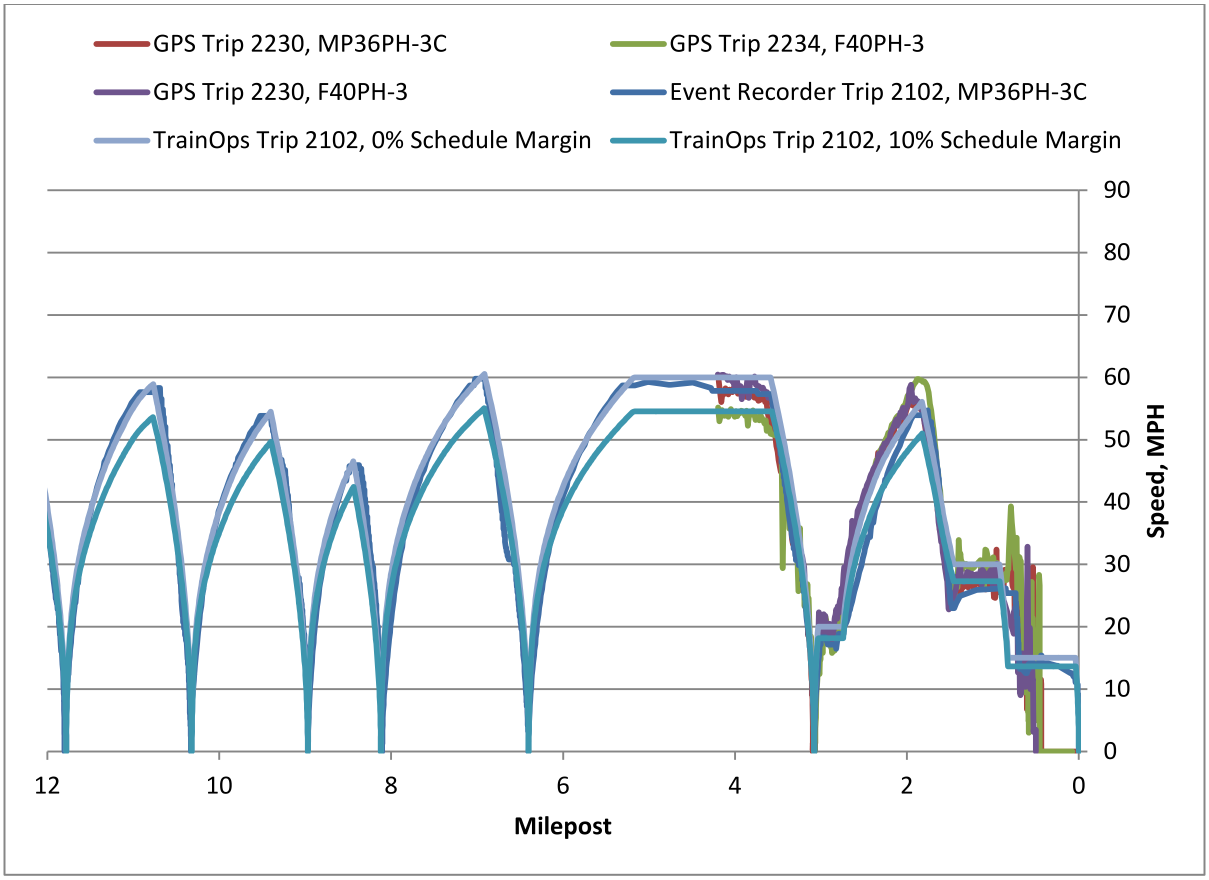


Figure 5: Simulated Southbound Speed Profiles

While these calculations demonstrate that a 10% schedule margin is appropriate and necessary in order to match observed travel times, de-rating acceleration poses a problem when calculating fuel consumption based on simulated train performance. In order for the simulation software to calculate the power commanded to produce effort at the rail correctly, the schedule margin must be 0% (no schedule margin). With schedule margin, the simulated train will never demand the maximum power, skewing the engine's apparent notch setting downward. In order to compromise between the conflicting requirements that the simulation match observed travel times, while making using the full range of engine notch settings, dwell times are adjusted. The simulation uses no schedule margin, which serves as the basis for the notch setting profile of the trip. However, dwell times are increased in order to match the total end-to-end travel time by the appropriate fraction required by the schedule margin; in this case, 10%. The difference between the theoretical travel times achieved in the model and the observed real-world travel times are thus reckoned as time at idle, with the HEP generator running, rather than de-rating train performance while moving.

3.2 Matching Fuel Consumption

In order to allow a direct comparison against the available fuel consumption data sources, Trip 2125 was simulated in TrainOps using a consist of six Nippon-Sharyo gallery cars and a single Nippon-Sharyo cab car, led by an MP36PH-3C.

The calculation process for deriving fuel consumption from the simulation outputs relied on knowledge of several characteristics of the vehicles in question. The simulation output includes speed, acceleration and traction power at the wheel for each time-step, based on the tractive effort curve of the locomotive and the size of the consist. The algorithm for calculating train acceleration does not explicitly identify which notch the prime mover is set to for each time-step. However, the notch was inferred based on the instantaneous tractive effort, the tractive effort curve of the vehicle, a table of rated power by notch for the locomotive, and knowledge of both the generator efficiency (assumed to be 82% in keeping with rail manufacturer standard practice) and the mechanical efficiency of the vehicle, which varies with speed.

EMD, the manufacturer of the 16-cylinder 645F3B diesel prime mover which provides motive power to the MP36PH-3C locomotive, has published a table of fuel consumption rate and power output by notch for the purposes of calculating emissions. This source data is reproduced here as Table 7. The “Power in Notch” value is used to infer the effective notch at which the locomotive operates in each time-step, with the locomotive assumed to operate in the lowest notch which provides adequate power to deliver the commanded effort at the rail. The “Fuel Rate” value is used to calculate total fuel consumption, based on the time that the simulated trip spends in each notch.

Table 7: EMD 16-645F3B Locomotive Fuel Consumption and Power Output by Notch

Notch	Power in Notch, bhp	Fuel Rate, lb/hr
DB	38	91
Idle	9	22
1	205	92
2	475	179
3	1005	363
4	1353	480
5	1876	652
6	2766	919
7	3454	1136
8	3866	1281

The head-end power demand of the consist was estimated based on a 50 kW/car load for each of the seven total trailer and cab cars, plus an 18 kW load for the locomotive itself, for a total load of 368 kW. The fuel consumption rate as a function of load of the Caterpillar C18 diesel generator set which provides head-end power for the gallery cars has been assessed by researchers at North Carolina State University for the North Carolina Department of Transportation, cited below.

A head-end load of 368 kW requires the generator to run with a constant ultra-low sulfur diesel fuel burn rate of 28.05 gal/hour. This figure is based on linear interpolation from the data presented in Table 8, which is reproduced from the study cited. The reported mass flow rate is converted to a volumetric flow rate based on a fuel mass density of .832 kg/l. The fuel consumption during each time-step was summed to calculate the fuel consumed during the entire simulated trip.

Table 8: Observed Load, Engine Output and Time-Based Fuel Use (Frey & Hu, 2015)

Load Box Load, kW	Engine Output, bhp	Fuel Consumption, gram/second
50	83	5.7
125	126	7.8
250	349	18.4
375	532	24.9
500	692	32.7

The total time spent in each notch by simulated Trip 2125 during the 1:25:09 of simulation is summarized in Table 9. Table 9 also presents the total energy used in each notch setting, in units of horsepower-hours, for use in emissions calculations. As described in Section 3.1, dwell times have been increased in order to match the end-to-end travel time of the trip to that which would exist if the appropriate 10.0% schedule margin were included. This results in an effective dwell time at each inline station of 74 seconds.

Table 9: Time and Energy in Notch for Simulated Trip 2125

Notch Setting	Time in Notch	Energy Expended, bhp-hr	Diesel Fuel Consumption, gal
Dynamic Brake	0:18:49	11.92	4.11
1	0:03:52	13.21	0.85
2	0:00:20	2.64	0.14
3	0:02:47	46.62	2.43
4	0:01:40	37.58	1.92
5	0:04:22	136.53	6.83
6	0:03:54	179.79	8.6
7	0:01:43	98.82	4.68
8	0:32:54	2119.86	101.16
Propulsion Total	**1:10:21**	**2646.97**	**130.73**
Idle	0:14:48	2.22	0.78
HEP Generator	1:25:09	740.45	38.15
Total	**1:25:09**	**6036.61**	**169.67**

The result of this process is a calculated total fuel consumption of 169.67 gallons by Trip 2125 from Chicago Union Station departure to Fox Lake Station arrival. The prime mover consumes 77.51% of this fuel, while the HEP generator set is responsible for the remaining 22.49%. Over the 49.45 mile long route, this works out to an average of 3.43 gal/mile. As expected, this value is lower than the 3.88 gal/mile value computed for the same consist in the earlier study, which also factors in fuel consumed outside of the revenue trip time.

The distribution of time spent in each notch output by simulated trip 2125 can be compared qualitatively to event recorder data showing time in notch for two real-world Milwaukee District North trips recorded on October 8, 2018, as seen in Table 10. While the three trips each follow a different stopping pattern, and should not be expected to match closely, there are discernible similarities, particularly in the fractions of time spent in Dynamic Braking mode, at Idle, and in Notch 8 (full throttle). This serves to confirm the validity of the process used to assess the notch setting in each time-step based on the tractive effort exerted and table of power outputs by notch setting.

Table 10: Fraction of Trip in Notch Setting

Notch Setting By Output	Simulated Trip 2125	Event Recorder, Trip 2126	Event Recorder, Trip 2102
Dynamic Braking	22%	23%	20%
Idle	17%	17%	24%
1	5%	2%	1%
2	0%	11%	2%
3	3%	1%	1%
4	2%	2%	0%
5	5%	0%	0%
6	5%	0%	0%
7	2%	0%	0%
8	39%	44%	52%

Simulated train performance and fuel consumption match the measured performance to a degree which demonstrates that the model accounts for all important effects. The available data on fuel consumption rates is not of adequate accuracy to justify fine-tuning the model to match its outputs to the data precisely. The cumulative fuel consumption is plotted alongside the simulated speed profile in Figure 6.

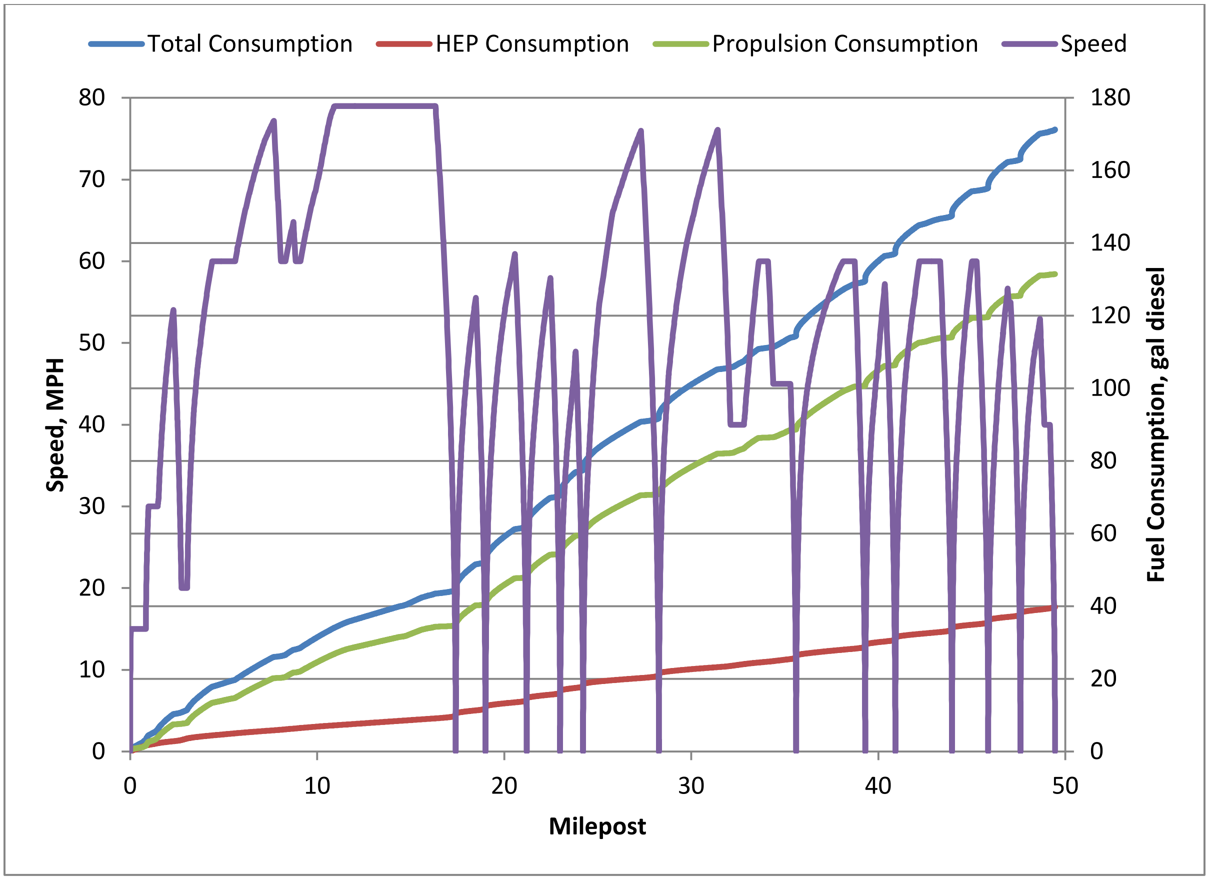


Figure 6: Simulated Speed and Cumulative Fuel Consumption for TrainOps Trip 2125

4 Dual-Fuel Operation

4.1 Diesel vs. CNG Fuel Consumption

One method under consideration to reduce diesel fuel consumption and emissions by Metra locomotives is dual-fuel conversion, in which a portion of the diesel fuel consumed by an existing locomotive engine is replaced by CNG. Previous research and development work by freight railroads and locomotive manufacturers has demonstrated that conversion of existing locomotive engines is technologically feasible, by means of a conversion kit.

This study has focused on the performance characteristics demonstrated by conversion equipment marketed by Engenious Engineering™, previously known as Energy Conversions Inc. This manufacturer's kit has been used to convert EMD prime movers to dual-fuel use, including 645-series engines such as that used by the MP36PH-3C evaluated in Section 3.2.

A dual-fuel mixture of diesel fuel and CNG offers several advantages over diesel as the sole fuel type, including lower emissions of several pollutants and potential fuel costs savings. An advantage of dual-fuel over CNG as the sole fuel source is that it is possible to minimize any negative effect on the horsepower developed by a converted engine. In order to develop the same power at a given notch setting as a diesel-fuel powered engine, the fraction of fuel which is comprised by CNG must be varied. At lower notch settings, corresponding to lower RPM, the lower energy density of CNG requires that diesel make up a greater fraction of the fuel consumed. At higher notch settings and rpm, it is possible to substitute CNG for a greater fraction of the diesel fuel required to maintain the engine's speed. Within this study, it is assumed that fuel substitution has no effect on the tractive effort curve of the locomotive evaluated. Coupled with evidence provided by the supplier that changes to the weight of the locomotive are negligible, the conversion is assumed to have no impact on travel times.

Engenious Engineering™ has provided an estimate of the fraction of diesel fuel which can be replaced by CNG at each notch setting, shown in Table 10. These values can be understood as the fraction of energy provided by each source. For the purposes of this study, it is assumed that this substitution schedule does not cause any decrease in available power at any rpm, such that the tractive effort curve and vehicle performance are not negatively affected by operating on dual-fuel.

Table 11: CNG Substitution for Diesel by Notch Using Engenious Engineering™ Conversion Kit

Throttle	Fraction of Fuel Diesel, By Diesel Volume	Fraction of Fuel CNG, By Diesel Equivalent Volume
Dynamic Brake	100%	0
Idle	100%	0
Notch 1	100%	0
Notch 2	100%	0
Notch 3	30%	70%
Notch 4	30%	70%
Notch 5	20%	80%
Notch 6	20%	80%

Throttle	Fraction of Fuel Diesel, By Diesel Volume	Fraction of Fuel CNG, By Diesel Equivalent Volume
Notch 7	10%	90%
Notch 8	10%	90%

In order to calculate the volume of CNG needed to replace the volume of diesel fuel substituted out, the concept of the standard cubic foot (SCF) of gas is useful. Natural gas volume is dependent on its state, unlike liquid fuels. Within the natural gas market it is therefore conventional to describe a quantity of gas based on its volume at standard temperature and pressure, though in reality a given quantity of natural gas occupies a much smaller volume when held at the pressures which are sold and used as CNG. Based on a volumetric energy density for diesel fuel of 128,488 Btu/gal and a mass energy density for CNG of 20,160 Btu/lb at standard conditions, 139.30 SCF of CNG are equivalent to one gallon of diesel fuel.

Applying the substitution schedule outlined in Table 10 to the fuel consumption by notch calculated for the simulated trip examined in Section 3.2 results in the fuel substitution presented in Table 11. The consumption of a total of 110.65 gallons of diesel fuel is avoided by substituting CNG, representing 65.27% of the fuel consumed by the same trip when fueled exclusively by diesel. A total of 15413.75 SCF of CNG are used in its place. Since the simulated train spends a plurality of the trip in Notch 8, where CNG substitution is maximized, a comparatively large fraction of the fuel is replaced by CNG. Averaged over the entire period during which the locomotive is in Notch 8, the engines consumes CNG at a rate of 385.5 SCF/min.

Table 12: Dual-Fuel Use by Simulated Trip 2125

Fuel Use Component	Duratio n	Diesel, gal	Volume of Diesel Replaced by CNG, gal	SCF of CNG Replacing Diesel
Dynamic Brake	0:18:49	4.11	0.00	0.00
Idle	0:14:48	0.78	0.00	0.00
Notch 1	0:03:52	0.85	0.00	0.00
Notch 2	0:00:20	0.14	0.00	0.00
Notch 3	0:02:47	0.73	1.70	236.48
Notch 4	0:01:40	0.58	1.34	187.25
Notch 5	0:04:22	1.37	5.47	761.58
Notch 6	0:03:54	1.72	6.88	958.74
Notch 7	0:01:43	0.47	4.21	586.86
Notch 8	0:32:54	10.12	91.05	12682.80
Propulsion Prime Mover Subtotal	**1:25:09**	**20.86**	**110.65**	**15413.75**
Auxiliary Power (HEP)	1:25:09	38.03	0.00	0.00
Total	**1:25:09**	**58.89**	**110.65**	**15413.75**

Note that the HEP generator set remains solely diesel-fueled in this simulation. In this case, the HEP generator is responsible for the majority of diesel fuel consumption. Given the larger volume required to store an equivalent quantity of fuel energy as CNG, there is some concern that powering both the HEP and prime mover fully or partially with CNG would require an impractically large storage tank. In previous field tests of freight road locomotives powered by dual-fuel using converter kits, a separate "tender" tank car has been used to store adequate fuel for longer routes.

4.2 Emissions

The same data source which provided the fuel consumption rate by notch which is presented in Table 7 also tabulates the emissions rates by notch of four pollutants for the engine used by the MP3PH-3C locomotive. These pollutants are regulated by the Environmental Protection Agency (EPA). These rates are summarized in Table 12. Note that the values for emissions by the HEP generator are derived from the North Carolina Department of Transportation study which is cited.

Table 13: EMD 16-645F3B Locomotive Emissions by Notch for Diesel-Fueled Operation

Notch	Hydrocarbons, g/bhp-hr	Carbon Monoxide, g/bhp-hr	Nitrogen Oxide, g/bhp-hr	Particulate Matter, g/bhp-hr
Dynamic Brake	7.75	11.32	79.79	1.78
Idle	8.44	11	111	2.89
1	0.19	0.29	5.39	0.25
2	0.44	0.48	16.46	0.3
3	0.31	0.74	13.99	0.3
4	0.26	0.8	13.87	0.23
5	0.26	1.03	13	0.21
6	0.24	0.83	15.39	0.24
7	0.27	0.44	15.8	0.21
8	0.28	0.47	14.75	0.24
HEP at 368kW Load*	0.28	0.18	6.9	0.4

*(Frey & Hu, 2015)

The net emissions by the prime mover for the simulated trip, 2125, can be calculated using the values for energy expended by the engine in each notch from Table 9. The total emissions for fully diesel-fueled operation of trip 2125 are presented in Table 13.

