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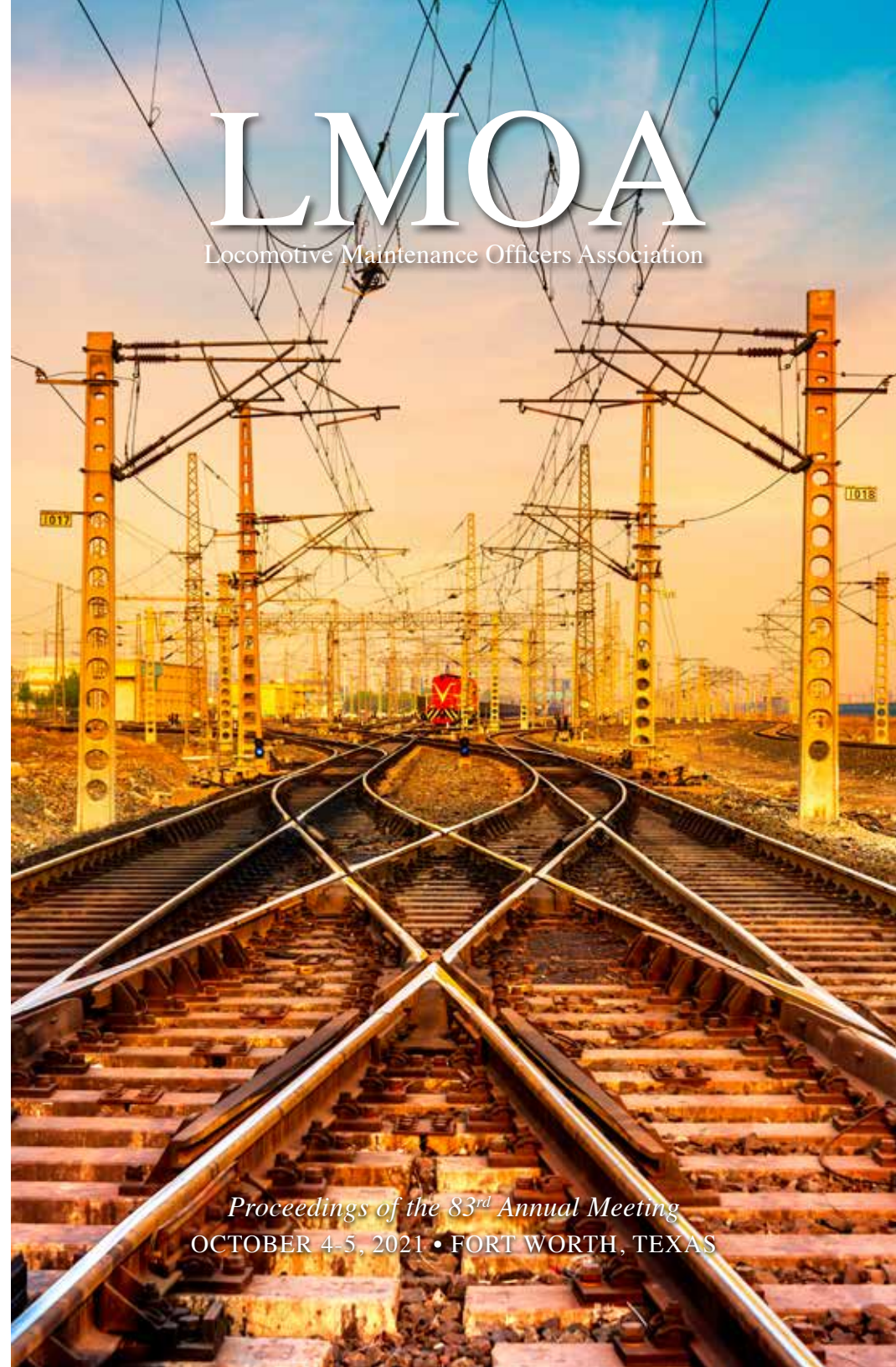
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2021