Table 14: Emissions by Simulated Trip 2125, Diesel Operation

Notch Setting By Output	Energy Expended in Notch, bhp-hr	Hydrocarbons, g	Carbon Monoxide, g	Nitrogen Oxide, g	Particulate Matter, g
Dynamic Brake	11.92	92.36	134.90	950.88	21.21
Idle	2.22	18.74	24.42	246.42	6.42
1	13.21	2.51	3.83	71.21	3.30

Notch Setting By Output	Energy Expended in Notch, bhp-hr	Hydrocarbons, g	Carbon Monoxide, g	Nitrogen Oxide, g	Particulate Matter, g
2	2.64	1.16	1.27	43.44	0.79
3	46.62	14.45	34.50	652.23	13.99
4	37.58	9.77	30.07	521.28	8.64
5	136.53	35.50	140.63	1774.90	28.67
6	179.79	43.15	149.23	2766.97	43.15
7	98.82	26.68	43.48	1561.40	20.75
8	2119.86	593.56	996.33	31267.89	508.77
Propulsion Prime Mover Subtotal	**2649.19**	**837.88**	**1558.65**	**39856.60**	**655.69**
HEP at 368kW Load	740.45	207.33	133.28	5109.11	296.18
Total	**3389.64**	**1045.21**	**1691.94**	**44965.71**	**951.87**

Complete data on the emissions profile of a converted dual-fuel engine are not available, so a full computation of the increase or decrease in emissions of each pollutant resulting from the fuel substitution is not possible.

However, limited test data on emissions by a converted locomotive in Notch 8 are available. While these should not be interpreted as an authoritative description of the performance of a converted locomotive, they offer a qualitative description of the changes to the emissions profile which can be expected from converting a locomotive to use dual-fuels. In particular, the dual-fuel engine will produce less particulate matter and nitrogen oxide per unit of energy expended. However, hydrocarbon and carbon monoxide emissions will increase, in part due to incomplete combustion: natural gas is itself a mixture of hydrocarbon gases, primarily methane.

The measured emissions rates in Notch 8 for a prime mover converted by Engenious Engineering™ to dual-fuel propulsion, which may be taken as an approximation of the performance of a converted MP36PH-3C, are presented in Table 14. The resulting total emissions for the portion of simulated trip 2125 during which the train operates in Notch 8 are included as well. As anticipated, for equal energy expenditure, the dual-fuel vehicle emits less particulate matter and nitrogen oxide, while emitting more hydrocarbons and carbon monoxide. Note that no comparison is made of emissions by the HEP generator, as no changes to its fuel source are proposed.

Table 15: Comparison of Notch 8 Emissions Using Diesel Fuel vs. Representative Dual-Fuel Operation

Variable	Diesel-Fuel	Dual-Fuel	% Increase
Time in Notch 8	0:32:54		
Energy Expended in Notch 8, bhp-hr	2119.86		
Hydrocarbons, g/bhp-hr	0.28	0.31	10.71%
Carbon Monoxide, g/bhp-hr	0.47	8.50	1708.51%
Nitrogen Oxide, g/bhp-hr	14.75	3.60	-75.59%

Variable	Diesel-Fuel	Dual-Fuel	% Increase
Particulate Matter, g/bhp-hr	0.24	0.20	-18.75%
Hydrocarbons, g	593.56	657.16	10.71%
Carbon Monoxide, g	996.33	18018.78	1708.51%
Nitrogen Oxide, g	31267.89	7631.48	-75.59%
Particulate Matter, g	508.77	413.37	-18.75%

5 Conclusions

The simulation calibration process successfully replicated velocity profiles of Metra trains on the Milwaukee District Lines. The calibration process found that a 1.1 MPHPS station stopping brake rate matched real-world performance. This "comfort braking" rate is significantly below the trains' full service brake rate but is consistent with typical train handling. The calibration process also found that a 10.0% schedule margin was appropriate to replicate overall point-to-point travel times. These values will be applied to all locomotive models and fuel types going forward in the Metra Alternative Fuels Study.

While there is considerable variability in travel time and fuel consumption between different locomotives, different train consists, and different engineer behavior, the calculation process outlined in this report demonstrates a methodology which can be applied to any subset or proposed variant of Metra's rolling stock, if sufficient vehicle performance information is available.

A benchmark trip using the MP36PH-3C locomotive and seven passenger cars, operating on schedule 2125, served to establish the fuel demands of a diesel-powered locomotive-hauled consist between its first revenue departure and last revenue arrival, which was not available through any real-world source data. For this particular simulated schedule, 77.51% of fuel demand is by the prime mover, while 22.49% of fuel is consumed by the HEP generator set.

A proposed alternative fuel system would supply an existing diesel prime mover with a mixture of diesel and CNG, with the aim to minimize diesel fuel usage without restricting the traffic effort available at any speed. Based on comparison to the benchmark simulation of Trip 2125 and system performance as related by the manufacturer of the conversion system, this alternative fuel system reduces diesel fuel consumption by 65.27%. Diesel fuel use by the prime mover alone is reduced by 84.14% (the HEP generator is assumed to continue to be fueled solely by diesel). While detailed emissions data are not available, preliminary data suggest that this conversion could reduce nitrogen oxide emissions by 75.59% and reduce particulate matter emissions by 18.65% when at peak power output. However, the same source suggests hydrocarbon emissions would increase by 1708.51%, while carbon monoxide emissions would increase by a more modest 10.71%.

In order to improve the accuracy of the calculated fuel savings and emissions savings from this alternative fuel technology, additional test information is needed. In particular, the tractive effort curve, fuel consumption, and emissions must be tested across the full range of vehicle speeds and throttle settings. Moreover, the performance should be verified by a party external to the manufacturer of the conversion system.

In order to improve the accuracy of the fuel consumption calculation method used in this model, it would be necessary to accurately and precisely measure the fuel tank level immediately before and after a revenue trip, such that only the fuel consumed during the trip is accounted for. Alternatively, all operations between refueling the train, such as yard moves and terminal layovers, could be accurately accounted for, such that they can be accounted for in the simulation.

In compliance with Rail Safety Improvement Act of 2008, Metra is installing Positive Train Control (PTC) on the Milwaukee District Lines. PTC may result in somewhat slower speeds approaching civil speed restrictions (such as those related to curves), diverging movements at interlockings, interlocking signals at stop or restricting, and end-of-track locations. These effects, which can only be fully quantified after the PTC system is in service and has reached a level of operational maturity, are not included in the calibration simulation. Because PTC will have virtually identical effects on the performance of all locomotive models and all fuel types, PTC will not be considered in the comparative simulations of this study.

6 Works Cited

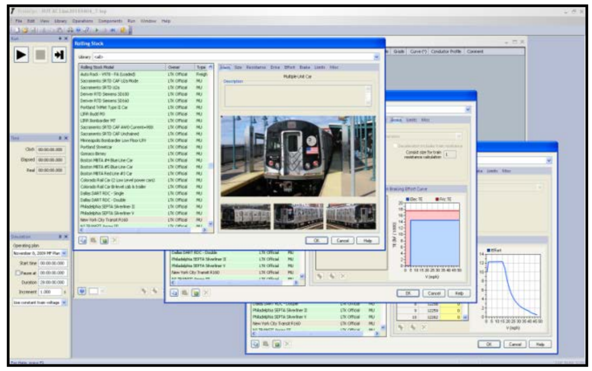
Frey, H. C., & Hu, J. (2015). *Measurement of Locomotive Head End Power Engine Fuel and Emissions.* North Carolina State University, Department of Civil, Construction and Environmental Engineering. Raleigh, NC: North Carolina Department of Transportation.

LTK TrainOps® Software Description

LTK TrainOps® Simulation Software Description

TrainOps is the proprietary LTK operations and electrical network simulation software for all types of rail systems. It supports a wide range of analyses, ranging from conceptual planning exercises to detailed engineering design work. Popular TrainOps applications in the planning and design areas are described below.

Developed and continually enhanced by a team of in-house software engineers, TrainOps is written in the C++ language and targeted for operation on high-performance 64-bit Windows computers. The capabilities of the software reflect the industry-leading expertise of the more than 300 LTK rail professionals specializing in vehicles, traction power, train control, infrastructure and operations.



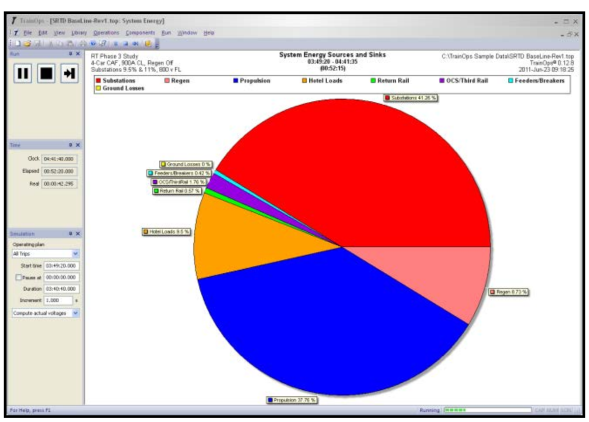
TrainOps features detailed rolling stock libraries (as well as the ability to add customized models), organized into locomotive, multiple unit, freight car and passenger coach categories.

Each TrainOps release is subject to quality testing by an independent TrainOps Quality Assurance Team. TrainOps testing includes user interface, functional, computational accuracy, processing efficiency, output reporting and many other tests – more than 8,000 in all. In addition, TrainOps' train performance and electrical network simulation algorithms are regularly validated through successful calibration to existing "real world" rail systems.

Typical TrainOps Applications

Optimizing Rolling Stock Selection and Performance: Many rail systems are interested in determining the optimal trade-off of train weight and power, as well as understanding if rolling stock under consideration can satisfy existing or planned trip times. For locomotive-hauled passenger trains, future capacity growth in the form of longer trains can have adverse performance impacts. TrainOps' comprehensive rolling stock library and user flexibility in creating and editing new rolling stock models support these analyses.

Optimizing Adhesion and Power/Weight Ratios: Heavy haul freight networks optimize their operating consists by tailoring power/weight ratios to specific alignments. Often done using "rules of thumb", TrainOps offers a more sophisticated approach. With detailed modeling of adhesion, rail gradient (vertical profile), curvature (horizontal alignment) and distributed train length algorithms, TrainOps can determine if a train has the right power/weight ratio to ascend that ruling grade and to make that advertised trip time.



TrainOps' computation of energy supply and consumption by category is updated dynamically during simulation. The dark red shows energy supplied by the utility and the light red shows energy productively recovered through regenerative braking.

Maximizing Electrified Rail Network Energy Recovery: Regenerative braking – returning electrical energy to the rail power distribution system or even back to the supplying utility – offers opportunities for electrified rail networks to recover some energy used. Depending on the density of traffic, the type of vehicle control systems and many other factors, recovery can approach or exceed 20 percent. TrainOps' capabilities allow systems to optimize their infrastructure, operations and vehicles to maximize the electrical energy being returned to the system through braking. TrainOps also supports analyses of mixed fleets of regenerative braking-equipped and non-equipped trains. TrainOps' sophisticated algorithms support the optimization process to reduce the carbon footprint of electrified rail networks and optimize their energy saving and energy recovery characteristics.

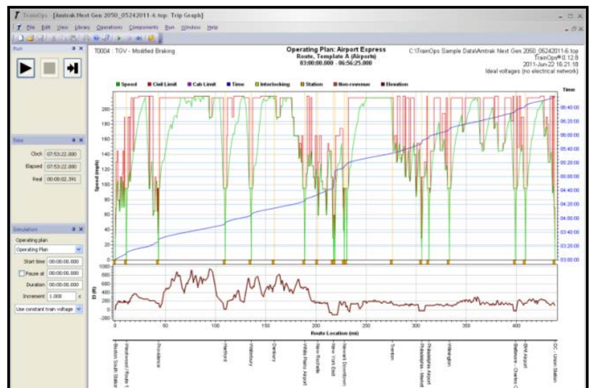
Optimizing New Rail Alignments and Layouts: For new systems and system extensions, the planning process can produce many alignment alternatives. TrainOps' capabilities, including ability to toggle on and off specific alignment combinations within the same database supports analysis of the best trip times and most energy-efficient operation. TrainOps' rapid modeling capabilities, including the ability to import alignment information from external data sources, allow fast turn-around in simulating all of the alternatives

Developing Integrated Operating Plans: "Mixed-use corridor" is an increasingly common term as rail lines that once handled only freight service grow to accommodate commuter rail and high speed intercity rail services. With support for multiple train types, train consists, train classes and class-specific speed restrictions, TrainOps supports the development and optimization of integrated operating plans. These plans accommodate the disparate requirements of all rail operators on mixed-use corridors. TrainOps' comprehensive modeling capability captures train interaction on both the mainline (where line capacity is a precious commodity) and at terminals (where "throat" interlocking and station tracks are precious commodities).

Analyzing Existing and Proposed Operating Plans: TrainOps supports the assessment of future operating plans in terms of on-time performance predictions, energy usage, rolling stock requirements, and the ability of the traction power system to support the proposed train level under "normal" and "contingency" operations.

Supporting the Alternatives Analysis and Environmental Impact Statement Process: Alternative Analyses and Environmental Impact Statements need detailed train operations information. TrainOps supports these wide-ranging analytical needs, including outputs that can support:

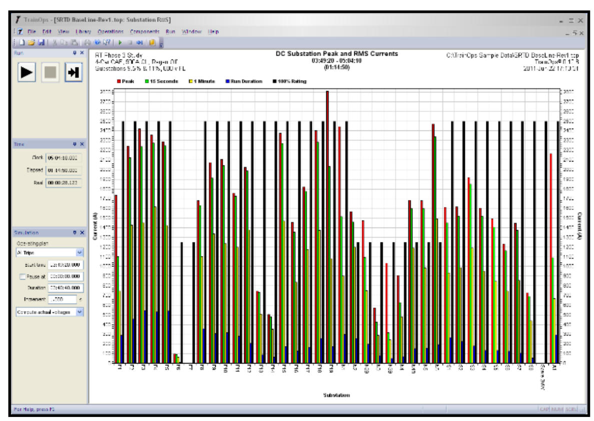
- Operations and maintenance cost models,
- Noise and vibration studies,
- Rail-highway at-grade crossing gate down time predictions for vehicular traffic studies,
- Energy usage analyses,
- Fossil fuel emissions levels,
- "Before" and "after" trip time and throughput generation for ridership modeling purposes.



Very high speed rail simulation showing maximum authorized speed (red), simulated velocity (green) and trip time (blue).

Producing Cost-Effective Traction Power Designs: For new and expanding systems, TrainOps supports the detailed analyses needed to generate the most cost-effective designs, while ensuring operability under normal and contingency (degraded) conditions. Outputs include substation instantaneous, peak, and average power flows, with average statistics available over various user-selected time intervals (for comparison with "nameplate ratings" of the planned traction power system components). Other TrainOps outputs supporting the traction power design process include:

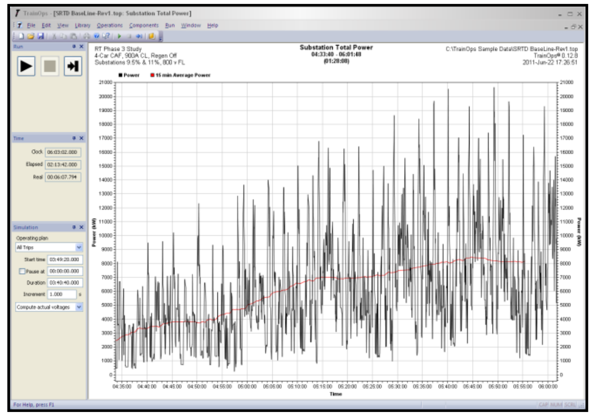
- Substation instantaneous voltage and current,
- Substation peak average and peak RMS currents for user-selected time intervals,
- Feeder RMS currents,
- Running rail voltage rise ("touch potential") with respect to ground and stray currents.



Peak and RMS currents shown for each substation in the system, along with 100% nameplate ratings, allow visual confirmation that all substations are properly sized for a new or reconfigured network.

Evaluating Capacity Benefits of New Train Control Designs: TrainOps' unique "signal wake" function quantifies minimum supportable headways (signal system capacities) for any alignment, using defined train consists, stopping patterns, dwell times and signal system parameters. This capability can be used to identify capacity "pinch points" and to evaluate the capacity benefits of small-scale changes such as signal relocations, speed changes and signal control line changes. TrainOps can also be used to evaluate trade-offs in complete signal system redesigns, including such architectures as:

- Wayside signals,
- Wayside signals with cab signal overlay,
- Cab signals
- Target-based cab signals with profiling
- Wayside signals with Positive Train Control (PTC) overlay,
- Communications-based train control.

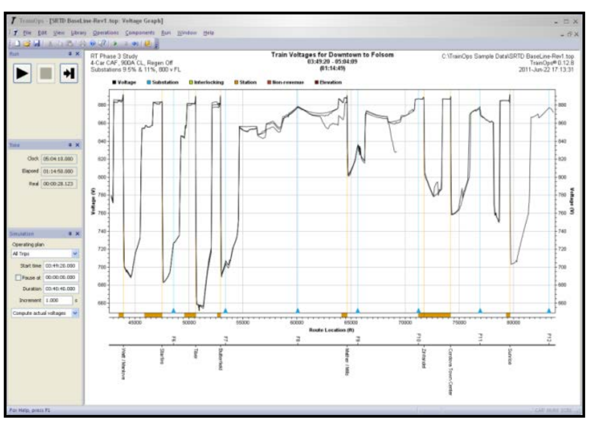


TrainOps dynamic (while the simulation runs) display of system-wide power demand (black) with 15-minute running average power demand for utility tariff computations (red).

For studies where no train control design is available or where the focus is on traction power design, TrainOps supports “line of sight” train operation. This ensures realistic train separation without the need to enter site-specific signal details. TrainOps also includes street running intersection modeling capabilities, appropriate for light rail and streetcar networks. This includes support for probabilistic delays at each intersection, with variation by time of day and direction.

TrainOps supports the analysis of Positive Train Control systems both in terms of stand-alone systems or systems overlaid on conventional signaling systems. The software supports different brake rates for the same train consist and for multiple consists, depending on the type of train control system and type of enforcement. For example, TrainOps can test the benefits of PTC with different enforced brake rates for civil speed restrictions versus stop signal enforcement.

Supporting Negotiation of Electricity Tariffs: For electrical network modeling, TrainOps’ outputs include consumption and peak demand for each supply point (substation connection or rail network transmission system supply point) in the system. This allows analysis, in support of electric tariff negotiations, of coincident demand charges (the collective demand of all substations) versus a non-coincident demand structure. Similarly, it allows analysis of demand versus consumption charge trade-offs, as well as predicting how much energy will be regenerated and returned to the utility (and where). If multiple utilities are supplying the rail network, these TrainOps capabilities can be used to determine how demands are distributed among the supplying utilities.



TrainOps overlay of multiple trains’ voltage experience along a rail line, allowing fast identification of system locations in need of traction power reinforcement.

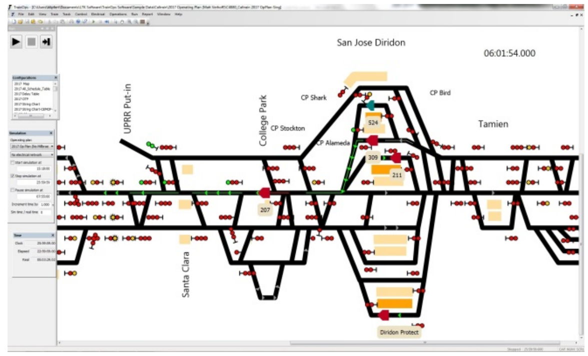
Solving Traction Power Performance Issues: Traction power systems designed and constructed years ago may warrant upgrading and TrainOps can be used to determine the most cost-effective capital investment plan. TrainOps modeling can determine whether existing substations, OCS/third rail and power cables are adequate or whether some enhancements are required, particularly as service is increased and new vehicles are introduced. A thorough analysis supported by TrainOps will reveal the rail system’s strengths and weaknesses, allowing for an integrated and updated new design.

TrainOps’ outputs include plots of instantaneous train voltages at third rail pickup shoes/pantographs for all trains operating on a given route. This graphic yields an overlaid voltage profile along the alignment and zeros in on traction power weak spots, TrainOps supports rapid investigation of potential solutions to traction power performance issues – adding a substation, adding a tie station/circuit breaker house, changing substation “no load” voltages, upgrading the running rails, third rail/catenary or negative return system, adding a cross-bond or even altering the train schedule (headway or train length).

TrainOps Database Development

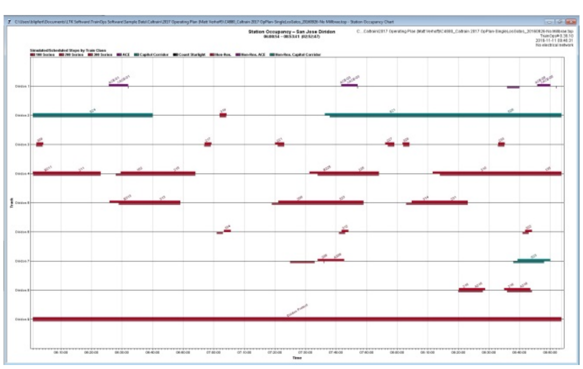
TrainOps is developed using modern software technologies and development methods. There is no inherent software limit on the size of the rail network, the complexity of the traction power system (if modeled), the number of trains that can be simulated, or the duration of simulation. In short, it can model any rail network of any size.

TrainOps was specifically developed to enable comprehensive modeling and studies of AC and DC-electrified railroad and transit train operation, as well as operations of fossil fuel-powered trains. The program provides user-friendly inputs (including the ability to "cut and paste" from spreadsheets) for all relevant system and rolling characteristics, including:



TrainOps run-time graphics show the status of each interlocking route, including green (route established), red (stacked route – route requested but occupied by another train, purple (route requested but not yet established) and gray (route being released).

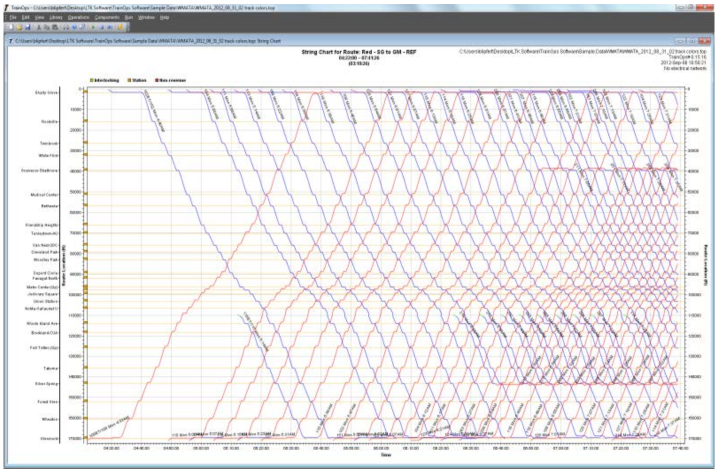
- Route alignment data, including track gradients, horizontal alignment and speed restrictions (which can differ by train class),
- Passenger station locations,
- Train data, including weight, dimensions, propulsion system characteristics, and braking system parameters,
- System train control data, including wayside signaling, cab signaling and Positive Train Control inputs (optional) with user-friendly "point and click" control line data entry (optional),
- Electrical power supply system data, comprising traction power supply substations and tie stations/circuit breaker houses (optional),
- Electrical distribution system, such as overhead catenary, trolley wire system, or third rail system, and substation feeder cables (optional),
- Operations data, such as train consist sizes, train consist manipulations at terminals/yards, operating plan (timetable) inputs, passenger station stopping pattern, train loadings and station dwell times,
- Dispatching data, such as route request points (or dispatcher route establishment goals ahead of each train as a function of train class), routing preferences and route establishment times after a conflicting train has released a route, and
- Variability data, such as dispatch uncertainty (for trains leaving yards or arriving from external locations), schedule margin, schedule holds at stations, interlocking route establishment times (dispatcher attentiveness), street signal (intersection) hold times and probabilities of a red signal, tractive effort and brake application rate (optional).



Terminal track occupancy diagram showing simulated times (above the line) and scheduled times (below the line) with train classes distinguished by color.

TrainOps Electrical Network Simulation Algorithms

Unlike most competing products, TrainOps' dynamic simulation algorithms capture the interaction – during each simulation computational step – of trains and the power system as conditions change along the alignment. Voltage variation at the train third rail shoe or pantograph affects train performance, so when the voltage decreases, the acceleration, velocity and location of the train are altered. Power demand of the train decreases, enabling the traction power system to partially recover from the voltage sag. With this powerful feedback algorithm, TrainOps captures the



TrainOps time-distance string chart for rapid transit service ramp-up, including color coding by track and representation of midline turnback locations.

performance loss caused by low voltages. Similarly, TrainOps can demonstrate the impacts on the traction power system of a line blockage (such as the opening of a movable bridge) and the ability of the system to support multiple "stacked" trains restarting.

Competing products overstate the third rail or catenary voltages and currents, as well as the substation power demands, in simulations with dense train operations or contingency traction power configurations. This means that in comparison with TrainOps, voltages predicted by competing products are lower, and currents and substation power demands are higher, sometimes unrealistically so. The powerful TrainOps dynamic simulation algorithms avoid this issue, ensuring that simulation-based capital investment decisions are the right ones.

<u>TrainOps Operations Simulation Algorithms</u>

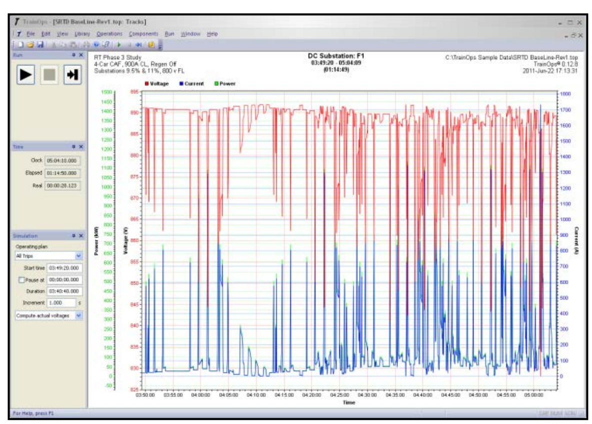
TrainOps provides full dynamic routing capability, ranging from selection of alternative tracks at a transit terminal to meet/pass planning on single/multiple track railroad to full network optimization where there may be completely different routes to travel from one city to another. This dynamic routing capability is fully user-configurable on a site-specific location, with the ability to specify different "decision strengths" at each interlocking where a routing choice is available. For large rail networks where individual interlockings are controlled by different railroads' dispatchers, preferences can be specified on how specific train classes (which may represent the trains of one railroad versus another) are expedited.

Competing simulation products sometimes use internal iteration to produce the best dispatch solution. This can produce overly-optimistic results versus "real world" operations, as actual dispatchers do not have the opportunity to try to multiple strategies and then select the specific dispatching moves that work best. TrainOps' dispatch algorithms work as the simulation runs, providing transparency in how the rail network is being dispatched.

<u>TrainOps Modeling Flexibility</u>

Mainline railroad, very high speed rail, monorail, Automated Guideway Transit ("people movers"), streetcars, light rail and heavy rail traction power systems, as well as electric trolley bus systems, can be simulated. TrainOps supports completely flexible rail network/traction power system modeling with all system components represented individually in the model. A typical simulation may include the following variations in rail network infrastructure and operational attributes:

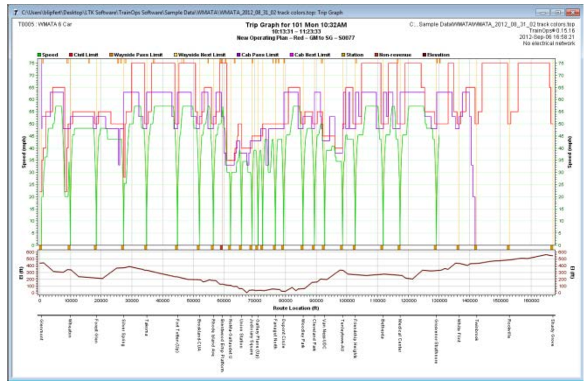
- Changes in gradients, curvature and speed restrictions (including different speeds for different train classes) as function of individual track or route,
- Substations of different input voltages, output voltages, and power ratings,
- Changes in third rail sections, overhead catenary, or



TrainOps run-time graph of voltage, current and power as a function of simulated time for a user-selected substation.

trolley wire along the alignment,

- Detailed representation of the positive circuit with jumpers between tracks and conductor section breaks,
- Changes in running rail characteristics,
- Detailed representation of the negative return circuits with cross-connections between rails. TrainOps includes series resistances due to impedance bonds and shunt resistances between the running rails and ground, supporting output of running rail-to-ground voltages and stray currents returning to system substations,
- AC feeders and return circuits, positive and negative DC feeders of different cable types, resistances, and lengths,
- Different vehicles and train make-ups (as multiple units or locomotive-hauled trains), including homogeneous and heterogeneous consists,
- Different passenger station stopping patterns for each train trip, such as express, local and skip-stop train service,
- Different passenger station dwell times for each station and train,
- A different loading pattern for each train as it travels along the alignment making possible, for example, simulation of fully loaded trains in downtown areas and partially loaded trains in suburbs,
- Static loads representing stationary trains in storage yards,
- Outages of substations, feeder breakers, and feeders,
- User-selectable time step, ranging from coarse computations for rapid-response planning studies to fine computations for sophisticated engineering analyses.



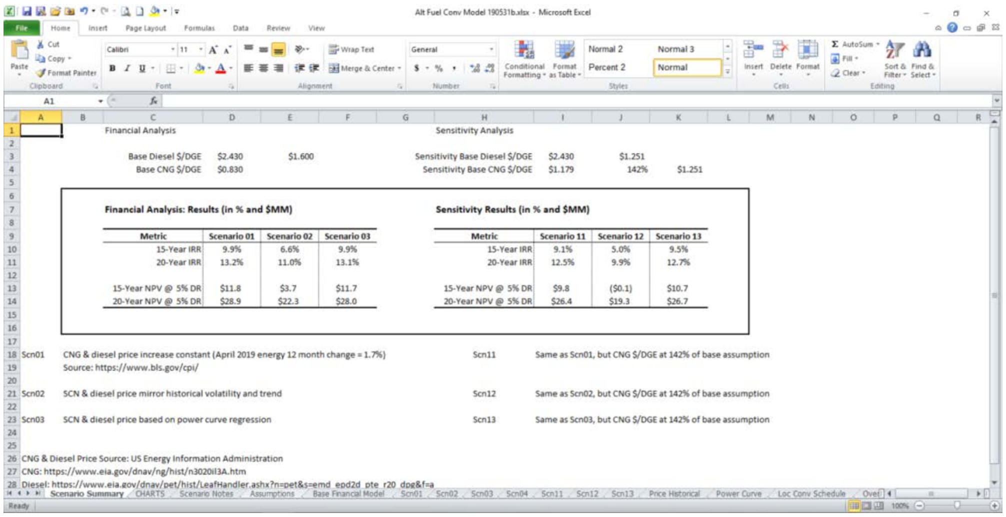
TrainOps trip graph for an ATC cab signal system with civil speed enforcement. Graphs are dynamically updated while the simulation runs (note the right end of the green plot shows the current location of the train; the right end of the purple plot shows the limit of dispatcher route establishment for this train trip).

CMCG Financial Analysis Detailed Data

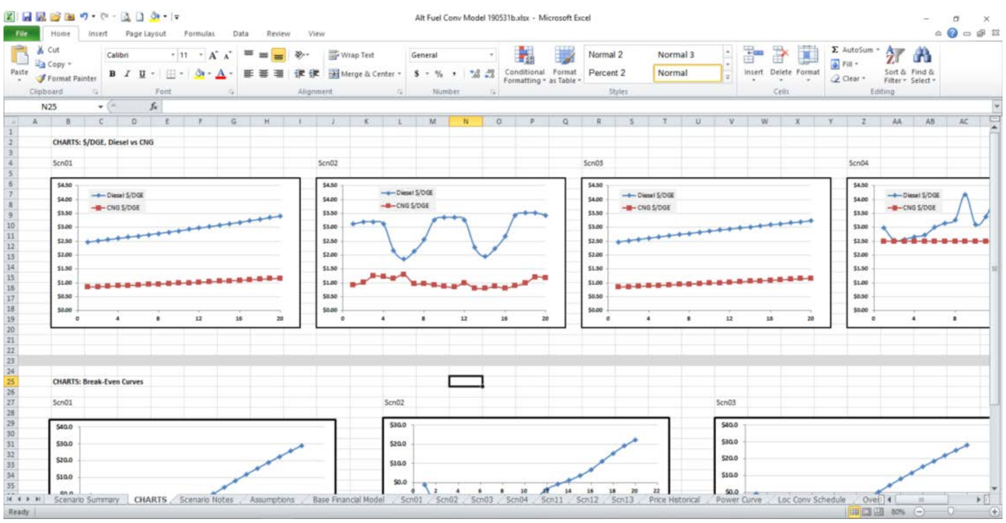
Financial Model Documentation

The financial analysis model was implemented using Microsoft Excel spreadsheets. A workbook file was developed containing spreadsheets used in the financial analysis. These spreadsheets can be found in the following tabs:

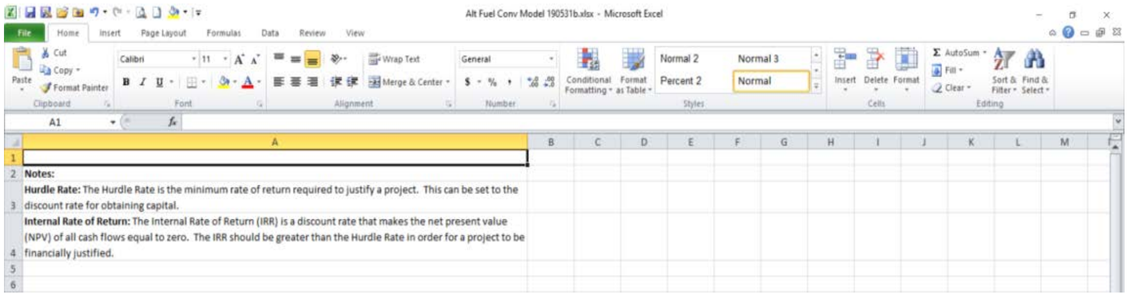
1. *Scenario Summary*: This tab contains the summary of the financial analysis results across the different scenarios.



2. *Charts*: This tab contains comparison charts for the cost per DGE of diesel and CNG across different scenarios. This tab also contains the Cumulative Discounted Cash Flow charts that are used to determine the break-even year for each scenario.

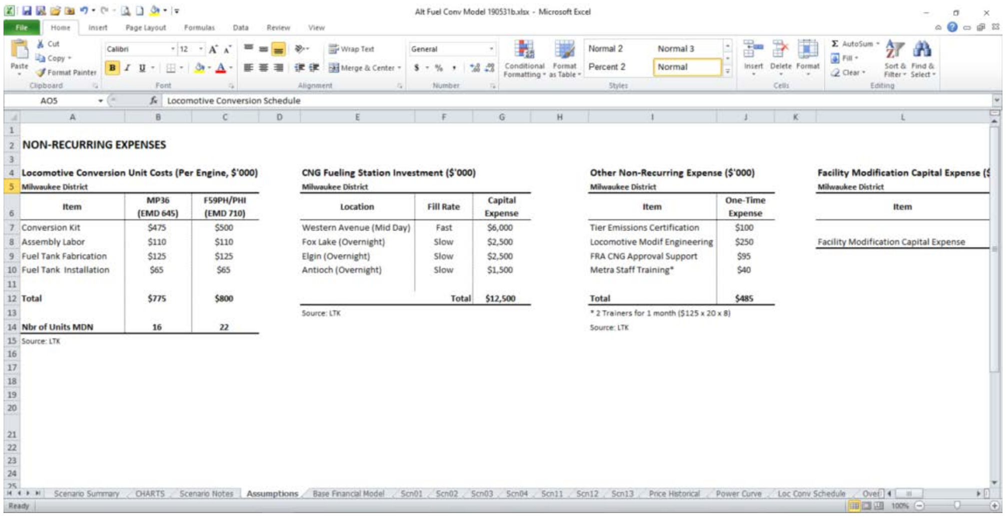


3. *Scenario Notes*: This tab contains definitions of financial terms and is for reference only.



4. *Assumptions*: This tab contains tables of key assumptions regarding operating conditions and estimated costs of converting the Milwaukee District rail lines to partial natural gas usage. The main financial model will reference the contents of this tab in the financial calculations and any changes in the values in the tables will cascade through the financial model. The assumptions are organized in separate tables with the following headings:
   a. Locomotive Conversion Unit Costs (Per Engine, $'000): contains the cost components of converting an MP36 and F59PH/PHI locomotive engine
   b. CNG Fueling Station Investment ($'000): contains the capital investment required to install CNG fueling stations
   c. Other Non-Recurring Expense ($'000): contains all other categories of non-recurring expenses
   d. Facility Modification Capital Expense ($'000): contains capital costs (engineering and construction) to meet code requirements for modifying/upgrading facilities for dual fuel locomotive maintenance.
   e. CNG Cost Components: contains the different cost components for determining the cost per diesel gallon equivalent (DGE) for compressed natural gas (CNG)
   f. Base Fuel Price: contains the assumed current cost per diesel gallon equivalent (DGE) of diesel and CNG.
   g. Fuel Consumption: summarizes the total diesel fuel consumed by locomotives operating in the Milwaukee District, as well as the estimated average diesel fuel consumption per locomotive.
   h. Diesel Substitution %: contains the factor that represents the percent of diesel replaced by CNG during operations.
   i. First Year Fuel Savings: contains the percentage of the annual locomotive fuel savings that can be achieved in the first year of conversion, given the locomotives converted are not in full operation during the entire year.
   j. Annual Inflation: contains the annual inflation rate for yearly operating expenses
   k. Filling Station Operating Cost ($'000): contains the components of the annual cost of operating the filling station at each location.
   l. Incremental Maintenance Cost Per Engine Per Year: contains the cost of maintaining the locomotive engine, in addition to current maintenance costs.

m. Locomotive Conversion Schedule: contains the number of locomotives converted per year in the conversion timeline.