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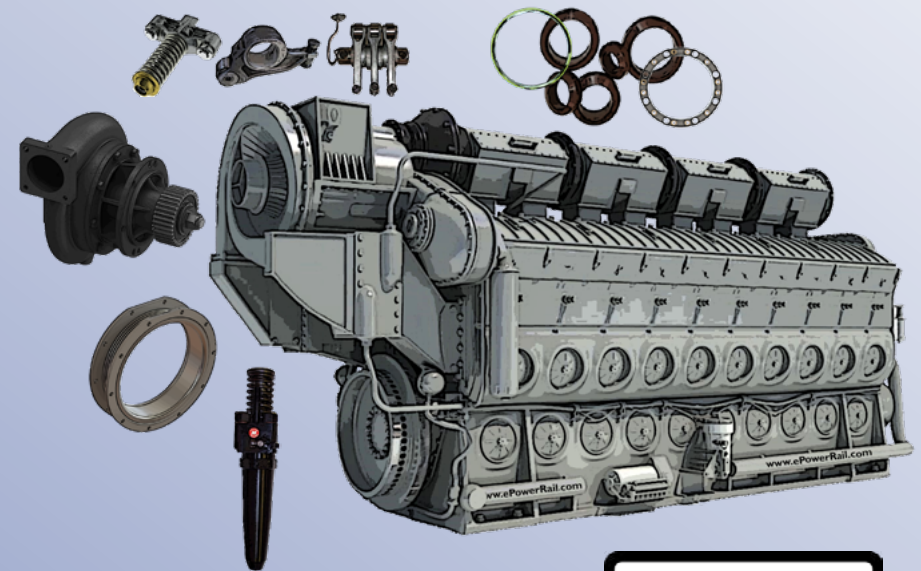
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2020 LMOA MVP RECIPIENTS

The Executive Board of LMOA wishes to congratulate the following individuals who were selected as the Most Valuable Person (MVP) of their respective committees for 2020.

NAME	COMMITTEE	COMPANY
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Peter Scholtens	Locomotive Software and Systems	Integrity Rail

This honor is bestowed on an annual basis to those individuals who perform meritorious service and make significant contributions to their respective committee. The honoree receives a plaque that is presented to them by their supervisors.

LMOA EXECUTIVE COMMITTEE



Dennis Nott

March 26, 1951 - May 9, 2021

Boise, Idaho - Dennis Lloyd Nott, 70, of Boise Idaho took his last train ride on Sunday May 9, 2021.

Dennis was born March 26, 1951 in Charles City Iowa, to Edna and Lloyd Nott (brother Lyle born in 1944). The family lived above the Briggs Trucking Company Depot across from the Illinois Central/Milwaukee Road tracks--he caught the train bug early. Despite moving to Floyd in 1966; Dennis attended Charles City Community High School where he lettered in football, track, general rabble rousing, and rode out the 1968 May 15, F5 tornado in the boys' shower. The tornado roared through Charles City vaporizing the second floor of the trucking depot and all childhood mementos stored there; possibly explaining Dennis' need to save every RR ball cap, calendar, booklet, or magazine; and loose nuts, bolts, etc. In 1969, he became a Cyclone himself, attending Iowa State University in Ames. In 1970 he met future wife Sarah, while playing flag football and decided any girl who could block that hard was worth dating. In 1973 Dennis graduated with a BS in Construction Engineering (Civil Engineer). He first worked for Jackson Construction, while Sarah finished her degree. In early 1974 Morrison Knudsen Company's Railroad Division hired him--a dream job for a rail fan! Dennis moved to Idaho; never regretting leaving the Midwest, snow, humidity, and tornadoes. He returned to marry Sarah over the July 4th weekend. For their memorable honeymoon; Dennis hitched a U-Haul trailer to her small car (no AC) and drove Sarah and black lab Sarge to Boise in the summers' heat.

In 1977 they moved to Columbus Ohio where Dennis worked for CONRAIL-track quality control; and began building both his model railroad and lifelong friendships with Dick Joyce (Nancy) and many others. They missed Idaho, and in 1981 when MK International hired him as Project Engineer for the Cerrejon Coal Project in Colombia; loaded a moving van and each chauffeured a black lab back to Boise. In 1983 with his portion of the project done on time and under budget (is there