Alt Fuel Conv Model 190531b.xlsx - Microsoft Excel

AO5 — Locomotive Conversion Schedule

NON-RECURRING EXPENSES

Locomotive Conversion Unit Costs (Per Engine, $'000)
Milwaukee District

Item	MP36 (EMD 645)	F59PH/PHI (EMD 710)
Conversion Kit	$475	$500
Assembly Labor	$110	$110
Fuel Tank Fabrication	$125	$125
Fuel Tank Installation	$65	$65
Total	$775	$800
Nbr of Units MDN	16	22

Source: LTK

CNG Fueling Station Investment ($'000)
Milwaukee District

Location	Fill Rate	Capital Expense
Western Avenue (Mid Day)	Fast	$6,000
Fox Lake (Overnight)	Slow	$2,500
Elgin (Overnight)	Slow	$2,500
Antioch (Overnight)	Slow	$1,500
	Total	$12,500

Source: LTK

Other Non-Recurring Expense ($'000)
Milwaukee District

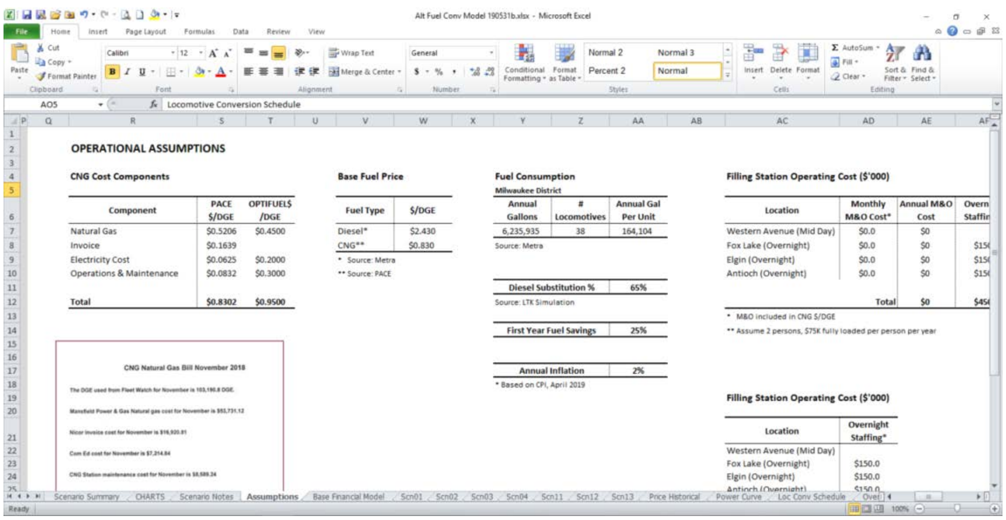
Item	One-Time Expense
Tier Emissions Certification	$100
Locomotive Modif Engineering	$250
FRA CNG Approval Support	$95
Metra Staff Training*	$40
Total	$485

* 2 Trainers for 1 month ($125 x 20 x 8)
Source: LTK

Facility Modification Capital Expense ($
Milwaukee District

Item
Facility Modification Capital Expense

Scenario Summary / CHARTS / Scenario Notes / Assumptions / Base Financial Model / Scn01 / Scn02 / Scn03 / Scn04 / Scn11 / Scn12 / Scn13 / Price Historical / Power Curve / Loc Conv Schedule / Over



Alt Fuel Conv Model 190531b.xlsx - Microsoft Excel

AO5 — Locomotive Conversion Schedule

OPERATIONAL ASSUMPTIONS

CNG Cost Components

Component	PACE $/DGE	OPTIFUEL$ /DGE
Natural Gas	$0.5206	$0.4500
Invoice	$0.1639	
Electricity Cost	$0.0625	$0.2000
Operations & Maintenance	$0.0832	$0.3000
Total	$0.8302	$0.9500

CNG Natural Gas Bill November 2018

The DGE used from Fleet Watch for November is 103,190.8 DGE.

Mansfield Power & Gas Natural gas cost for November is $53,731.12

Nicor invoice cost for November is $16,920.81

Com Ed cost for November is $7,214.84

CNG Station maintenance cost for November is $8,589.34

Base Fuel Price

Fuel Type	$/DGE
Diesel*	$2.430
CNG**	$0.830

* Source: Metra
** Source: PACE

Fuel Consumption
Milwaukee District

Annual Gallons	# Locomotives	Annual Gal Per Unit
6,235,935	38	164,104

Source: Metra

Diesel Substitution %	65%

Source: LTK Simulation

First Year Fuel Savings	25%

Annual Inflation	2%

* Based on CPI, April 2019

Filling Station Operating Cost ($'000)

Location	Monthly M&O Cost*	Annual M&O Cost	Overn Staffin
Western Avenue (Mid Day)	$0.0	$0	
Fox Lake (Overnight)	$0.0	$0	$15
Elgin (Overnight)	$0.0	$0	$15
Antioch (Overnight)	$0.0	$0	$15
	Total	$0	$45

* M&O included in CNG $/DGE
** Assume 2 persons, $75K fully loaded per person per year

Filling Station Operating Cost ($'000)

Location	Overnight Staffing*
Western Avenue (Mid Day)	
Fox Lake (Overnight)	$150.0
Elgin (Overnight)	$150.0
Antioch (Overnight)	$150.0

Scenario Summary / CHARTS / Scenario Notes / Assumptions / Base Financial Model / Scn01 / Scn02 / Scn03 / Scn04 / Scn11 / Scn12 / Scn13 / Price Historical / Power Curve / Loc Conv Schedule / Over

5. Updated Data: This tab reflects updates to cost estimates of non-recurring expenses based on comments and feedback from Metra and the RTA.

6. Base Financial Model: This tab serves as a template for creating scenarios and contains the main financial analytical model. To create a scenario, a copy of this tab is generated and changes are made to the parameters of the model. There are three sections in the financial model:
   a. Model Assumptions: Entries in columns B through F of this tab make reference to the 'Assumptions' tab. Those sections have the following headings:
      i. RETROFIT COST: contains the cost of converting an MP36 and F59PH/PHI locomotive engine.
      ii. Number of Units: contains the number of locomotives per engine type. This table is for reference only and not used in the analysis.

iii. BASE FUEL PRICE: contains the base diesel and CNG cost per DGE.
iv. FUEL PRICE SENSITIVITY FACTOR: contains the factor to be multiplied to the base diesel and CNG cost per DGE when performing sensitivity analysis on base price assumptions.
v. First Year Fuel Savings: references the First Year Fuel Savings factor in the 'Assumptions' tab.
vi. FUEL CONSUMPTION: contains the parameters that determine the amount of diesel fuel that is displayed by CNG, which is calculated as average diesel gallons consumed per engine per year multiplied by the diesel substitution percentage. Separate parameters are outlined for MP36 and F59PH/PHI locomotive engines.
vii. Non-Recurring Expenses (NRE): contains the different categories of NRE and their respective amounts.
viii. NRE Spend Schedule: contains assumptions on how much of the NRE is allocated to Year 1 and Year 2 of the conversion timeline. The model assumes the Facility Modification Capital Expense and the Other Non-Recurring Expense cost categories are incurred in Year 1 of the horizon, and that the CNG Fueling Station Maintenance & Operating Cost contains the annual maintenance and operating cost of the fueling station.
ix. Locomotive Maintenance Cost: contains the cost of maintaining the locomotive engine that is in addition to current maintenance costs.
x. Annual Inflation: contains the annual inflation rate for yearly operating expenses.

b. Cash Flow Calculation: Columns I through AC, up to Row 64, contains the financial model calculations to determine the year-by-year cash flow, from Year 1 through Year 20. The various parts of the model are referenced by the following rows:
    i. Rows 8 to 12: contains the locomotive conversion schedule by engine type, in number of locomotive units per year.
    ii. Rows 14 to 16: contains the calculation of the retrofit cost per year as determined by the conversion schedule and the retrofit unit costs by engine type.
    iii. Rows 21 to 22: contains the cumulative number of locomotives converted in each year.
    iv. Rows 25 to 28: contains the calculated total amount of DGE that CNG will replace for each year, which depends on the number of locomotive units converted in the year. The DGE for the year is calculated as the sum of the following:
        1. The number of locomotives converted in year multiplied by the net diesel gallons converted to CNG multiplied by the first fuel savings;
        2. The cumulative number of locomotives in the previous year multiplied by the net diesel gallons converted to CNG.
    v. Rows 30 to 32: contains the calculations for the cost per DGE of diesel. Row 31 contains the year over year rate in which the diesel price is to change from the

previous year to the current year. Across scenarios, different price forecasts for diesel will be reflected by different values in Row 31.

vi. Row 34 to 36: contains the calculations for the cost per DGE of CNG. Row 35 contains the year over year rate in which the CNG price is to change from the previous year to the current year. Across scenarios, different price forecasts for CNG will be reflected by different values in Row 35.

vii. Row 39 to 42: contains the diesel and CNG costs for each year, as well as the annual fuel savings for converting to dual fuel engine locomotives.

viii. Row 45: contains the total NRE for each year.

ix. Row 48 to 50: contains the annual maintenance and operating cost for each year, increasing based on the assumed rate of inflation.

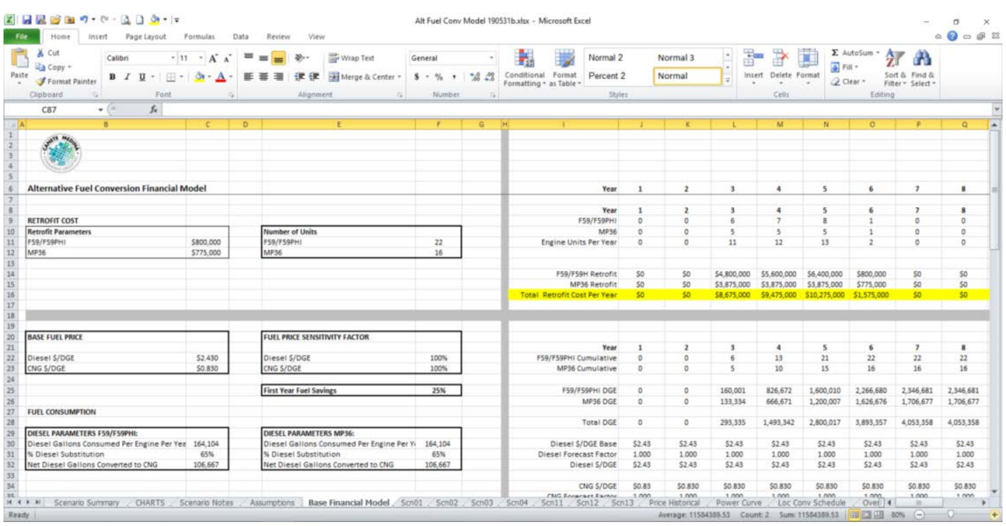
x. Row 53 to 55: contains the annual cost of maintaining the locomotive engine that is in addition to current maintenance costs.

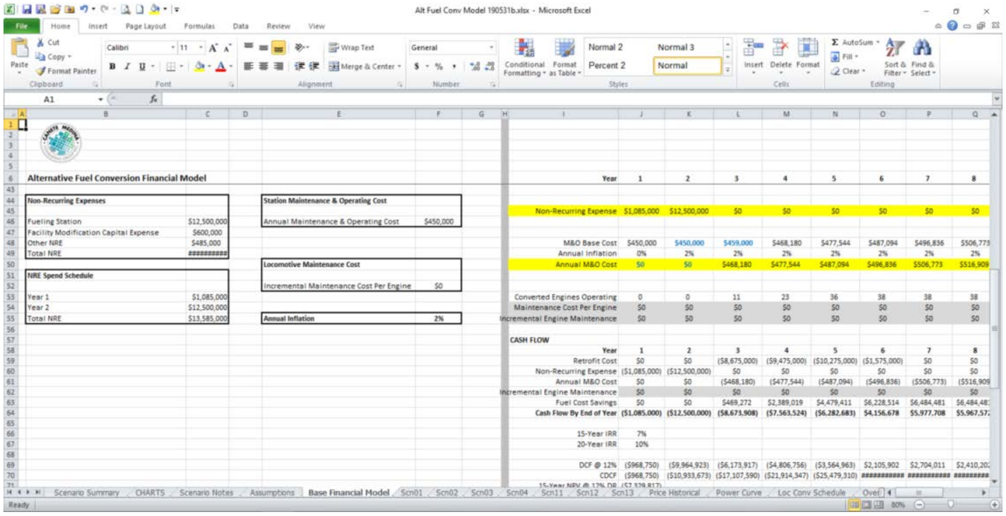
xi. Row 57 to 64: contains the cash flow calculation for each year, which is the sum of all the costs (represented as negative numbers) and the fuel cost savings (represented as positive numbers).

c. Financial Performance Metrics: Columns I through AC, from Row 66 to 92, contains the calculation of the metrics used to assess the financial viability of dual-fuel conversion initiative. The metrics and their definitions are discussed in the Financial Analysis Results of the report. Those metrics are the following:

i. Internal Rate of Return (IRR): The 15-year IRR is calculated in cell J66 and the 20-year IRR is calculated in cell J67.

ii. Discounted Cash Flow (DCF), Cumulative Discounted Cash Flow (CDCF), 15-Year Net Present Value (NPV), 20-Year NPV: The DCF, CDCF, 15-Year NPV and 20-Year NPV for the assumed Discount Rate of Return are calculated in Row 89 to 92. Row 69 to 87 provides calculations for the same metrics under different Discount Rate of Return values.

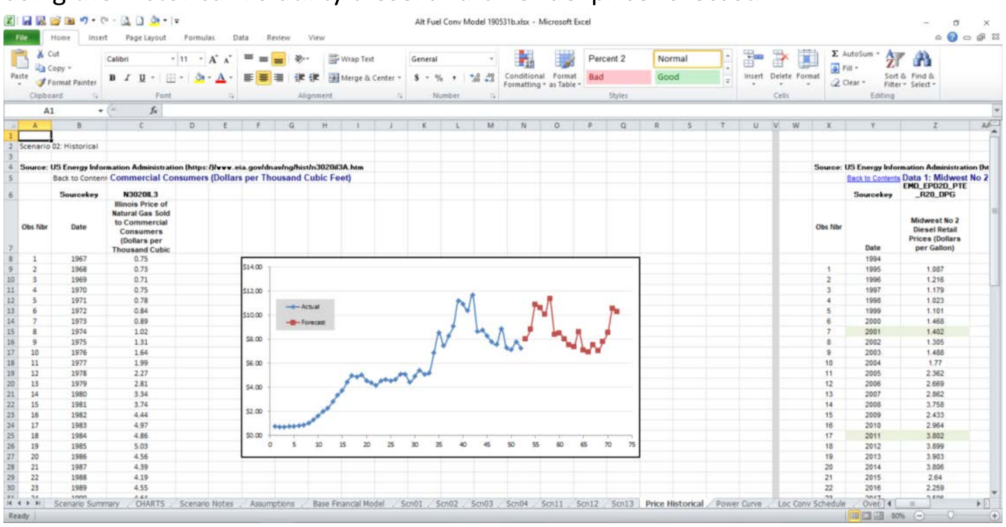




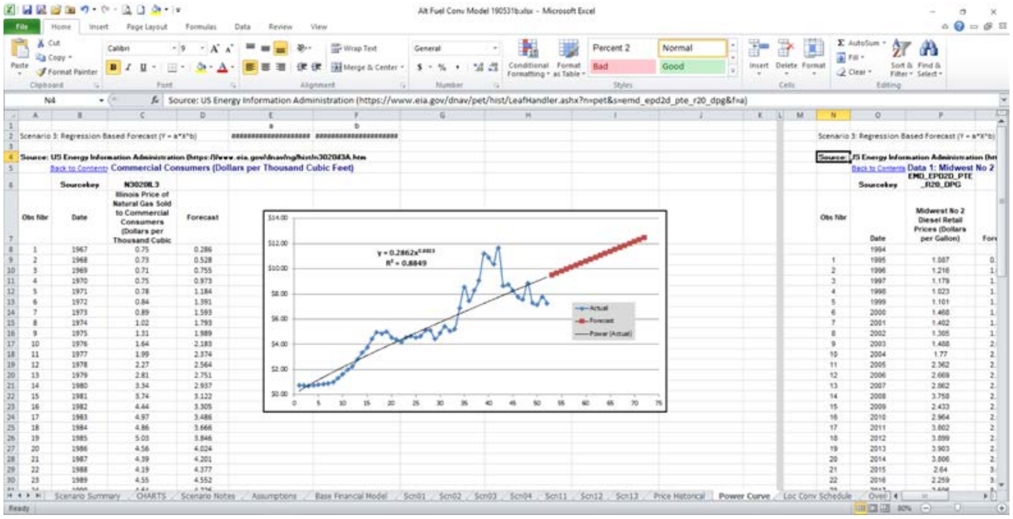
7. Scn01, Scn02, and Scn03: These tabs contain the financial model calculations for Scenario 1 (Scn01), Scenario 2 (Scn02), and Scenario 3 (Scn03) of the analysis.

8. Scn11, Scn12, and Scn13: These tabs contain sensitivity analysis regarding Scenario 1 (Scn11), Scenario 2 (Scn12), and Scenario 3 (Scn13). The sensitivity analysis explores how the differences between diesel and CNG prices impact the financial metrics and tries to assess how much does the CNG/diesel price ratio have to increase, before the 15-year NPV approaches zero. This analysis was also used to validate the model.

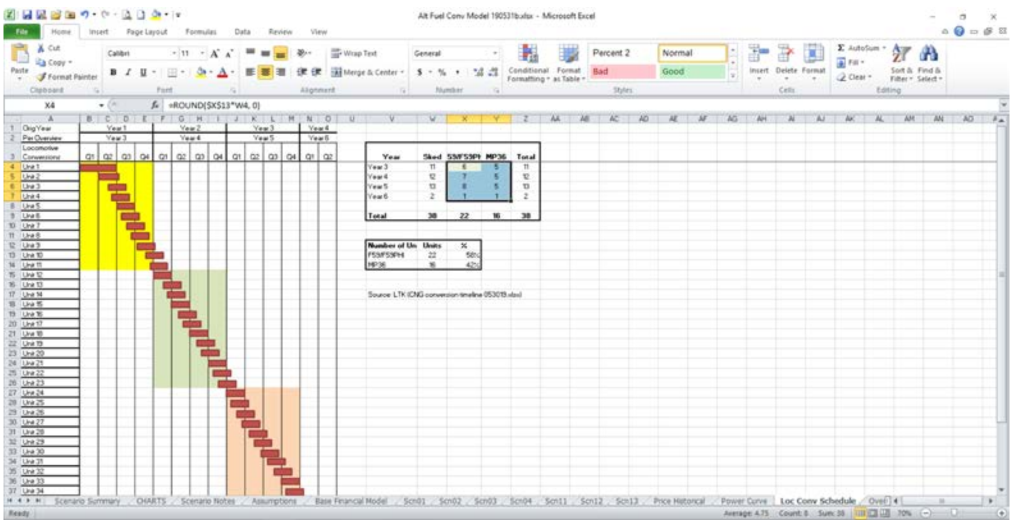
9. Price Historical: This tab contains the work-up for determining the parameters for Scenario 2, using the Historical Volatility diesel and CNG fuel price forecast.



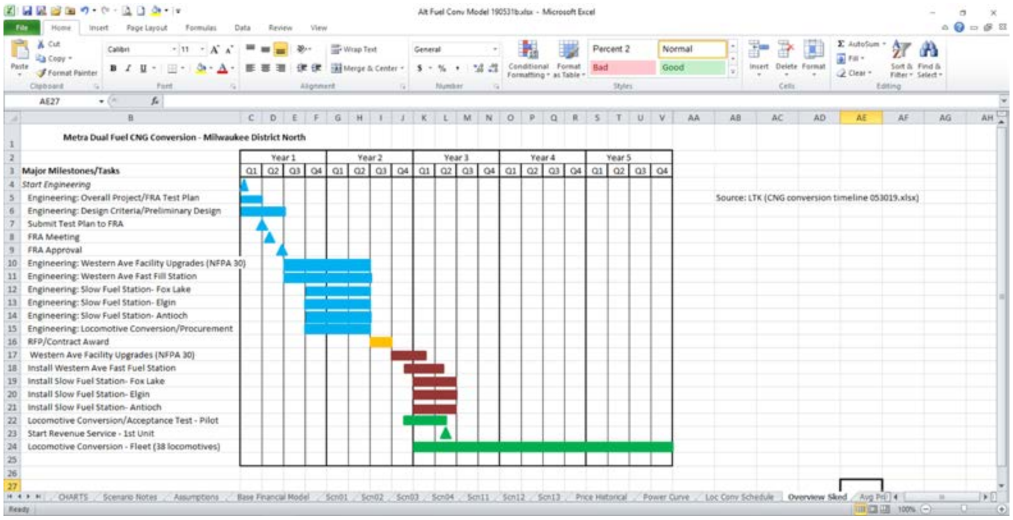
10. Power Curve: This tab contains the work-up for determining the parameters for Scenario 3, using the Power Curve Regression diesel and CNG fuel price forecast.



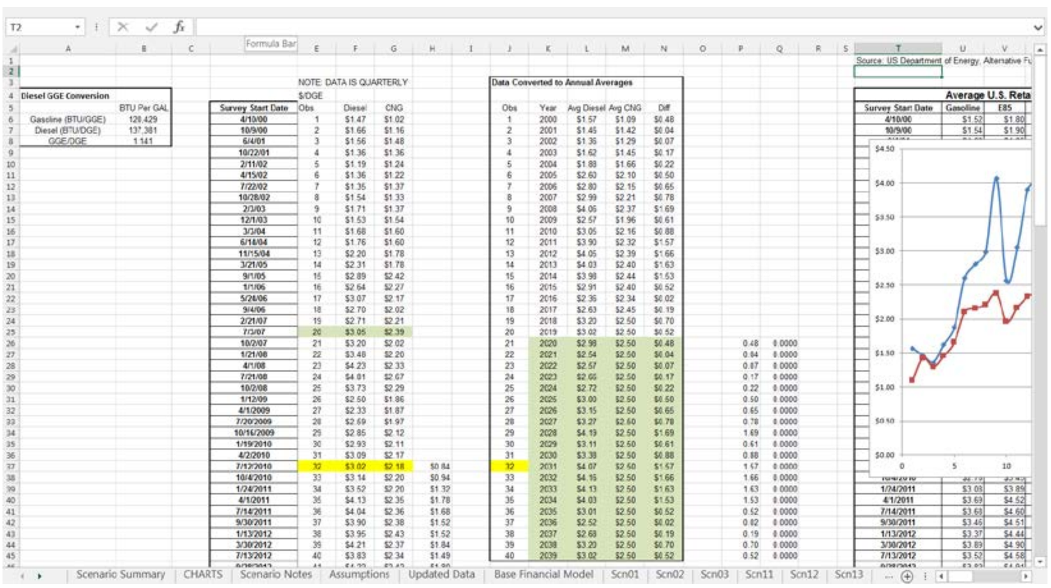
11. Loc Conv Schedule: This tab contains the work-up for determining the number of locomotives converted each year for each engine type, based on the overall locomotive conversion schedule.



12. Overview Sked: This tab contains the proposed dual fuel CNG conversion schedule for the Metra Milwaukee District Line.



13. Avg Prices: This tab contains the historical prices for diesel fuel and CNG.



Diesel GGE Conversion	BTU Per GAL
Gasoline (BTU/GGE)	128,429
Diesel (BTU/DGE)	137,381
GGE/DGE	1.141

NOTE: DATA IS QUARTERLY
$/DGE

Survey Start Date	Obs	Diesel	CNG	
4/10/00	1	$1.47	$1.02	
10/9/00	2	$1.66	$1.16	
6/4/01	3	$1.56	$1.48	
10/22/01	4	$1.36	$1.36	
2/11/02	5	$1.19	$1.24	
4/15/02	6	$1.36	$1.22	
7/22/02	7	$1.35	$1.37	
10/28/02	8	$1.54	$1.33	
2/3/03	9	$1.71	$1.37	
12/1/03	10	$1.53	$1.54	
3/3/04	11	$1.68	$1.60	
6/14/04	12	$1.76	$1.60	
11/15/04	13	$2.20	$1.78	
3/21/05	14	$2.31	$1.78	
9/1/05	15	$2.89	$2.42	
1/1/06	16	$2.64	$2.27	
5/24/06	17	$3.07	$2.17	
9/4/06	18	$2.70	$2.02	
2/21/07	19	$2.71	$2.21	
7/3/07	20	$3.05	$2.39	
10/2/07	21	$3.20	$2.02	
1/21/08	22	$3.48	$2.20	
4/1/08	23	$4.23	$2.33	
7/21/08	24	$4.01	$2.67	
10/2/08	25	$3.73	$2.29	
1/12/09	26	$2.50	$1.86	
4/1/2009	27	$2.33	$1.87	
7/20/2009	28	$2.69	$1.97	
10/16/2009	29	$2.85	$2.12	
1/19/2010	30	$2.93	$2.11	
4/2/2010	31	$3.09	$2.17	
7/12/2010	32	$3.02	$2.18	$0.84
10/4/2010	33	$3.14	$2.20	$0.94
1/24/2011	34	$3.52	$2.20	$1.32
4/1/2011	35	$4.13	$2.35	$1.78
7/14/2011	36	$4.04	$2.36	$1.68
9/30/2011	37	$3.90	$2.38	$1.52
1/13/2012	38	$3.95	$2.43	$1.52
3/30/2012	39	$4.21	$2.37	$1.84
7/13/2012	40	$3.83	$2.34	$1.49

Data Converted to Annual Averages

Obs	Year	Avg Diesel	Avg CNG	Diff		
1	2000	$1.57	$1.09	$0.48		
2	2001	$1.45	$1.42	$0.04		
3	2002	$1.36	$1.29	$0.07		
4	2003	$1.62	$1.45	$0.17		
5	2004	$1.88	$1.66	$0.22		
6	2005	$2.60	$2.10	$0.50		
7	2006	$2.80	$2.15	$0.65		
8	2007	$2.99	$2.21	$0.78		
9	2008	$4.06	$2.37	$1.69		
10	2009	$2.57	$1.96	$0.61		
11	2010	$3.05	$2.16	$0.88		
12	2011	$3.90	$2.32	$1.57		
13	2012	$4.05	$2.39	$1.66		
14	2013	$4.03	$2.40	$1.63		
15	2014	$3.98	$2.44	$1.53		
16	2015	$2.91	$2.40	$0.52		
17	2016	$2.36	$2.34	$0.02		
18	2017	$2.63	$2.45	$0.19		
19	2018	$3.20	$2.50	$0.70		
20	2019	$3.02	$2.50	$0.52		
21	2020	$2.98	$2.50	$0.48	0.48	0.0000
22	2021	$2.54	$2.50	$0.04	0.04	0.0000
23	2022	$2.57	$2.50	$0.07	0.07	0.0000
24	2023	$2.66	$2.50	$0.17	0.17	0.0000
25	2024	$2.72	$2.50	$0.22	0.22	0.0000
26	2025	$3.00	$2.50	$0.50	0.50	0.0000
27	2026	$3.15	$2.50	$0.65	0.65	0.0000
28	2027	$3.27	$2.50	$0.78	0.78	0.0000
29	2028	$4.19	$2.50	$1.69	1.69	0.0000
30	2029	$3.11	$2.50	$0.61	0.61	0.0000
31	2030	$3.38	$2.50	$0.88	0.88	0.0000
32	2031	$4.07	$2.50	$1.57	1.57	0.0000
33	2032	$4.16	$2.50	$1.66	1.66	0.0000
34	2033	$4.13	$2.50	$1.63	1.63	0.0000
35	2034	$4.03	$2.50	$1.53	1.53	0.0000
36	2035	$3.01	$2.50	$0.52	0.52	0.0000
37	2036	$2.52	$2.50	$0.02	0.02	0.0000
38	2037	$2.68	$2.50	$0.19	0.19	0.0000
39	2038	$3.20	$2.50	$0.70	0.70	0.0000
40	2039	$3.02	$2.50	$0.52	0.52	0.0000

Source: US Department of Energy, Alternative Fu

Average U.S. Reta

Survey Start Date	Gasoline	E85
4/10/00	$1.52	$1.80
10/9/00	$1.54	$1.90
1/24/2011	$3.08	$3.89
4/1/2011	$3.69	$4.52
7/14/2011	$3.68	$4.60
9/30/2011	$3.46	$4.51
1/13/2012	$3.37	$4.44
3/30/2012	$3.89	$4.90
7/13/2012	$3.52	$4.58

CNG Safety Data Sheet

SAFETY DATA SHEET

1. Product and Company Identification

Product identifier **Compressed Natural Gas (CNG)**

Other means of identification Not available

Recommended use Fuel

Recommended restrictions None known.

Manufacturer information Irving Oil Refining G.P.
Box 1260
Saint John, NB E2L 4H6 CA
Phone: (506) 202-2000
Refinery: (506) 202-3000
Emergency Phone: 1-800-424-9300 (CHEMTREC)

Supplier See above.

2. Hazards Identification

Physical hazards	Flammable gases	Category 1
	Gases under pressure	Compressed gas
Health hazards	Not classified.	
Environmental hazards	Not classified.	
WHMIS 2015 defined hazards	Not classified	

Label elements

Signal word Danger

Hazard statement Extremely flammable gas.
Contains gas under pressure; may explode if heated.

Precautionary statement

Prevention Keep away from heat/sparks/open flames/hot surfaces. - No smoking.

Response Leaking gas fire: Do not extinguish, unless leak can be stopped safely. Eliminate all ignition sources if safe to do so.

Storage Store in a well-ventilated place. Protect from sunlight. Store in a well-ventilated place.

Disposal Dispose of waste and residues in accordance with local authority requirements.

WHMIS 2015: Health Hazard(s) not otherwise classified (HHNOC) None known

WHMIS 2015: Physical Hazard(s) not otherwise classified (PHNOC) None known

Hazard(s) not otherwise classified (HNOC) None known.

Supplemental information None.

3. Composition/Information on Ingredients

Mixture

Chemical name	Common name and synonyms	CAS number	%
Natural Gas, Dried		68410-63-9	100

All concentrations are in percent by weight unless ingredient is a gas. Gas concentrations are in percent by volume.

4. First Aid Measures

Inhalation If symptoms develop move victim to fresh air. If symptoms persist, obtain medical attention.

Skin contact Flush with cool water. Remove contact lenses, if applicable, and continue flushing. Obtain medical attention if irritation persists.

Eye contact	Flush with cool water. Remove contact lenses, if applicable, and continue flushing. Obtain medical attention if irritation persists.
Ingestion	Not a normal route of exposure as this product is a gas at room temperature and pressure.
Most important symptoms/effects, acute and delayed	Direct contact with eyes may cause temporary irritation.
Indication of immediate medical attention and special treatment needed	Provide general supportive measures and treat symptomatically. Treat patient symptomatically.
General information	Keep away from sources of ignition. No smoking. If you feel unwell, seek medical advice (show the label where possible). Ensure that medical personnel are aware of the material(s) involved and take precautions to protect themselves. Show this safety data sheet to the doctor in attendance. Avoid contact with eyes and skin. Wear rubber gloves and safety glasses with side shields. Keep out of reach of children.

5. Fire Fighting Measures

Suitable extinguishing media	Stop the flow of gas. Dry chemical. Carbon dioxide.
Unsuitable extinguishing media	Do not use a solid water stream as it may scatter and spread fire. Water may be ineffective.
Specific hazards arising from the chemical	Contents under pressure. It is extremely dangerous to extinguish the fire without stopping the flow of gas. Gas and air will mix resulting in an explosion which may be more destructive than the original fire. Vapors are lighter than air and may travel along the ground to some distant source of ignition and flash back. May accumulate in confined spaces, resulting in an explosion and/or asphyxiation hazard.
Special protective equipment and precautions for firefighters	Firefighters should wear full protective clothing including self-contained breathing apparatus.
Fire-fighting equipment/instructions	In case of fire: Stop leak if safe to do so. Move containers from fire area if you can do so without risk. Do not direct water at source of leak or safety devices as icing may occur.
Specific methods	Use standard firefighting procedures and consider the hazards of other involved materials.
General fire hazards	Extremely flammable gas.
Hazardous combustion products	May include and are not limited to: Oxides of carbon. Oxides of sulfur. Oxides of nitrogen.

6. Accidental Release Measures

Personal precautions, protective equipment and emergency procedures	Keep out of low areas. Keep people away from and upwind of spill/leak. Do not touch damaged containers or spilled material unless wearing appropriate protective clothing. Ventilate closed spaces before entering them. Local authorities should be advised if significant spillages cannot be contained. For personal protection, see section 8 of the SDS.
Methods and materials for containment and cleaning up	Refer to attached safety data sheets and/or instructions for use. Extinguish all flames in the vicinity. Stop leak if you can do so without risk. If possible, turn leaking containers so that gas escapes rather than liquid. Isolate area until gas has dispersed. Use water spray to reduce vapors or divert vapor cloud drift. Prevent entry into waterways, sewer, basements or confined areas. For waste disposal, see section 13 of the SDS.
Environmental precautions	Do not discharge into lakes, streams, ponds or public waters.

7. Handling and Storage

Precautions for safe handling	Do not handle, store or open near an open flame, sources of heat or sources of ignition. Protect material from direct sunlight. All equipment used when handling the product must be grounded. Avoid contact with eyes, skin and clothing. Wear appropriate personal protective equipment. Provide adequate ventilation. Observe good industrial hygiene practices. Wash hands before breaks and immediately after handling the product. When handling, do not eat, drink or smoke.
Conditions for safe storage, including any incompatibilities	Prevent electrostatic charge build-up by using common bonding and grounding techniques. Store in original tightly closed container. Store in a cool, dry place out of direct sunlight. Do not store at temperatures above 120°F (49°C). Store away from incompatible materials (see Section 10 of the SDS). Keep out of reach of children.

8. Exposure Controls/Personal Protection

Occupational exposure limits

Canada. British Columbia OELs. (Occupational Exposure Limits for Chemical Substances, Occupational Health and Safety Regulation 296/97, as amended)

Components	Type	Value
Natural Gas, Dried (CAS 68410-63-9)	TWA	1000 ppm

Biological limit values No biological exposure limits noted for the ingredient(s).

Appropriate engineering controls Use process enclosures, local exhaust ventilation, or other engineering controls to control airborne levels below recommended exposure limits.
Oxygen concentrations in work spaces must not be permitted to fall below 19%.

Individual protection measures, such as personal protective equipment

Eye/face protection Face shield or chemical goggles.

Skin protection

Hand protection Impervious gloves. Confirm with reputable supplier first.

Other Where contact is likely, wear chemical-resistant gloves, a chemical suit, rubber boots, and chemical safety goggles plus a face shield.

Respiratory protection For confined spaces, wear a NIOSH-approved (or equivalent) full-facepiece airline respirator in the positive pressure mode with emergency escape provisions.
Respirator should be selected by and used under the direction of a trained health and safety professional following requirements found in OSHA's respirator standard (29 CFR 1910.134), CAN/CSA-Z94.4 and ANSI's standard for respiratory protection (Z88.2).

Thermal hazards Not applicable.

General hygiene considerations Handle in accordance with good industrial hygiene and safety practice. Wash hands before breaks and immediately after handling the product. When using, do not eat, drink or smoke.

9. Physical and Chemical Properties

Appearance Compressed gas.

Physical state Gas.

Form Compressed gas

Color Colorless

Odor Odorless

Odor threshold Mercaptan - 1 ppb

pH Not applicable

Melting point/freezing point -296.68 °F (-182.6 °C) @ 1atm

Initial boiling point and boiling range -258.52 °F (-161.4 °C) @ 1atm

Pour point Not available.

Specific gravity 0.717 grams/L @ 0°C/0.871 grams/mL @ 60°F

Partition coefficient (n-octanol/water) Not applicable

Flash point -305.9 °F (-187.7 °C) Tag Closed Cup

Evaporation rate Not applicable

Flammability (solid, gas) Flammable gas.

Upper/lower flammability or explosive limits

Flammability limit - lower (%) > 5 (estimated)

Flammability limit - upper (%) < 15.4 (estimated)

Explosive limit - lower (%) Not available.

Explosive limit - upper (%) Not available.

Vapor pressure 522 kPa @ 37.8°C/100°F

Vapor density 0.56 (Air = 1)

Relative density Not available.

Solubility(ies) 3.5% @ 17°C/62.6°F

Auto-ignition temperature 1000.4 °F (538 °C)

Decomposition temperature Not available.

Viscosity Not available.

Other information

Flash point class Flammable IA

10. Stability and Reactivity

Reactivity May react with incompatible materials.

Possibility of hazardous reactions Hazardous polymerization does not occur.

Chemical stability Stable under recommended storage conditions.

Conditions to avoid Avoid temperatures exceeding the flash point. Contact with incompatible materials. Extreme heat and freezing temperatures.
Heat, open flames, static discharge, sparks and other ignition sources.

Incompatible materials Oxidizers. Acids. Halogenated compounds.

Hazardous decomposition products May include and are not limited to: Oxides of carbon. Oxides of sulphur. Oxides of nitrogen.

11. Toxicological Information

Routes of exposure Eye, Skin contact, Inhalation, Ingestion.

Information on likely routes of exposure

Ingestion Not available.

Inhalation No adverse effects due to inhalation are expected.

Skin contact No adverse effects due to skin contact are expected.

Eye contact Direct contact with eyes may cause temporary irritation.

Symptoms related to the physical, chemical and toxicological characteristics Direct contact with eyes may cause temporary irritation.

Information on toxicological effects

Acute toxicity

Components	Species	Test Results
Natural Gas, Dried (CAS 68410-63-9)		
Acute		
Inhalation		
LC50	Rat	> 20000 ppm
Oral		
LD50	Not available	

Skin corrosion/irritation Prolonged skin contact may cause temporary irritation.

Exposure minutes Not available.

Erythema value Not available.

Oedema value Not available.

Serious eye damage/eye irritation Direct contact with eyes may cause temporary irritation.

Corneal opacity value Not available.

Iris lesion value Not available.

Conjunctival reddening value Not available.

Conjunctival oedema value Not available.

Recover days Not available.

Respiratory or skin sensitization

Respiratory sensitization Not available.

Skin sensitization This product is not expected to cause skin sensitization.

Mutagenicity Not classified.

Carcinogenicity This product is not considered to be a carcinogen by IARC, ACGIH, NTP or OSHA. See below.

US. OSHA Specifically Regulated Substances (29 CFR 1910.1001-1050)

Not listed.

Reproductive toxicity Not classified.

Teratogenicity Not classified.

Specific target organ toxicity - single exposure Not classified.

Specific target organ toxicity - repeated exposure Not classified.

Aspiration hazard Not likely, due to the form of the product.

Chronic effects Not available.

12. Ecological Information

Ecotoxicity Not available.

Persistence and degradability No data is available on the degradability of this product.

Bioaccumulative potential Bioconcentration potential is low.

Mobility in soil No data available.

Mobility in general Not available.

Other adverse effects No other adverse environmental effects (e.g. ozone depletion, photochemical ozone creation potential, endocrine disruption, global warming potential) are expected from this component.

13. Disposal Considerations

Disposal instructions Dispose of contents/container in accordance with local/regional/national/international regulations.

Local disposal regulations Dispose in accordance with all applicable regulations.

Hazardous waste code The waste code should be assigned in discussion between the user, the producer and the waste disposal company.

Waste from residues / unused products Empty containers or liners may retain some product residues. This material and its container must be disposed of in a safe manner (see: Disposal instructions).

Contaminated packaging Empty containers should be taken to an approved waste handling site for recycling or disposal. Since emptied containers may retain product residue, follow label warnings even after container is emptied.

14. Transport Information

Transport of Dangerous Goods (TDG) Proof of Classification Classification Method: Classified as per Part 2, Sections 2.1 – 2.8 of the Transportation of Dangerous Goods Regulations. If applicable, the technical name and the classification of the product will appear below.

U.S. Department of Transportation (DOT)

Basic shipping requirements:

UN number UN1971

Proper shipping name Natural gas, compressed (with high methane content)

Hazard class 2.1

Packaging exceptions 306

Transportation of Dangerous Goods (TDG - Canada)

Basic shipping requirements:

UN number UN1971

Proper shipping name NATURAL GAS, COMPRESSED with high methane content

Hazard class 2.1

DOT

TDG

15. Regulatory Information

Canadian federal regulations This product has been classified in accordance with the hazard criteria of the Hazardous Products Regulations (SOR/2015-17) and the SDS contains all the information required by the HPR.

Export Control List (CEPA 1999, Schedule 3)

Not listed.

Greenhouse Gases

Not listed.

Precursor Control Regulations

Not regulated.

WHMIS 2015 Exemptions Controlled

US federal regulations This product is a "Hazardous Chemical" as defined by the OSHA Hazard Communication Standard, 29 CFR 1910.1200.

TSCA Section 12(b) Export Notification (40 CFR 707, Subpt. D)

Not regulated.

CERCLA Hazardous Substance List (40 CFR 302.4)

Not listed.

US. OSHA Specifically Regulated Substances (29 CFR 1910.1001-1050)

Not listed.

Superfund Amendments and Reauthorization Act of 1986 (SARA)

Hazard categories
Immediate Hazard - No
Delayed Hazard - No
Fire Hazard - Yes
Pressure Hazard - Yes
Reactivity Hazard - No

SARA 302 Extremely hazardous substance No

SARA 311/312 Hazardous chemical No

SARA 313 (TRI reporting)

Not regulated.

Other federal regulations

Clean Air Act (CAA) Section 112 Hazardous Air Pollutants (HAPs) List

Not regulated.

Clean Air Act (CAA) Section 112(r) Accidental Release Prevention (40 CFR 68.130)

Not regulated.