any other way?), Dennis was promoted to Project Facility Coordinator of the Cerrejon Port which he completed in 1984. He returned to MK's Railroad Division as a project engineer, and continued his world travels with managerial positions in Locomotive Engineering, Construction, Services, Maintenance, and Sales. In 1985 baby Maggie joined the family, and in 1991, the first Cardigan Welsh Corgi. In January 1992, with MK verging on collapse; Dennis accepted the Southern Pacific Lines job of Assistant Plant Manager of the Burnham Locomotive shop in Denver. Golden, CO was nice; but when Motive Power restructured MK, the lure of Boise brought humans and critters (lab, cardigan, kitty, and bunny) back "home". From 1993 to 1998 Dennis' managerial job titles changed almost yearly (he kept the business cards to prove it). He was VP of Sales and Marketing and VP of Operations and Maintenance when Motive Power became Wabtec in 1998. In 2005, tired of corporate shenanigans (NOT Dennis' term), he formed his own company, Northwestern Consulting—locomotive consulting for the railroad industry. As a sole owner, he worked on projects for CBH Grain in Australia, Saudi Rail Organization, Pacific Harbor Lines, Belt Railway of Chicago, and New York and Atlantic railway. The original goal was to earn the same amount of money, working half as much, so he had time for fishing or working on his ever-expanding model railroad.

A perfect Friday for Dennis was leaving for fishing at "O-dark-thirty" with friend, Bruce Young; and spending the evening with buddy Mark Sachs working on the amazing Model RR in the basement. Dennis loved the passing parade of dogs and cats who shared their home for 47 years, and always fed the backyard squirrels peanuts. He accepted "free" firewood from neighbors' trees; never counting the hours and effort it took to split and stack it. Throughout the years he hosted relatives and friends for extended tours of the west, and enjoyed many fall trips following the rails with friends in the east. The 60+ year annual Nott fishing trip to MN, morphed from flying (never had the lure or pole he wanted), to trekking cross country by truck, 60's music playing, pulling his own boat with every pole, tackle box, net, fish basket, fish finder etc. he owned. Sarah and Maggie crammed in wherever they fit. A true locomotive connoisseur, Dennis easily identified locomotives on any rail line by sight (even from 75 mph on the interstate). He spent hundreds of hours with friends, waiting by the tracks with his camera for a perfect shot. Dennis was a proud member and supporter of the Locomotive Maintenance Officers Association (LMOA) and served as past president and board member. His brotherhood of LMOA friends throughout the country is legion.

Dennis who tolerated no fools, gave "colorful" commentary of others on the road or waterway; not tempered by whomever was with him. Ditto for referees or coaches while watching football games on TV. Despite hating Florida's heat and humidity (work boots and jeans on the beach?), he tolerated several trips to visit Sarah's family. He watching gator hunting on Swamp People, and yelled "Shoot 'em!" (an enhanced version was directed at TV anchors, politicians or celebrities he didn't like).

Diagnosed April 28th with aggressive metastatic pancreatic cancer, Dennis boarded an express train May 9th. He left at the station: many beloved relatives, neighbors and friends; his LMOA brothers from other mothers; Railroad business associates throughout the country; wife of 47 years-Sarah, daughter Maggie and Brandon Dumont, his little man-Radar, big guy-Turbo, and lap princess-Miki.

Celebration of Life will be 11 AM, May 29 at EXPO Idaho's Western Town. Come prepared to share memories! Lunch and beverages will follow. Absences excused for: fishing or camping, and judging or competing in dog events. In lieu of flowers; memorials may be sent to: The Amherst Railway Society, Idaho Fish and Wildlife Foundation, or Boise's VFW: Capitol City Post 63.

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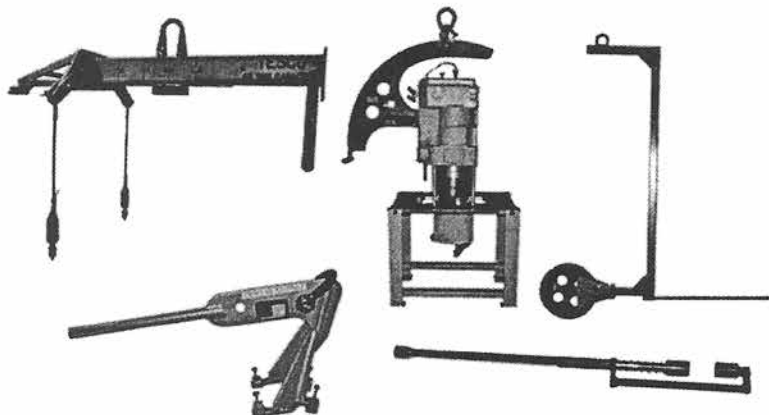
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Report on the Committee on Fuel, Lubricants and Environmental

MONDAY, OCTOBER 4, 2021

9:00 AM



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PERSONAL HISTORY

Anju Singla Regional Sales Manager American Refining Group

Anju joined American Refining Group (ARG) on August 27, 2018 as Railroad Sales Specialist and her current position is Regional Sales Manager. She is responsible for developing and managing existing and new Class 1 and short line railroad accounts and is responsible for sales in the marine industry.