US state regulations See below

US - Minnesota Haz Subs: Listed substance

Natural Gas, Dried (CAS 68410-63-9) Listed.

US - Texas Effects Screening Levels: Listed substance

Natural Gas, Dried (CAS 68410-63-9) Listed.

US. Massachusetts RTK - Substance List

Natural Gas, Dried (CAS 68410-63-9)

US. New Jersey Worker and Community Right-to-Know Act

Not regulated.

US. Pennsylvania Worker and Community Right-to-Know Law

Natural Gas, Dried (CAS 68410-63-9)

US. Rhode Island RTK

Not regulated.

US. California Proposition 65

California Safe Drinking Water and Toxic Enforcement Act of 1986 (Proposition 65): This material is not known to contain any chemicals currently listed as carcinogens or reproductive toxins.

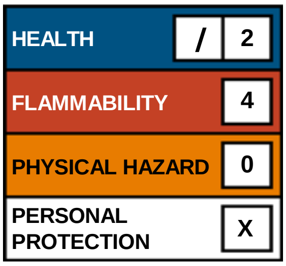
Inventory status

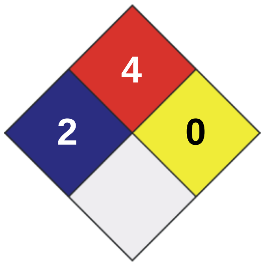
Country(s) or region	Inventory name	On inventory (yes/no)*
Canada	Domestic Substances List (DSL)	Yes
Canada	Non-Domestic Substances List (NDSL)	No
United States & Puerto Rico	Toxic Substances Control Act (TSCA) Inventory	Yes

*A "Yes" indicates that all components of this product comply with the inventory requirements administered by the governing country(s)

16. Other Information

LEGEND	
Severe	4
Serious	3
Moderate	2
Slight	1
Minimal	0





Disclaimer

The information contained in this form is based on data from sources considered to be reliable but Irving Oil Refining G.P. does not guarantee the accuracy or completeness thereof. The information is provided as a service to the persons purchasing or using the material to which it refers and Irving Oil Refining G.P. expressly disclaims all liability for loss or damage including consequential loss or for injury to persons including death. The information shall not be reproduced, published or distributed in any manner without prior consent in writing of Irving Oil Refining G.P.

Issue date 11-October-2018

Version # 02

Effective date 22-February-2017

Prepared by Dell Tech Laboratories, Ltd. Phone: (519) 858-5021

Other information For an updated SDS, please contact the supplier/manufacturer listed on the first page of the document.

Pace CNG Cost November 2018

CNG Natural Gas Bill November 2018

The DGE used from Fleet Watch for November is 103,190.8 DGE.

Mansfield Power & Gas Natural gas cost for November is $53,731.12

Nicor Invoice cost for November is $16,920.81

Com Ed cost for November is $7,214.84

CNG Station maintenance cost for November is $8,589.24

The total cost per DGE for November 2018 is $0.8302.

Mansfield Power & Gas	
Natural gas cost per DGE =	$0.5206
Nicor Invoice cost per DGE =	$0.1639
Electric cost per DGE =	$0.0625
CNG station maint. cost per DGE =	$0.0832
	$0.8302

The average price of Diesel fuel for November 2018 was $2.28 per gallon.

This is $1.45 savings per DGE over diesel fuel.

$1.45 X 103,190.8 = $149,626.66 savings for November 2018.

Total savings in 2018 thru November $1,958,059.93

Mansfield Power & Gas

Pace Suburban Bus System
550 W. Algonquin Rd
Arlington Heights, IL 60005

REMIT TO:
Mansfield Power and Gas
Receivables Account
P.O. Box 733714
Dallas, TX 75373-3714

INVOICE

Service Location: South CNG - 4469220987
Utility: Nicor
Rate Plan Expiration: September 30, 2021
Rate: NGI Chicago Citygate- 0.0025

Charges:

Previous Amount Due:	$	47,632.62
Payment Received:	$	(47,632.62)
Current Amount Due:	$	53,731.12
Total Amount Due:	$	53,731.12

Account Number	Statement Date	Total Due Now	Due Date
2000194 - 1811	12/7/2018	$ 53,731.12	1/6/2019

Category	Total Vol. (Therms)	Amount
Energy Delivery Summary:	153,517.48	$ 53,731.12
Charges and Fees:		$ -

Energy Delivery Charges Details:

Month	Service Location	Account Number	Total Volume(Therms)	Price	Amount
Nov-18	2101 W. 163rd Street	4469220987	153,517.48	0.3500	$ 53,731.12

Voucher# 358308
Accuracy Verified kp Date 12/11/18
Approved for Payment
Account# 1009463
Account# 226535 South CNG Rct

DEC10'18 3:13PM FIN

Charges and Fees:

Late Payment Notice
If payment is not made by the due date, balances on gas accounts will incur the greater of a 1.5% or $10.00 service charge

Contract Volume (Therms)		Utility Account Number	4469220987
Billed Usage (Therms)	153,517.48	Meter/Station ID Number	2000194
Balancing Band (Therms)		Service From	November 1, 2018
Imbalance Volume (Therms)		Service To	November 30, 2018
BTU Factor		Billing Period (Days)	30
		Statement Period	November-18

KEEP THIS STATEMENT FOR YOUR RECORDS

PLEASE SEND ELECTRONIC PAYMENTS ONLY, DO NOT REMIT CASH, CHECKS, OR MONEY ORDERS

Mansfield Power & Gas

Remit to:	Mansfield Power and Gas
	Receivables Account
ABA	061092387
Acct. No.	133828639

Account Number	2000194
Due Date	1/6/2019
Total Due	$53,731.12
Past Due Date	1/7/2019
After Due Date	$54,537.08

Customer Service
Monday - Friday, 8:00 am - 5:00 pm EST
www.mansfieldpowergas.com

Questions? Call us
678-207-3350

Vehicles Monthly Miles to Date Report (with last odometer)

Report for All Divisions and All Departments and All Vehicles and Type 11 for Revenue Vehicles between 11/01/2018 12:00 AM and 11/30/2018 11:55 PM

Division 0096 (South)

Vehicle Number	Division	Dept	LTD Odometer From Last Trans	LTD MPG From Last Trans	Miles Run	Total Fuel	Total Oil	Total Cool	Total ATF
015500	0096		120932.0	3.1	3384.2	906.1	25.3	4.6	2.1
015501	0096	TRAN	121147.9	3.9	2983.9	783.6	0.0	12.1	0.0
015502	0096	TRAN	107437.2	3.3	4002.0	967.0	0.0	2.4	0.0
015503	0096	TRAN	119811.7	3.8	3389.9	921.2	28.0	44.8	0.0
015504	0096	TRAN	132628.4	4.2	4576.4	1118.6	28.5	4.8	3.3
015505	0096	TRAN	131153.6	4.7	4208.6	1034.8	28.4	2.5	0.0
015506	0096	TRAN	119614.2	3.7	3077.2	828.9	25.3	1.2	0.0
015507	0096	TRAN	126127.0	3.7	3195.4	879.5	27.7	0.0	0.0
015508	0096	TRAN	133841.5	3.7	3338.2	853.0	28.5	2.4	0.0
015509	0096	TRAN	125711.1	3.9	3000.9	762.4	28.0	7.1	0.0
015510	0096	TRAN	99152.5	3.7	4092.0	1039.7	31.6	9.9	0.0
015511	0096	TRAN	125972.6	4.3	4088.9	991.0	0.0	30.2	0.0
015512	0096	TRAN	130603.6	3.2	3842.0	1005.7	29.4	20.1	3.3
015514	0096	TRAN	137311.4	4.1	3673.2	910.9	27.3	47.2	0.0
015515	0096	TRAN	130133.0	4.0	3002.3	762.0	26.9	5.3	2.1
015516	0096	TRAN	104148.8	4.1	3054.0	795.8	0.0	0.0	0.0
015517	0096	TRAN	117307.8	3.5	4223.1	1074.4	0.0	0.0	0.0
015518	0096	TRAN	125136.1	3.7	3750.4	1007.3	0.0	4.9	0.7
015519	0096	MAIN	109763.5 *	2.9 *	0.0	0.0	0.0	0.0	0.0
015520	0096	MAIN	114701.9	3.9	3179.7	843.9	0.0	0.0	1.2
017500	0096	MAIN	94216.3	4.0	5191.7	1307.5	0.0	5.1	1.0
017501	0096		88263.4	4.4	4132.4	1019.3	27.4	44.8	0.0
017502	0096	MAIN	83183.7	3.8	3822.9	1004.8	28.3	27.5	0.0
017503	0096	MAIN	74550.2	4.2	3940.1	984.9	0.0	52.3	17.8
017504	0096	MAIN	86295.4	3.6	2970.8	789.9	0.0	0.0	0.0
017505	0096	MAIN	84553.1	4.1	4866.9	1235.4	27.7	48.5	0.0
017506	0096	MAIN	84860.7	4.0	4611.3	1170.6	26.9	12.6	0.0
017507	0096	MAIN	89483.4	4.4	4266.2	1090.1	24.8	7.3	0.0
017508	0096	MAIN	43388.0	4.1	4753.7	1161.7	25.5	14.6	2.2
017509	0096	MAIN	83949.5	4.1	4660.7	1183.0	28.3	45.6	4.1
017510	0096	MAIN	87481.0	4.0	4852.1	1203.5	0.0	0.0	0.0
017511	0096	MAIN	85614.1	3.9	4572.4	1141.5	28.5	13.1	0.0
017512	0096	MAIN	85796.5	3.9	4217.0	1052.6	0.0	2.4	2.3
017514	0096	MAIN	79949.3	4.2	4241.4	1080.5	27.1	14.1	19.3
017515	0096	MAIN	81549.5	4.3	4701.6	1193.8	27.5	9.5	0.0
017516	0096	MAIN	78338.0	4.0	3988.7	989.1	25.7	4.4	16.5
017517	0096	MAIN	76945.5	3.2	3147.2	797.2	25.8	14.9	16.6
017518	0096	MAIN	89305.8	4.0	4739.2	1201.6	28.0	28.8	3.1
017519	0096	MAIN	84948.8	3.9	3615.5	917.1	29.0	0.0	0.0
017520	0096	MAIN	88595.6	3.7	4227.0	1101.9	32.4	0.0	0.0
017521	0096	MAIN	77661.1	3.9	3766.3	950.8	27.0	2.7	18.6
017522	0096	MAIN	78965.8	3.7	4341.9	1165.3	27.4	8.3	0.0
017523	0096	MAIN	85733.8	4.3	3946.8	1027.6	31.7	7.2	0.1
017524	0096	MAIN	85740.4	4.2	4930.6	1252.4	28.0	5.8	0.0
017525	0096	MAIN	78491.4	3.7	3926.8	994.0	28.3	8.6	0.0
017526	0096	MAIN	71695.5	3.3	4065.2	1063.2	32.7	27.3	0.0
017527	0096	MAIN	69691.8	4.1	4590.7	1164.9	28.7	8.8	0.0
017528	0096	MAIN	76216.6	3.7	3787.3	1071.4	15.4	14.4	18.9
017529	0096	MAIN	73656.2	3.9	4569.6	1244.5	28.6	72.3	1.5
017530	0096	MAIN	73192.8	3.8	4351.3	1109.2	31.3	20.7	0.0
017531	0096	MAIN	68483.2	3.8	4494.8	1177.6	24.7	36.3	1.2
017532	0096	MAIN	54273.5	3.9	5243.9	1338.6	56.2	2.8	0.0

** indicates current LTD odometer and/or MPG because vehicle was not serviced during the specified time period*

Vehicle Number	Division	Dept	LTD Odometer From Last Trans	LTD MPG From Last Trans	Miles Run	Total Fuel	Total Oil	Total Cool	Total ATF
017533	0096	MAIN	68504.0	3.9	4390.9	1158.5	27.4	10.2	1.1
017534	0096	MAIN	76399.2	3.7	4115.8	1041.8	3.3	4.9	18.4
017535	0096	MAIN	47114.2	2.9	534.9	184.7	0.0	0.0	0.0
017536	0096	MAIN	67899.6	3.8	4100.4	1045.5	27.2	46.9	0.0
017537	0096	MAIN	77272.7	3.8	4534.3	1173.4	27.1	2.9	18.5
017538	0096	MAIN	66997.8	3.7	5118.2	1298.8	28.0	42.4	0.0
017539	0096	MAIN	70995.1	4.3	4411.0	1136.2	34.4	17.3	0.0
017540	0096	MAIN	73561.5	4.1	4423.9	1139.7	26.7	11.2	0.0
017541	0096	MAIN	57512.9	3.7	3876.6	975.4	27.9	3.4	0.0
017542	0096	MAIN	71888.6	3.7	5038.9	1296.8	27.5	7.0	5.2
017543	0096	MAIN	67222.2	3.8	2561.9	650.0	29.3	10.5	0.0
017544	0096	MAIN	71786.1	4.0	4373.0	1135.0	30.9	16.1	1.7
017545	0096	MAIN	71798.7	3.7	4846.1	1244.6	27.0	4.5	0.0
017546	0096	MAIN	68125.9	4.3	5029.6	1248.1	33.3	4.9	0.0
017547	0096	MAIN	67987.8	4.0	4371.6	1081.7	30.1	0.0	0.0
017548	0096	MAIN	17044.2	3.9	1575.1	481.8	28.2	9.7	0.0
017549	0096	MAIN	69070.4	3.6	3983.0	1066.5	28.5	51.5	0.0
017550	0096	MAIN	57192.2	3.7	4031.2	1065.8	0.0	20.9	0.9
017551	0096	MAIN	66374.9	4.0	4142.4	1067.7	27.3	5.5	0.0
017552	0096	MAIN	51675.7	4.0	4403.9	1097.0	27.4	2.7	1.1
017553	0096	MAIN	62712.3	4.0	4304.0	1078.8	28.7	0.0	5.2
017554	0096	MAIN	54044.1 *	3.4 *	0.0	0.0	0.0	0.0	0.0
017555	0096	MAIN	66650.3	4.1	4785.4	1245.2	29.3	62.2	0.0
017556	0096	MAIN	66077.8	3.9	4983.9	1240.4	30.1	12.9	0.0
017557	0096	MAIN	64351.1	3.9	4357.5	1050.3	31.8	5.1	0.0
017558	0096	MAIN	66795.2	4.2	5545.9	1355.7	31.3	45.5	2.2
017559	0096	MAIN	63330.4	3.9	4356.1	1109.0	27.0	8.6	2.9
017560	0096	MAIN	64799.0	4.6	4103.7	975.7	0.0	0.5	0.0
017561	0096	MAIN	63771.6	4.2	4899.2	1188.6	33.9	5.2	0.0
017562	0096	MAIN	59533.1	4.4	2437.8	626.0	28.5	11.3	0.0
017563	0096	MAIN	69839.0	3.4	5479.3	1294.6	31.9	7.4	0.0
017564	0096	MAIN	48657.0	4.0	4837.8	1231.8	6.5	7.0	0.0
017565	0096	MAIN	58383.2	4.3	4857.0	1171.5	32.1	22.6	0.0
017566	0096	MAIN	63130.0	4.0	2646.3	622.2	0.0	5.9	0.0
017567	0096	MAIN	55410.7	4.2	5141.5	1234.7	29.0	9.1	0.0
017568	0096	MAIN	60695.9	3.8	3971.2	1066.0	3.3	15.0	0.0
017569	0096	MAIN	57653.0	4.2	3664.6	946.5	28.6	44.6	1.0
017570	0096	MAIN	57445.9	4.1	5173.5	1273.4	27.1	15.0	0.0
017571	0096	MAIN	59552.9	3.7	4810.5	1225.9	28.1	10.5	0.0
018500	0096	MAIN	27573.3	3.9	5057.9	1288.3	28.1	0.9	0.0
018501	0096	MAIN	27140.6	4.0	4997.8	1266.5	32.1	6.7	2.7
018502	0096	MAIN	25959.4	4.0	5010.8	1215.3	28.9	5.8	0.0
018503	0096	MAIN	4005.0	3.8	568.2	148.2	0.0	0.0	0.0
018504	0096	MAIN	4375.9	3.5	446.6	129.7	0.0	0.0	0.0
018505	0096	MAIN	28568.1	4.3	6124.8	1493.6	27.2	10.9	0.0
018506	0096	MAIN	25864.2	4.1	2425.1	635.7	0.0	3.0	0.0
018507	0096	MAIN	20684.3	3.8	3128.2	830.5	2.1	13.2	0.0
018508	0096	MAIN	12043.8	3.9	1202.9	325.6	0.0	0.0	0.0
018509	0096	MAIN	27255.8	4.0	4925.5	1236.0	3.3	2.1	0.0
018510	0096	MAIN	26914.4	3.5	5605.5	1424.2	28.6	12.4	0.0
				3.9	**405307.5**	**103190.8**	**2176.8**	**1376.1**	**196.8**

102 Vehicle(s) in Division 0096

** indicates current LTD odometer and/or MPG because vehicle was not serviced during the specified time period*

Nicor Gas

Gas Transportation Customer Service Center P.O. Box 190 Aurora, IL 60507-0190 (630) 983-4040

DEC10'18 3:22PM FIN

SET #: 465

ACCOUNT NUMBER 4469220987 5
Issue Date 12/03/18
Rate 74 TRANSPORT SERVICE
BILLING PERIOD 11/01/18 to 12/01/18, 30 Days

Customer PACE SUBURBAN BUS D
IVISION OF THE RTA
Meter Number 1509007

Service Address 2101 W 163RD
PL-CNGFACILITY
MARKHAM

Total Current Bill due on 1/18/19 $ 16,920.81

Please see the enclosed calculation sheet(s) for a detailed description of your current charges.

4469220987-1811 ~~Cost~~ Brenda 3391

ACCOUNT SUMMARY

	Total Current Bill	$	16,920.81
	Previous Account Balance	$	17,975.70
11/20/18	Payment Received, Thank you!	$	-17,975.70
	Total Due	$	16,920.81

Voucher # 358480

Accuracy Verified WH Date 12-12-18

Approved for Payment ______

Account# 1000136

Account# 11-22107-0-504113-201

44692209875 S 11/1/18-12/1/18 Due 1/18/19

Customers can review the Nicor Gas Customer Information Packet and access rules related to our service standards and reliability at nicorgas.com/about-us/customer-news.