She has 9 years of lubricant sales and 14 years of Research & Development (R&D). She previously worked for Soltex Inc of Houston as a sales representative.

Anju holds a BS degree in Chemistry from St. Louis University and received an MBA from Averett University in Virginia. Additionally, she has a Bachelors and Masters degree in Theology.

Anju currently resides in Richmond, Virginia. In her spare time, she preaches to inmates at the City Jail and at the local Assisted Living Facility in Richmond. She is an avid runner and participates in 5K, 10K and half marathon events.

She is a widow. Her beloved husband, Gus, passed away in 2000.

Review of Trends in Railroad Diesel Fuel Properties Over the Past Decade -or- A Decade of Diesel Fuel

*Prepared by
Corey Ruch – BNSF Railway*

*with great assistance from and thanks to: (in alphabetical order)
Dwight Beebe – Temple Engineering, Rachel Flott – BNSF Railway,
Steven Fritz – SwRI, Jerainne Heywood Ph. D. – Wabtec,
Laura Rasmussen – Progress Rail, Inc*

From introduction and testing of the first diesel locomotives over 100 years ago, to the latest and most modern diesel locomotives of today, one thing has remained constant – the diesel fuel.

...or has it?

Abstract

This paper attempts to review the past decade of diesel fuel sample testing data compiled by major North American Railroads. Due to their substantial fuel consumption, relatively frequent / routine fuel sampling and testing programs, railroads can provide a historic insight into how the fuel landscape is changing. Data from more than 18,000 fuel samples tested over the past decade are examined. Observations are made about various trends in diesel fuel and some predictions are extended toward the future.

Introduction

Interestingly, when Rudolf Diesel first invented the compression-ignition engine in the 1890s, the predominant claim at the time was that the “rational heat motor would work with any kind of fuel in any state of matter.”

Indeed, early experiments with everything from coal tar, paraffin oil, crude oil, gas oil, fuel oil, peanut oil, illuminating gas to lamp oil, shale oil, and more, proved the engines could run on a variety of fuels. However, by the early 1900s

it was becoming apparent the engines ran best on the various fuel oils distilled from petroleum, such as kerosene.

By the 1930’s more complex engines meant the fuel needed to evolve as well. Attempts to specify and produce a consistent standard fuel were initiated, though the world would have to wait until after World War II for the first “modern” high quality fuels to emerge. This new era of fuel was largely based on newly minted standards such as DIN 51601, VTL 9140-001 and NATO F 54.

The possibly more familiar **ASTM D975 Standard Specification for Diesel Fuel** was first established in 1948. ASTM D975 underwent the first revision 12 years later in 1960 and a second revision an additional 7 years later, in 1967. However, as shown in Figure 1, plotting D975 specification revisions by year, it is clear the slow and meandering pace of revision has not continued during the past decade.

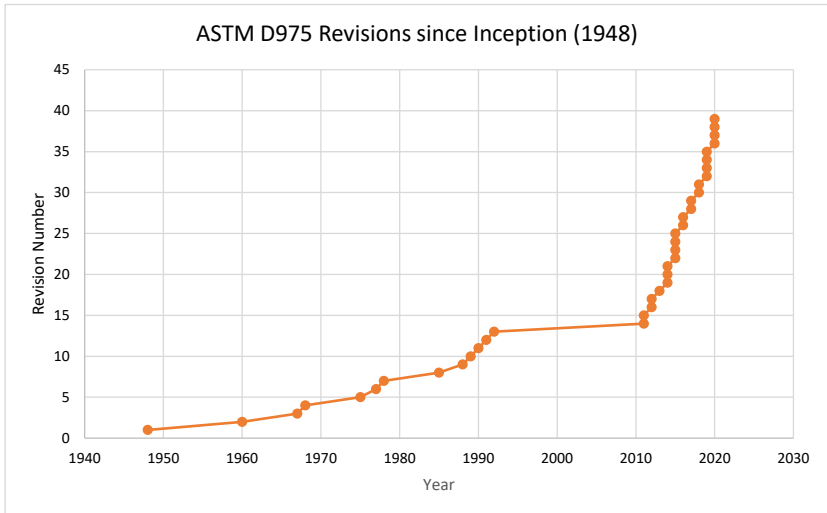


Figure 1

https://global.ihs.com/family_search_res.cfm?input_doc_number=&input_doc_title=&document_name=ASTM%20D975&item_s_key=00019358&stage=H&show_all=Y&eqid=161173911&start_row=1

In fact, a specification which was receiving updates on an average of once per decade in the late 1950s to 1970s, is now receiving two, three and four updates per year as we begin the third decade of the 21st century.