ENERGY PROFILE	This year
Average daily cost	$564.02
Average daily therms	5,117.24

QUESTIONS ABOUT YOUR GAS SERVICE?
Customer Service 630 983-4040
Your account number is: 4469220987 5 9

Detach and return this portion with payment

Nicor Gas

ACCOUNT NO.
4469220987 5
Total Amount Due
$16,920.81

PACE SUBURBAN BUS D
550 W Algonquin Rd
Arlington Heights IL 60005

BILL PAYMENT CENTER
Nicor Gas
P.O. BOX 5407
CAROL STREAM, IL 60197-5407

44 69 22 0987 5 0016920811 0016920811 9

Nicor Gas

as Transportation Customer Service Center P.O. Box 190 Aurora, IL 60507-0190 (630) 983-4040

CURRENT CALCULATIONS

SET #: 465

AME:
AILING ADDRESS: PACE SUBURBAN BUS D
IVISION OF THE RTA
550 W Algonquin Rd
Arlington Heights IL 60005

FOR SERVICE AT:
2101 W 163RD
PL-CNGFACILITY
MARKHAM

SERVICE FROM: 11/01/18
TO: 12/01/18
ISSUED: 12/03/18

ROUP: 7113
CCOUNT NO.: 4469220987

RATE: 74

TRANSPORT ID: 7113

OF DAYS: 30

METER READINGS PRESENT	PREVIOUS	GAS METERED	DISPL	FACTORS TEMP	PRESS	SUPER	GAS DELIVERED	BTU	THERMS
2841760	2693720	148040	1.0000	1.000	1.000	1.000	148040	1.037	153,517.48 (1)
				TOTAL METERED					153,517.48
				LESS NOMINEE TRANSPORTATION THERMS					153,517.48 (2)
				NI-GAS SUPPLIED					0.00
				MAXIMUM DAILY CONTRACT QUANTITY					6,543.00
				STORAGE BANKING SERVICE CAPACITY					215,919.00
				CRITICAL DAY SBS RIGHTS (THERMS)					3,413.68

DEC10'18 3:21PM FIN

MAILING ADDRESS:

PACE SUBURBAN BUS D
550 W Algonquin Rd
Arlington Heights IL 60005

Nicor Gas

as Transportation Customer Service Center P.O. Box 190 Aurora, IL 60507-0190 (630) 983-4040

CURRENT CALCULATIONS

SET #: 465

CUSTOMER: PACE SUBURBAN BUS D
ACCOUNT NO.: 4469220987

SERVICE FROM: 11/01/18
TO: 12/01/18

	THERMS	RATE		DOLLARS
RANSPORTATION ADMINISTRATION				8.00
ONTHLY CUSTOMER CHARGE				169.54
ECORDING DEVICE CHARGE				16.00
DV. AGENCY COMPENSATION ADJ				.04
NERGY EFFICIENCY PROGRAMS	153,517.48	.0056		859.70
RANCHISE COST ADJUSTMENT				.27
ISTRIBUTION CHARGE:				
STEP 1	150.00	.0979	14.69	
STEP 2	4,850.00	.0327	158.60	
STEP 3	148,517.48	.0260	3,861.45	
OTAL DISTRIBUTION CHARGE				4,034.74
TORAGE BANKING SERVICE CHARGE	215,919.00	.0052		1,122.78
NVIRONMENT COST	153,517.48	.0028		429.85
RANSPORTATION SERV ADJUSTMENT	153,517.48	-.0002		30.70-
AX COST ADJUSTMENT	153,517.48	.0008		122.82-
UALIFYING INFRASTRUCTURE CHRG	$5,222.72	.0487		254.35
OTAL CHARGES BEFORE TAXES				6,741.75
TATE USE TAX	153,517.48	.0240		3,684.42
	DOLLARS	**RATE**		
TATE UTILITY FUND TAX	$6,741.75	.0010		6.74
UNICIPAL TAX	$6,741.75	.0515		347.20
UNICIPAL GAS USE TAX	153,517.48	.0400		6,140.70
URRENT TOTAL - SEE GAS SERVICE BILL FOR ACCOUNT BALANCE				$16,920.81

FOOTNOTES:

(1) SEE SUMMARY OF STORAGE ACTIVITY FOR DETAIL.

(2) DETERMINED BY GROUP TRANSPORTATION THERMS DELIVERED DIVIDED BY TOTAL THERMS DELIVERED. SUBJECT TO SUPPLIER BILLING.

OTE: ALL QUANTITIES ARE IN THERMS.
FOR COMPARISON PURPOSES, THE GAS SUPPLY CHARGE (GSC) FOR THIS BILLING PERIOD IS .3543 PER THERM.

DEC10'18 3:21PM FIN

Nicor Gas
ias Transportation Customer Service Center P.O. Box 190 Aurora, IL 60507-0190 (630) 983-4040

SUMMARY OF DAILY USAGE

SET #: 465

CUSTOMER: PACE SUBURBAN BUS D
ACCOUNT NO.: 4469220987

SERVICE FROM: 11/01/18
TO: 12/01/18

ATE	DAILY USAGE	NOMINEE SUPPLIED THERMS	ACCUMULATED COMPANY SUPPLIED	AUTHORIZED EXCESS RECEIVED	UNAUTHORIZED EXCESS RECEIVED
1-01	6,253.11	6,253.11	0.00	0.00	0.00
1-02	6,029.97	6,024.97	0.00	0.00	0.00
1-03	3,639.87	3,639.87	0.00	0.00	0.00
1-04	2,125.85	2,125.85	0.00	0.00	0.00
1-05	6,304.96	6,304.96	0.00	0.00	0.00
1-06	6,439.77	6,439.77	0.00	0.00	0.00
1-07	6,201.26	6,201.26	0.00	0.00	0.00
1-08	6,336.07	6,336.07	0.00	0.00	0.00
1-09	6,170.15	6,170.15	0.00	0.00	0.00
1-10	3,598.39	3,598.39	0.00	0.00	0.00
1-11	2,136.22	2,136.22	0.00	0.00	0.00
1-12	6,149.41	6,199.91	0.00	0.00	0.00
1-13	5,973.12	5,973.12	0.00	0.00	0.00
1-14	6,066.95	6,066.95	0.00	0.00	0.00
1-15	5,796.83	5,796.83	0.00	0.00	0.00
1-16	6,118.30	6,118.30	0.00	0.00	0.00
1-17	3,525.80	3,525.80	0.00	0.00	0.00
1-18	2,219.18	2,219.18	0.00	0.00	0.00
1-19	6,139.04	6,139.04	0.00	0.00	0.00
1-20	5,869.42	5,869.42	0.00	0.00	0.00
1-21	6,045.71	6,095.71	0.00	0.00	0.00
1-22	2,385.10	2,385.10	0.00	0.00	0.00
1-23	5,869.42	5,869.92	0.00	0.00	0.00
1-24	3,660.61	3,660.61	0.00	0.00	0.00
1-25	2,198.44	2,198.99	0.00	0.00	0.00
1-26	6,056.08	6,056.08	0.00	0.00	0.00
1-27	6,211.63	6,211.63	0.00	0.00	0.00
1-28	5,973.12	5,973.12	0.00	0.00	0.00
1-29	6,273.85	6,273.85	0.00	0.00	0.00
1-30	5,755.35	5,755.35	0.00	0.00	0.00
	153,517.48	153,517.48		0.00	0.00

DEC10'18 3:21PM FIN

CNG COM ED BILL

November 08, 2018 thru December 11, 2018

1. Electricity Supply Charge $14,281.47 divided by 395,438 kwh = $0.0361 kwh.
2. CNG Electricity Supply Charge $0.0361 X 101,716 kwh = $3,671.94.
3. Transmission Charge $0.00503 X 101,716 kwh = $511.63.
4. Misc. Procurement Charge $0.00119 X 101,716 kwh = $121.04.
5. Peak Distribution Charge $6.51 X 230.80 kw = $1,502.50.
6. IL. Electricity Distribution Charge $0.00119 X 101,716 kwh = $121.04.
7. Environmental Cost Recovery $0.00024 X 101,716 kwh = $24.41.
8. Renewable Portfolio Standard $0.00142 X 101,716 kwh = $144.43.
9. Zero Emission Standard $0.00190 X 101,716 kwh = $193.26.
10. Energy Efficiency programs $0.00019 X 101,716 kwh = $19.32.
11. Misc. Metering Charge and Capacity Charge $905.27.
    = $3,547.06 divided by 395,438 kwh
    = $0.0089 X 101,716 kwh = $905.27

Total $7,214.84

Total CNG Electricity Cost for this period $7,214.84 divided by total DGE used during this period 115,387.9 = $0.0625 cost per DGE.

5th
Brenda Willard
X 3356

ComEd. An Exelon Company

Page 1 of 2 Inv # 0870193007 - 1811

Account Number 0870193007

Name PACE CORP
Service Location 2101 W 163RD PL MARKHAM
Phone Number 708-331-0051

Issue Date December 12, 2018

Bill Summary

Previous Balance	$20,682.69
Total Payments - Thank You	$20,682.69
Amount Due on February 11, 2019	**$25,981.93**

'18DEC17 11:11AM AP&R

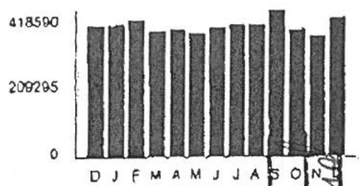
Visit ComEd.com

Customer Service / Power Outage
English
1.877.4COMED1 (1.877.426.6331)
Español
1.800.95.LUCES (1.800.955.8237)
Hearing/Speech Impaired
1.800.572.5789 (TTY)

Meter Information

Read Dates	Meter Number	Load Type	Reading Type	Meter Reading Previous	Meter Reading Present	Difference	Multiplier X	Usage
11/8-12/11	230076268	General Service	Total kWh	Actual	Actual			293722
11/8-12/11	230076268	General Service	On Pk kW	Actual	Actual			343.78
11/8-12/11	230076808	General Service	Total kWh	Actual	Actual			101716
11/8-12/11	230076808	General Service	On Pk kW	Actual	Actual			230.80

Your Usage Profile
13-Month Usage (Total kWh)



Electric Usage

Month	kWh
Dec-17	378801
Jan-18	380442
Feb-18	393308
Mar-18	361327
Apr-18	363029
May-18	353192
Jun-18	368643
Jul-18	378917
Aug-18	377764
Sep-18	418590
Oct-18	382951
Nov-18	347632
Dec-18	395438

Month Billed	Average Daily kWh	Temp
Last Year	11478.8	39
Last Month	11987.3	47
Current Month	11983.0	32

Vouchers
Accuracy Verified X Brenda Willard
Approved for Payment
Date 12/17/18
Account# 1000232
Account# 1L.22107.0.505211.500

Service from 11/8/2018 to 12/11/2018 - 33 Days **Commercial Hourly - 400 kW to 1000 kW**

Electricity Supply Services **$19,907.04**

Electricity Supply Charge	395,438 kWh			14,281.47
Transmission Services Charge	395,438 kWh	X	0.00503	1,989.05
Capacity Charge	594.29 kW	X	6.50504	3,865.88
Purchased Electricity Adjustment				-699.93
Misc Procurement Component Chg	395,438 kWh	X	0.00119	470.57

Delivery Services - ComEd **$4,441.87**

Customer Charge				101.63
Standard Metering Charge				27.47
Distribution Facilities Charge	574.58 kW	X	6.51000	3,740.52
IL Electricity Distribution Charge	395,438 kWh	X	0.00119	470.57
Meter Lease				11.17
Nonstandard Facilities Charge				90.51

For Electric Supply Choices visit pluginillinois.org

(continued on next page)

Return only this portion with your check made payable to ComEd. Please write your account number on your check.

ComEd. An Exelon Company

To pay by phone call 1-800-588-9477. A convenience fee will apply.

0000262 SL H 1247 60005 -C76-B1-P00000J

Account Number
0870193007

Payment Amount
$25981.93

PACE CORP
550 W ALGONQUIN RD
ARLINGTON HEIGHTS, IL 60005

Please pay this amount by 2/11/2019 **$25,981.93**

COMED
PO BOX 6112
CAROL STREAM, IL 60197-6112

087019300700000000090420000006

Taxes and Other				$1,633.02
Environmental Cost Recovery Adj	395,438 kWh	X	0.00024	94.91
Renewable Portfolio Standard	395,438 kWh	X	0.00142	561.52
Zero Emission Standard	395,438 kWh	X	0.00190	751.33
Energy Efficiency Programs	395,438 kWh	X	0.00019	75.13
Franchise Cost	$4,436.57	X	3.38400%	150.13

Total Current Charges **$25,981.93**

Thank you for your payment of $20,682.69 on November 26, 2018

Total Amount Due **$25,981.93**

Message Center

ComEd

- WAYS TO PAY: Looking for ways to pay your bill? Visit ComEd.com/PAY.
- ILLINOIS COMMERCE COMMISSION CONSUMER DIVISION: (800-524-0795): The Consumer Services Division is available to help resolve disputes with ComEd. However, customers should contact ComEd first before seeking assistance from the ICC.

1247-78-0000282-0001-0000375

CME906R 03/10

When you provide a check as payment, you authorize us to use information from your check either to make a one-time electronic fund transfer from your account or to process the payment as a check transaction.

Vehicles Monthly Miles to Date Report (with last odometer)

Report for All Divisions and All Departments and All Vehicles and Type 11 for Revenue Vehicles between 11/08/2018 12:00 AM and 12/11/2018 11:55 PM

Division 0096 (South)

Vehicle Number	Division	Dept	LTD Odometer From Last Trans	LTD MPG From Last Trans	Miles Run	Total Fuel	Total Oil	Total Cool	Total ATF
015500	0096		122473.5	3.7	4244.8	1128.3	25.3	4.6	0.0
015501	0096	TRAN	122591.4	3.8	3592.6	940.4	26.9	6.8	0.0
015502	0096	TRAN	109197.1	3.3	4195.8	1069.3	25.3	41.0	0.0
015503	0096	TRAN	120892.5	3.9	3754.4	1013.2	28.0	51.2	0.0
015504	0096	TRAN	133936.2	3.9	4821.2	1185.7	28.2	37.8	0.0
015505	0096	TRAN	131669.8	4.2	3938.0	970.5	28.4	2.5	0.0
015506	0096	TRAN	120590.8	3.1	3218.4	861.8	25.3	1.2	0.0
015507	0096	TRAN	127493.1	4.0	3659.1	969.0	0.0	0.0	0.0
015508	0096	TRAN	135290.4	4.1	3997.8	1013.0	28.5	0.0	0.0
015509	0096	TRAN	126707.5	3.4	3518.7	927.2	28.0	2.8	3.1
015510	0096	TRAN	100694.7	3.7	4479.1	1137.0	27.1	5.6	0.0
015511	0096	TRAN	126900.1	4.3	4180.5	998.0	28.5	30.2	0.0
015512	0096	TRAN	131752.5	3.6	4143.6	1113.1	29.4	12.8	3.3
015514	0096	TRAN	138990.2	4.4	4776.4	1163.4	0.0	10.4	0.0
015515	0096	TRAN	131304.4	3.6	3487.8	900.6	26.9	9.4	0.0
015516	0096	TRAN	104148.8	4.1	2301.8	590.2	0.0	0.0	0.0
015517	0096	TRAN	118886.4	3.8	5153.6	1319.7	27.8	5.4	1.1
015518	0096	TRAN	126930.9	3.5	4769.8	1298.9	27.2	4.9	0.7
015519	0096	MAIN	110239.5	3.3	778.5	236.3	0.0	0.0	0.0
015520	0096	MAIN	115785.5	3.9	3127.1	836.5	0.0	0.0	0.0
017500	0096	MAIN	95289.0	3.6	4778.3	1240.2	26.9	10.5	1.0
017501	0096		89419.2	3.9	4434.6	1074.4	27.4	44.8	0.0
017502	0096	MAIN	84851.0	3.8	4990.4	1287.5	28.3	32.2	0.0
017503	0096	MAIN	75900.8	4.3	4331.0	1086.5	28.6	118.4	17.8
017504	0096	MAIN	87909.2	4.0	3646.6	971.4	0.0	0.0	0.0
017505	0096	MAIN	86295.5	4.0	5358.6	1369.7	27.7	46.2	0.0
017506	0096	MAIN	86860.1	4.0	5881.0	1446.6	26.9	17.1	0.0
017507	0096	MAIN	90764.1	3.8	4025.3	1045.6	31.7	22.7	0.0
017508	0096	MAIN	44840.4	3.8	5255.4	1317.9	27.2	64.9	2.2
017509	0096	MAIN	85479.5	3.7	5069.0	1290.6	28.3	39.9	0.0
017510	0096	MAIN	88737.1	3.8	5136.3	1270.7	29.4	8.9	0.0
017511	0096	MAIN	87574.4	3.8	5193.8	1331.7	28.5	13.1	0.0
017512	0096	MAIN	87005.5	3.9	4114.9	1051.1	26.6	43.4	5.2
017514	0096	MAIN	81005.7	3.2	4261.3	1106.5	31.5	14.1	19.3
017515	0096	MAIN	83251.7	3.9	5302.8	1285.4	27.6	14.6	0.0
017516	0096	MAIN	80233.3	3.8	5158.7	1303.0	29.0	0.0	2.1
017517	0096	MAIN	76945.5	3.2	1945.8	505.0	25.8	14.9	0.0
017518	0096	MAIN	90724.0	3.8	5151.2	1312.2	28.0	22.7	3.1
017519	0096	MAIN	86494.0	4.1	4520.7	1149.8	0.0	0.0	0.0
017520	0096	MAIN	90315.5	4.1	4765.6	1234.7	30.7	46.0	0.0
017521	0096	MAIN	79477.0	3.8	4782.7	1208.7	27.0	2.7	0.0
017522	0096	MAIN	80470.4	3.7	4769.9	1260.5	28.9	14.1	0.0
017523	0096	MAIN	87198.5	4.0	4657.3	1208.0	33.7	8.1	0.0
017524	0096	MAIN	87523.8	4.0	5672.5	1447.4	26.5	46.2	0.0
017525	0096	MAIN	79849.3	3.7	4131.5	1060.8	28.3	8.6	0.0
017526	0096	MAIN	73076.7	3.5	4224.0	1135.9	32.7	27.3	0.0
017527	0096	MAIN	71068.7	3.9	5182.0	1300.1	27.2	14.1	0.0
017528	0096	MAIN	77603.5	3.9	3903.3	1035.2	40.1	18.7	18.9
017529	0096	MAIN	74744.1	4.0	4352.8	1177.4	28.6	13.0	1.5
017530	0096	MAIN	74528.9	4.2	4871.1	1213.4	34.6	25.7	0.0
017531	0096	MAIN	70504.6	4.0	5170.1	1336.6	28.0	37.6	1.2
017532	0096	MAIN	55137.8	3.5	5391.2	1400.7	28.2	7.0	0.0

** indicates current LTD odometer and/or MPG because vehicle was not serviced during the specified time period*

Vehicle Number	Division	Dept	LTD Odometer From Last Trans	LTD MPG From Last Trans	Miles Run	Total Fuel	Total Oil	Total Cool	Total ATF
017533	0096	MAIN	69716.9	4.1	4184.0	1116.9	0.0	6.0	0.0
017534	0096	MAIN	77443.2	3.7	4168.6	1074.4	31.7	8.4	18.4
017535	0096	MAIN	48690.5	4.2	2111.2	567.7	31.4	0.0	0.0
017536	0096	MAIN	69468.0	3.4	4578.3	1212.8	27.2	43.8	0.0
017537	0096	MAIN	78872.6	3.9	5213.9	1348.2	27.1	0.0	18.5
017538	0096	MAIN	68831.9	3.9	5673.5	1441.0	31.3	35.3	0.0
017539	0096	MAIN	73059.4	3.6	5436.4	1386.4	34.4	17.3	0.0
017540	0096	MAIN	75634.4	4.0	5279.8	1357.2	26.7	11.2	18.2
017541	0096	MAIN	59654.6	3.9	5202.1	1330.2	27.9	13.9	0.0
017542	0096	MAIN	74142.7	3.6	6041.7	1618.0	30.9	12.9	10.4
017543	0096	MAIN	67672.8	3.9	2189.3	573.5	15.4	52.3	0.1
017544	0096	MAIN	73088.2	3.9	5092.3	1282.7	30.9	3.7	1.7
017545	0096	MAIN	73407.9	4.1	4898.9	1249.7	27.0	4.5	0.0
017546	0096	MAIN	70152.0	3.8	5686.0	1441.7	39.9	10.9	0.0
017547	0096	MAIN	70003.5	4.2	5163.6	1278.8	31.2	5.7	1.0
017548	0096	MAIN	18492.6	3.7	2863.7	772.7	28.2	9.7	0.0
017549	0096	MAIN	70759.1	3.6	4442.2	1227.1	28.5	56.8	0.0
017550	0096	MAIN	58886.5	4.3	5059.3	1309.0	0.0	25.0	0.9
017551	0096	MAIN	67869.1	4.1	4932.2	1256.2	30.6	5.5	0.0
017552	0096	MAIN	53234.7	4.0	5211.0	1295.7	30.7	2.7	1.1
017553	0096	MAIN	64438.6	4.2	5309.0	1321.9	28.7	2.0	5.2
017554	0096	MAIN	54044.1 *	3.4 *	0.0	0.0	0.0	0.0	0.0
017555	0096	MAIN	68861.8	3.7	6639.7	1688.6	29.3	49.0	0.0
017556	0096	MAIN	67891.8	3.8	5104.8	1297.0	26.8	5.3	0.0
017557	0096	MAIN	65940.3	4.1	4947.6	1209.9	31.8	5.1	0.0
017558	0096	MAIN	67896.1	3.9	5500.4	1362.4	28.5	44.7	2.2
017559	0096	MAIN	64734.9	3.3	4747.5	1217.0	0.0	8.0	2.9
017560	0096	MAIN	66692.4	4.0	5070.4	1218.8	30.1	35.1	0.0
017561	0096	MAIN	65151.6	3.9	5029.7	1237.6	40.5	7.5	0.0
017562	0096	MAIN	60363.2	3.8	2357.1	659.8	28.5	14.4	0.0
017563	0096	MAIN	71711.2	3.9	6284.9	1508.3	33.9	7.5	0.7
017564	0096	MAIN	49969.0	4.0	4967.4	1258.1	34.5	7.0	0.0
017565	0096	MAIN	59914.3	4.2	5095.8	1230.6	30.8	6.9	0.0
017566	0096	MAIN	63290.4	3.5	1752.0	438.8	0.0	0.0	0.0
017567	0096	MAIN	57724.5	4.4	6621.9	1557.7	29.0	9.9	0.0
017568	0096	MAIN	61572.7	3.7	3910.8	985.4	30.6	19.1	0.0
017569	0096	MAIN	58678.7	4.0	3920.8	996.6	28.6	37.8	1.0
017570	0096	MAIN	58574.0	3.9	4808.8	1216.8	30.4	27.1	0.0
017571	0096	MAIN	61466.6	3.8	5417.5	1359.3	26.8	20.1	0.0
018500	0096	MAIN	29046.2	4.0	5600.1	1405.9	28.1	0.9	0.0
018501	0096	MAIN	29167.3	4.2	5780.6	1411.1	32.1	2.2	2.7
018502	0096	MAIN	27944.9	4.1	6025.7	1459.4	3.2	0.0	0.0
018503	0096	MAIN	4005.0	3.8	568.2	148.2	0.0	0.0	0.0
018504	0096	MAIN	4375.9	3.5	446.6	129.7	0.0	0.0	0.0
018505	0096	MAIN	30369.9	3.8	6393.5	1545.7	27.2	9.5	0.0
018506	0096	MAIN	25864.2	4.1	974.5	233.9	0.0	0.0	0.0
018507	0096	MAIN	22780.1	3.6	5224.0	1391.5	35.8	31.8	0.0
018508	0096	MAIN	13624.1	3.9	2783.2	734.7	0.0	2.1	0.0
018509	0096	MAIN	28687.7	4.3	4895.0	1205.0	39.2	8.1	0.7
018510	0096	MAIN	29016.4	3.7	6455.4	1680.6	28.8	9.0	0.0
				3.8	**452629.6**	**115387.9**	**2498.9**	**1719.8**	**166.2**