In Figure 2, a trend line provides a bit of humor in that the “Revisions” essentially become asymptotic to the 2024 – 2025 timeframe, meaning a standard continually in revision, never a page of dry ink!

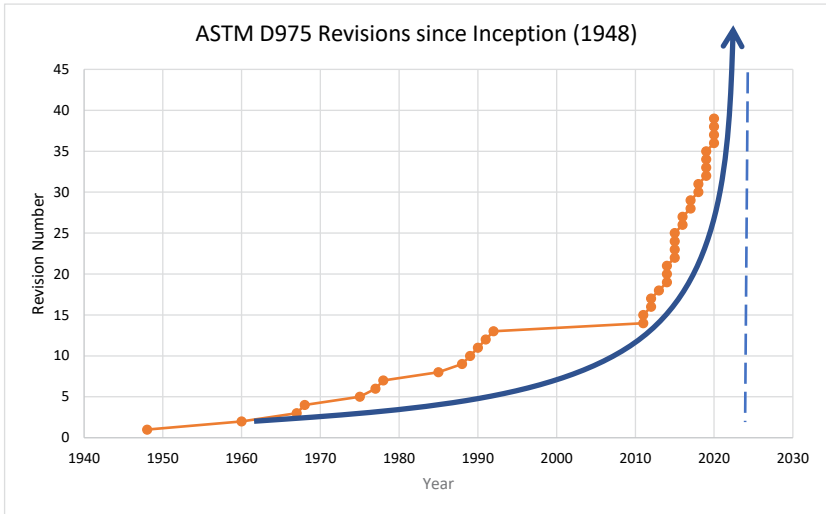


Figure 2

“Predictions are hard, especially about the future.” – Mark Twain, Yogi Berra, et. al.

Given the increasingly rapid cadence of ASTM D975 specification revisions, it becomes only natural to ask, “What, exactly is happening to the actual diesel fuel during this period?”

Throughout much of this time period, diesel fuel could fairly reliably be considered one substance – crude oil removed from the ground, refined to meet certain standards and burned in the diesel engine. Obviously, minor changes were made over the years. Improvement in overall fuel quality and cleanliness, narrower tolerances around key specifications to provide a more reliable overall product, the complete removal of some key components such as sulfur, or even establishment of new specifications for certain key fuel parameters.

This paper attempts to review the past decade of fuel sample data compiled by major North American railroads. Due to their substantial fuel consumption, relatively frequent and routine fuel sampling and testing programs, these railroads can provide a historic insight into how the fuel landscape is changing.

However, several factors should also be noted surrounding this data:

- The testing is most often performed on monthly samples obtained from the bottoms of storage and locomotive fuel tanks. By design, this is meant to be the ‘worst’ fuel present in the tank.

- Testing is performed with the expectation if this ‘worst case’ sample passes relevant tests, then the fuel in the tank above that level is also acceptable fuel. As such, most of the data presented in this report represents testing of ‘worst case’ fuel.
- In some instances, relatively few samples available for a given parameter may skew the sample data. No attempt has been made to standardize the data on a per sample or percent basis.
- “Special Request” samples may skew data. If a sample is specifically sent to test ‘how bad’ the fuel is – say a fuel with a known high water content – it may skew the data. In so much as possible, these samples have been purged from the bulk data.

Additionally, a list of modern fuel specifications and testing methods is provided for reference in Appendix A. With the above-mentioned caveats in place and modern test methods and specifications as a basis, let’s examine some of the data from routine testing of diesel fuel over the past decade.