102 Vehicle(s) in Division 0096

** indicates current LTD odometer and/or MPG because vehicle was not serviced during the specified time period*

Approved 12/6/18

INVOICE

Trillium CNG

A Love's Company

Customer:	0003487412
Invoice No:	181240161
Invoice Date:	12/04/2018
Page:	1 of 2

Pace
550 West Algonquin Rd

Arlington Heights, IL 60005-4412

Payment Terms:	NET 30 CDOI
Unit Of Measure:	GGE
PO Number:	225552
Contract Number:	

Please Remit To:

Trillium CNG
Attn: Accounts Receivable
PO Box 26210
Oklahoma City, OK 73126

Due Date:	01/03/2019
AMOUNT DUE:	**$1,100.00**

For billing questions, please call (800) 920-1166

Summary

Location	Description	Quantity	Unit Amt	Total
1172 - Markham IL	O&M Monthly Fee (Fixed)	0.000		$1,100.00
	1172 - Markham IL Subtotal:			**$1,100.00**
			Grand Total:	**$1,100.00**

Approved 12/4/18

INVOICE

Trillium CNG
A Love's Company

Customer: 3487412
Invoice No: 1811307412
Invoice Date: 12/04/2018

PACE - Suburban Bus
550 West Algonquin Rd.
Arlington Heights, IL 60005

Payment Terms: NET30
Contract Number: **225552**
Due Date: **1/3/2019**
AMOUNT DUE: **$237.68**

Please Remit To:
Trillium CNG
Attn: Accts Payable - C
PO Box 26210
Oklahoma City, OK 73126

For billing questions, please call (800)920-1166

Identifier	Description	Quantity	UOM	Unit Amt	Amount
	Labor	3.08	Each	75.00	$231.00
	Parker O-ring	2.00	Each	2.37	$4.74
	Parker O-ring - Discount	1.00	Each	-10%	-$0.47
	Parker O-ring 1"Seal Lok	1.00	Each	2.67	$2.67
	Parker O-ring 1"Seal Lok -Discount	1.00	Each	-10%	-$0.26
	Subtotal:				**$237.68**
	Taxes Subtotal:				**$0.00**

Current Charges: **$237.68**
T&M 11/1 Gas Leaking 4th Stage discharge pipe

*Return this portion with your check made payable to **Trillium CNG**. Please write your account number on your check.*

Payment Coupon

PACE - Suburban Bus
550 West Algonquin Rd.
Arlington Heights, IL 60005

Account Number: 3487412
Invoice Number: 1811307412

Please Remit To:
Trillium CNG
Attn: Accts Payable - C
PO Box 26210
Oklahoma City, OK 73126

Amount Due **$237.68**

Amount Paid .... $ ____________

Approved 11/30/18

INVOICE

Trillium CNG
A Love's Company

Customer: 3487412
Invoice No: 1811297412
Invoice Date: 11/29/2018

PACE - Suburban Bus
550 West Algonquin Rd.
Arlington Heights, IL 60005

Payment Terms:	NET30
Contract Number:	**225552**
Due Date:	**12/30/2018**
AMOUNT DUE:	**$4,548.27**

Please Remit To:
Trillium CNG
Attn: Accts Payable - C
PO Box 26210
Oklahoma City, OK 73126

For billing questions, please call (800)920-1166

Identifier	Description	Quantity	UOM	Unit Amt	Amount
	Discharge Valve – Part # B-3712-ZP	1.00	Each	378.64	$378.64
	Discharge Valve – Part # B-3712-ZP - Discount	1.00	Each	-10%	-$37.86
	Suction Valve – Part # B-4087-AA	1.00	Each	369.64	$369.64
	Suction Valve – Part # B-4087-AA -Discount	1.00	Each	-10%	-$36.96
	Concentric Valve – Part # B-5353-E	1.00	Each	937.65	$937.65
	Concentric Valve – Part # B-5353-E Discount	1.00	Each	-10%	-$93.76
	Suction Valve – Part # B-5512-CC	1.00	Each	1,241.78	$1,241.78
	Suction Valve – Part # B-5512-CC Discount	1.00	Each	-10%	-$124.17
	Discharge Valve – Part # B-5513-BB	1.00	Each	1,194.54	$1,194.54
	Discharge Valve – Part # B-5513-BB Discount	1.00	Each	-10%	-$119.45
	Discharge Valve – Part # B-3490-ZM	1.00	Each	362.25	$362.25
	Discharge Valve – Part # B-3490-ZM Discount	1.00	Each	-10%	-$36.22
	Suction Valve – Part #B-5173-BB	1.00	Each	569.10	$569.10
	Suction Valve – Part #B-5173-BB Discount	1.00	Each	-10%	-$56.91
	Subtotal:				**$4,548.27**
	Taxes Subtotal:				**$0.00**

Current Charges:
T&M Spare Set of Valves 8/31 **$4,548.27**

Return this portion with your check made payable to ***Trillium CNG****. Please write your account number on your check.*

Payment Coupon

PACE - Suburban Bus
550 West Algonquin Rd.
Arlington Heights, IL 60005

Account Number: 3487412
Invoice Number: 1811297412

Please Remit To:
Trillium CNG
Attn: Accts Payable - C
PO Box 26210
Oklahoma City, OK 73126

Amount Due **$4,548.27**

Amount Paid .... $ ____________

Approved 11/27/18
[signature]

INVOICE

Customer: 3487412
Invoice No: 1811217412
Invoice Date: 11/27/2018

Trillium
A Love's Company

PACE - Suburban Bus
550 West Algonquin Rd.
Arlington Heights, IL 60005

Payment Terms: NET30
Contract Number: **225552**
Due Date: **12/27/2018**
AMOUNT DUE: $983.39

Please Remit To:
Trillium CNG
Attn: Accts Payable - C
PO Box 26210
Oklahoma City, OK 73126

For billing questions, please call (800)920-1166

Identifier	Description	Quantity	UOM	Unit Amt	Amount
	Labor 9/20	1.02	Each	75.00	$76.50
	Labor 9/10	1.55	Each	75.00	$116.25
	Labor 10/23	4.05	Each	75.00	$303.75
	1 inch Wedge Anchors	1.00	Each	65.66	$65.66
	1 inch Wedge Anchors Discount	1.00	Each	-6.56	-$6.56
	Plates for Mount Plates	1.00	Each	268.80	$268.80
	Plates for Mount Plates discount	1.00	Each	-26.88	-$26.88
	Anchor Epoxy	1.00	Each	116.28	$116.28
	Anchor Epoxy discount	1.00	Each	-11.62	-$11.62
	Hammer Rental	1.00	Each	81.21	$81.21
	Subtotal:				**$983.39**
	Taxes Subtotal:				**$0.00**

Current Charges: **$983.39**
T&M 10/23 Broken Compressor Anchors

Return this portion with your check made payable to ***Trillium CNG****. Please write your account number on your check.*

Payment Coupon

PACE - Suburban Bus
550 West Algonquin Rd.
Arlington Heights, IL 60005

Account Number: 3487412
Invoice Number: 1811217412

Please Remit To:
Trillium CNG
Attn: Accts Payable - C
PO Box 26210
Oklahoma City, OK 73126

Amount Due **$983.39**

Amount Paid .... $ ____________

Trillium
A Love's Company

INVOICE

Approved 11/19/18

Customer: 3487412
Invoice No: 1811167412-2
Invoice Date: 11/16/2018

PACE - Suburban Bus
550 West Algonquin Rd.
Arlington Heights, IL 60005

Payment Terms:	NET30
Contract Number:	**225552**
Due Date:	**12/19/2018**
AMOUNT DUE:	**$1,719.90**

Please Remit To:
Trillium CNG
Attn: Accts Payable - C
PO Box 26210
Oklahoma City, OK 73126

For billing questions, please call (800)920-1166

Identifier	Description	Quantity	UOM	Unit Amt	Amount
	CT5000 Fill Nozzle	1.00	Each	1,911.00	$1,911.00
	CT5000 Fill Nozzle Discount	1.00	Each	-191.10	-$191.10
	Subtotal:				**$1,719.90**
	Taxes Subtotal:				**$0.00**

Current Charges:
T&M CT5000 Fill Nozzle **$1,719.90**

Return this portion with your check made payable to ***Trillium CNG****. Please write your account number on your check.*

Payment Coupon

PACE - Suburban Bus
550 West Algonquin Rd.
Arlington Heights, IL 60005

Account Number: 3487412
Invoice Number: 1811167412-2

Please Remit To:
Trillium CNG
Attn: Accts Payable - C
PO Box 26210
Oklahoma City, OK 73126

Amount Due **$1,719.90**

Amount Paid .... $ ____________

Pace Visit Notes 2/6/19

Telephone: 206-430-7661

LTK Engineering Services
1201 Third Avenue, Suite 850
Seattle, WA 98101

Facsimile: 206-288-1798

MEMORANDUM

TO: LTK RTA Alternative Energy Locomotive Study Team

FROM: John Alexander and Michael Condei

DATE: February 6, 2019

SUBJECT: Summary of Visit to PACE CNG Bus Facility

Pace visit 2/6/19 – Notes

Attendees:
Larry Braun - Pace
John (consultant) – Pace
Steve – Pace
Corey – Pace
Hersh – RTA
John A. – LTK
Mike C. - LTK

Location: Pace Bus Maintenance and Fueling facility in Markham IL

- They gave us a full tour of refueling stations and bus maintenance facility.
- The fueling operation was commissioned in May 2016.
- Fleet serviced from this facility was purchased new, designed and built for CNG fuel. Each bus has capacity for 189 DGE.
- A, 8" (120-130 psi) line coming in; Nicor installed at no charge to them; pressure is regulated to 80 psig incoming to compressor stations which provide 4,000 psi output (temperature compensated).
- They demonstrated refueling a bus for us, using one of their 2 fueling stations. ~21 DGE added in about 2 - 3 minutes (approx). The pump stops and checks tank level periodically to prevent overfilling. Nozzle plugs in to quick disconnect type fitting on bus. There are 2 fill ports, a 4,000 psi and a 2,000 psi on each fuel station which can be used for a slower fill.
- Compressors are 200 hp, each.
- The CNG compressor stations and storage tanks sit on a fenced-off 120' x 60' concrete pad.
- Ground grid connections incorporated within the pad.

- All buses are refueled overnight (same as diesels) so no change to operations. All 102 buses can be refueled on 8 hr shift.
- On average, about 4000 gal (DGE) of CNG is dispensed per day.
- There is a defueling (gas evacuation) station for use if the CNG tank needs to be emptied for repairs, however they don't routinely empty CNG tanks. All buses inside the maintenance facility had full tanks.
- After each bus is fueled, it is pulled into the maintenance facility for washing and other daily tasks.
- The fueling facility consists of 5 compressor units and 9 storage tanks (89 DGE each) for 800 DGE of buffering (may need to consider buffer tank size for locomotive refueling). They typically run 3 compressors, 2 are in reserve.
- Compressors are run in a lead-lag configuration to ensure that run time is balanced between all units.
- Each compressor station is self-contained and has its own local controls. Each station is also equipped with a methane detector to auto shutoff if a significant leak is detected.
- The compressors are 4 stage with several large HP pumps and motors.
- There is also a supervisory controller with remote data monitoring so offsite users can log in and monitor operations, also remote fault reporting.
- They had some startup issues last week due to the extreme cold; motors had a hard time turning over. Were able to resolve the issues working with their maintainer Trillium CNG. NOTE: Crankcase heaters may be required (not discussed at the meeting).
- Trillium CNG maintains the refueling stations; costs are reflected in their monthly DGE cost assessment and are relatively low (~$.08/DGE). Trillium provides periodic maintenance and is also on call for 2 hr response time if needed.
- There is also a diesel generator as a backup power supply in the event of electric power loss.
- The maintenance facility had to have the ventilation upgraded (5 air changes per hr per NFPA); hot water heat installed and lighting fixtures relocated 18" lower to be in code compliance. Also methane leak detectors & warning lights installed.
- Pace has plans to expand this system to other facilities. A new garage may be built in Wheeling, IL to replace the Des Plaines, IL garage. The Wheeling facility may be equipped with a similar system.

ECI/EE Summary Report 6/12/19

Telephone: 206-430-7661 **LTK Engineering Services** Facsimile: 206-288-1798
1201 Third Avenue, Suite 850
Seattle, WA 98101

MEMORANDUM

TO: LTK RTA Alternative Energy Locomotive Study Team

FROM: John Alexander, PE

DATE: June 26, 2019

SUBJECT: Summary of Visit with Scott Jensen of ECI/Engenious Engineering™

Thanks to Troy Alvarez, I was able to schedule a visit with Scott Jensen at the Energy Conversions Inc/Engenious Engineering™ facility in Fife, WA. Scott was gracious enough to spend several hours with me discussing the development of dual fuel diesel/natural gas engines and showing me his facility. The following summarizes my visit:

- Energy Conversions Inc has now become Engenious Engineering™ and has been absorbed by Peaker Services. ECI started out as a family run business and has been a leader in the large displacement engine dual fuel conversion business for over 30 years. Recently ECI was rebranded to Engenious Engineering™ and has become part of Peaker Services, which provides services to large displacement diesel engines and propulsion in the power, marine, industrial and rail industries.
- There is currently no active rail related work going on at this time; the last project was with NS to convert a switcher to 100% CNG. Most of their current work is on stationary diesel engines.
- Scott did show me their lab which has two EMD engines, an 8 cylinder 645 and a 16 cylinder 710 which are used for ongoing development (see photo).
- ECI/EE has developed conversion kits primarily for the EMD 645 and 710 engines, although there is a kit available for GE engines. The Economizer is allows 40-70% gas substitution. When I showed Scott the diesel CNG notch schedule that we have been using in the simulation, he said it was likely data from an Economizer conversion, which is an abbreviated kit: a gas control valve assembly, some sensors and electronic controls.
- The engine conversion kits for the 645 and 710 engines include: ECI pistons and specially designed cylinder heads to manage compression and combustion; ECI Gas injectors; Pilot fuel (diesel) control system; custom designed and built Electronic Control Unit (ECU) 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 after cooling tanks, radiators, pumps and valves. Scott indicated that the aftercooler was key to the performance of the dual fuel system to maintain power. The conversion kit also uses a number of EMD components and the piston and injectors can be used with existing EMD power assemblies.

- A lot of ECI/EE's development has been on the specially designed pistons and gas injectors which help to optimize combustion and reduce the chance of knocking from the NG due to lower compression ratios.
- With the above conversion kit, Scott provided me with the following notch schedule for diesel/NG consumption, which is much different than what we are currently using in the simulation:

CNG Substitution By Notch provided by EE

Throttle	Diesel	CNG
Dynamic Brake	100%	0
Idle	100%	0
Notch 1	100%	0
Notch 2	100%	0
Notch 3	30%	70%
Notch 4	30%	70%
Notch 5	20%	80%
Notch 6	20%	80%
Notch 7	10%	90%
Notch 8	10%	90%

- As this is a low pressure direct injection system, inlet gas pressure at the injection point on the head is 30 – 80 psig, max flowrate at 100% is in the 350 cfm range.
- Scott indicated that in volume the kits could be supplied in the $350-400K price range. There would likely need to be some NRE to configure the system for the Metra fleet as Scott has not developed the system around their locomotives.
- The engine control unit will likely be supplied by Woodward in the near future, as they are a business partner with Peaker Services. This will replace the ECI/EE developed controller.
- The kit can be installed in place on the engine; tooling and fixtures are provided. Scott estimates about 1,200 hours to do the first unit, based on his experience guiding the conversions at customer sites. Full documentation is available.
- There is also a low emission bank idling system, which can lower diesel emissions at idle: http://www.energyconversions.com/lei1.htm
- Unfortunately, other than what was installed on the test engines, there were not many components to see. Descriptions of the conversion kit components can be found on the website: http://www.energyconversions.com/loco2.htm
- Regarding emissions, the dual fuel engine will produce reduced PM and NOx but total hydrocarbons and CO will be higher due to the contribution of the methane in NG. All of the emissions data available was taken from the BN locomotive that was emissions tested at SWRI in 1991.
- In order to achieve Tier 3 with a dual fuel engine utilizing dynamic gas blending, Scott believes that an exhaust after treatment device such as DOC or DPF would need to be utilized.

- Scott is not certain what the EPA would require for a dual fuel locomotive Tier certification as there are separate emissions requirement for diesel and NG. He expects that the dual fuel engine would need to meet both standards, and there may be issues if the engine runs 100% diesel if no NG is available (note: there are allowances for a Tier 4 engine using urea after treatment to continue operation but in a reduced performance mode until the urea tank is refilled, I believe).
- The BN emissions test data is below:

EMD Line-Haul Duty Cycle Weighted Emissions (g/hp-hr)	**BN Experimental Dual-Fuel Locomotive**	**BN Dual-Fuel Locomotive on 100% Diesel Fuel**	**AAR Unmodified EMD 645E3B Engine**
Total Hydrocarbons (THC)	7.7	0.6	0.3
Non-Methane Hydrocarbons (NMHC)	0.9	0.6	0.3
Carbon Monoxide (CO)	10.0	1.4	0.7
Oxides of Nitrogen (NOx)	4.2	8.4	11.4
Particulate (PM)	0.33	0.49	0.27
Carbon Dioxide (CO2)	366	427	416
Sulfur Dioxide (SO2)	0.24[a]	1.50[a]	1.46[a]
Brake Thermal Efficiency (%)	33.7	37.6	37.4
Note: a - SO2 values computed using 0.43% Sulfur diesel fuel			

- Scott referred me to their website which contains quite a bit of data, although Peaker wants a lot of it removed as they consider it proprietary.
- Scott believes that the dual fuel CNG approach is a good one for a commuter railroad and the barriers to entry may be lower than the Class 1 freight railroads, who have never fully committed. There is an AAR LNG tender working group but it has not progressed very far.

EMD 645 8 Cylinder test engine; gas injection line is pipe running the head.

Gas injector installed in the top of EMD power assembly