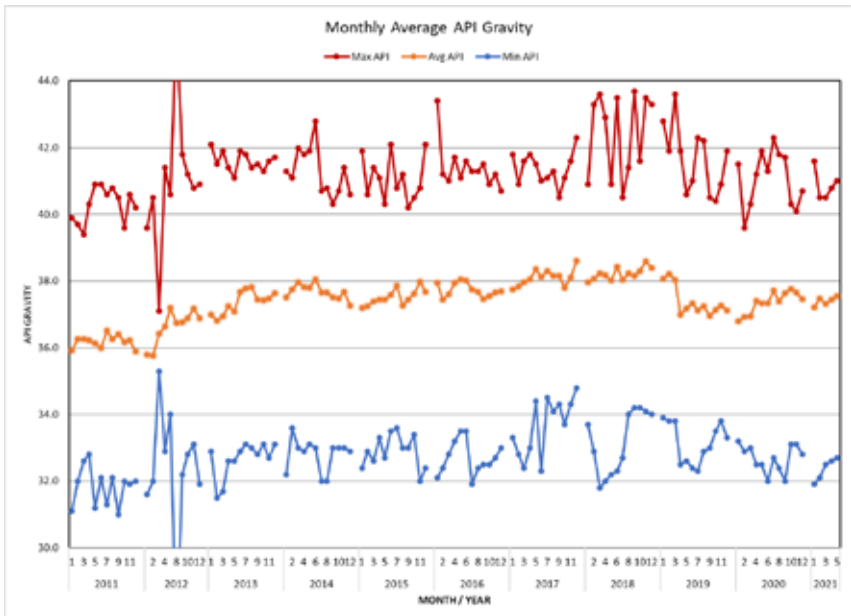


Figure 3

API Gravity

API gravity of the fuel is largely regarded as a quick/easy/simple method to measure the overall ‘health’ and ‘quality’ of the fuel. In one simple and virtually free test – so long as the hydrometer is not damaged – the observer can deter-

mine the density of the fuel – noting that *higher* API gravity means *lower* fuel density. This parameter can give insight into the approximate BTU content of the fuel, suggest contamination with gasoline, alcohol or other product and give approximate indications of the grade of diesel fuel...# 1, # 2, etc.

An ‘eyeball’ approximation of the API data displayed in Figure 3 shows average API Gravity (orange, center plot) rising from around 36.0 in 2011 to approximately 38.2 in 2018. Maximum (red, top) and Minimum (blue, bottom) API gravity measurements follow roughly the same trend, suggesting an overall shift in fuel density.

Curiously, a relatively sharp dip of approximately 1.0° API is noted around March 2019, followed by a slow rise again through 2020 and 2021. The dip may at first seem mysterious, however it also corresponds with a change in laboratory test method from ASTM D287 (Glass Hydrometer) to ASTM D7777 (Digital Density Meter) and involves slight changes in the temperature correction of the measurement.

However, regardless of the exact API Gravity number, across both test methods and throughout the decadal time span, the trend remained the same – increasing API Gravity of the fuel. Overall, this means a trend toward lighter / less dense diesel fuel.

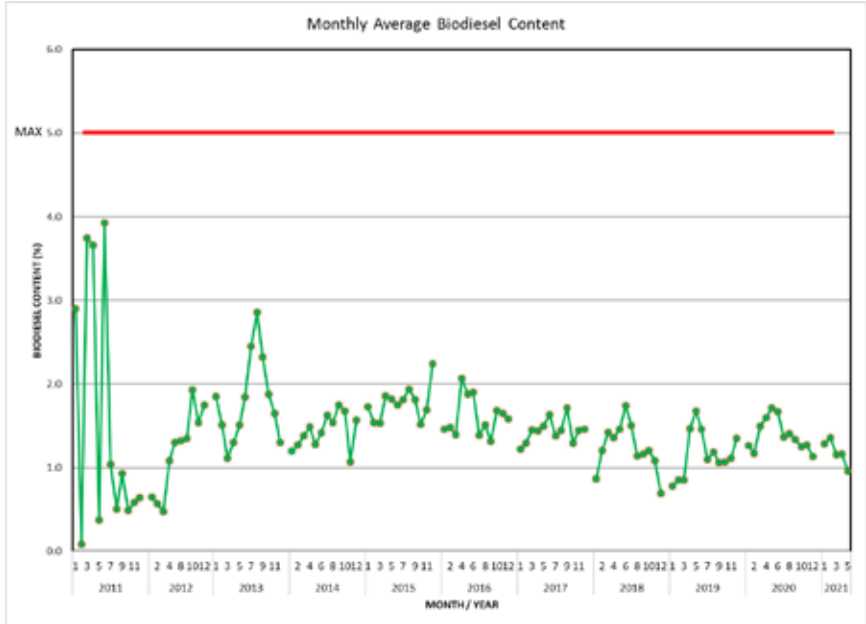


Figure 4

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Biodiesel Content

As with many graphs which will follow, biodiesel content (of selected samples*) displays somewhat of an ebb and flow pattern over the decade. The early 'spikes' in biodiesel content around the 2011 timeframe can be attributed to relatively few samples being obtained at this point in time and most blends were targeting the 3-5% biodiesel range.

As more samples were tested in later years, the data begins to take on a slightly smoother plot line more indicative of an average over dozens if not hundreds of samples. The years 2014-2015 do appear to show a general increase in the average biodiesel content, though levels do trend slightly downward through the 2016-2018 timeframe with a slight rise once again into 2019 and 2020.

An additional caveat for this graph must be stated:

As noted, the data represents 'selected samples' and does not intend to display a statistically random sampling and/or an average biodiesel content for the entire fuel supply.

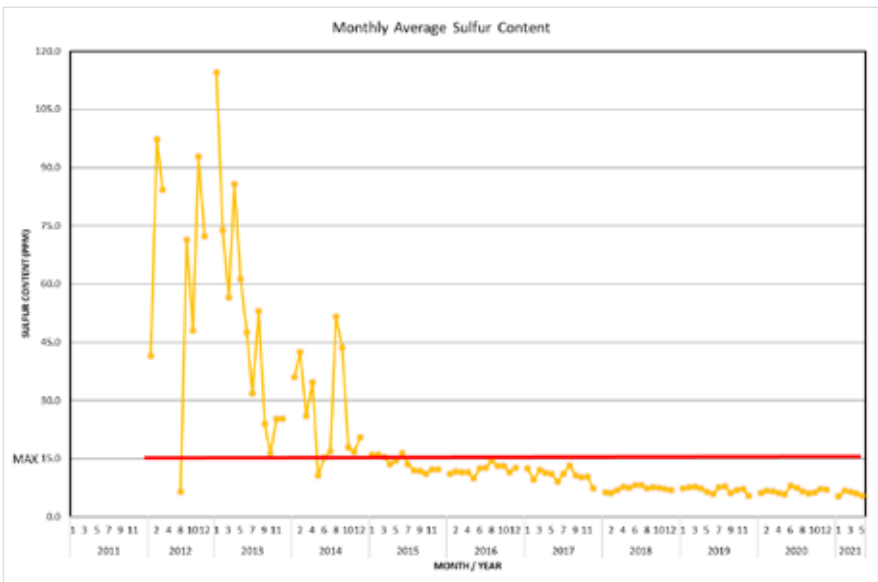


Figure 5

Sulfur Content

Sulfur content, and the removal there-of, represents one large environmental success story in the fuel landscape. Railroads were typically the ‘last resort’ when trying to dispose high sulfur ‘transmix’ fuel.

This ‘transmix’ was created anytime normal diesel fuel was sent through a pipeline after a delivery of high sulfur jet/aviation fuel. The low sulfur diesel fuel would pick up traces of the sulfur from the aviation fuel. Since it was allowable to contaminate ‘general use’ diesel fuel with aviation fuel, but never allowable to contaminate aviation fuel with general use diesel fuel, the mixed diesel fuel was always directed to sources other than aviation – railroads. For an in-depth discussion on the subject, refer to *“Transmix-Derived Fuel for Locomotives”*, Steven G. Fritz, et. al., Southwest Research Institute, Locomotive Maintenance Officers Association – Fuel, Lube and Environmental Committee, 2015.

With new regulations taking effect in 2012, Figure 5 displays sulfur levels, which were already on the decline, were effectively regulated to the Ultra Low Sulfur Diesel (ULSD) maximum of 15 parts per million (ppm) as indicated by the red line. With the 15ppm level achieved in 2012-2015, the trend has continued downward in the years since. Currently, the typical fuel sample in 2020-2021 contains only 5-6ppm sulfur on average.

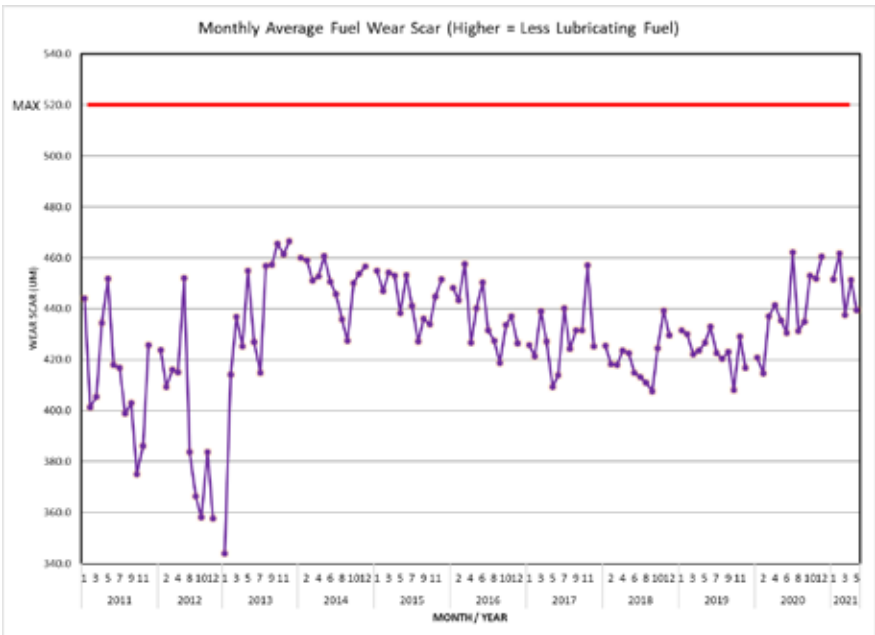


Figure 6

Fuel Lubricity

Fuel lubricity is reported in microns of wear scar, or essentially the size of a scar produced by vibrating a steel ball against a steel disk while both components are submerged in diesel fuel. Consequently, a larger wear scar / higher value means the fuel was less lubricating, while a smaller wear scar / lower value means the fuel was a more effective lubricant.

Figure 6 displays fuel lubricity over the past decade and reveals somewhat of a sinuous curve with lubricity in the 2011-2012 timeframe averaging approximately 420 microns. Lubricity notably worsened in the 2013-2014 timeframe with average wear scars approaching 460 microns, though improvements were made into the 2018-2019 timeframe, only to see wear scar again rise to an average around 450 microns in the 2020-2021 timeframe.

While average lubricity was always maintained well below the ‘520-micron maximum’ specification (red line), the notable ebb and flow of the average value hints at other factors affecting fuel during this time.

Two of the most considerable influences likely came from the introduction of biodiesel fuel which notably improves the lubricating properties of the fuel (lowers the wear scar number) and the removal of sulfur from the fuel which notably reduced the lubricating properties of the fuel (increased the wear scar number).

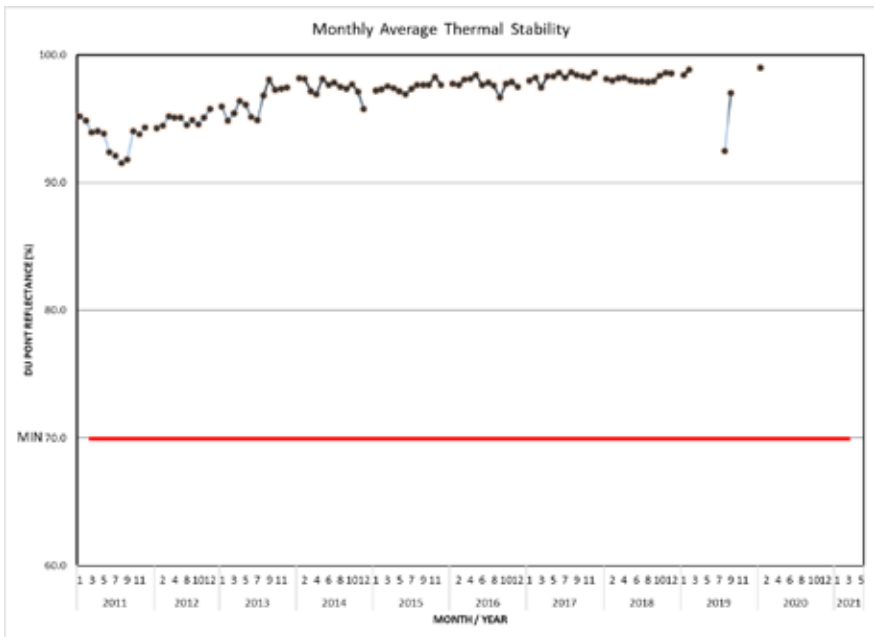


Figure 7

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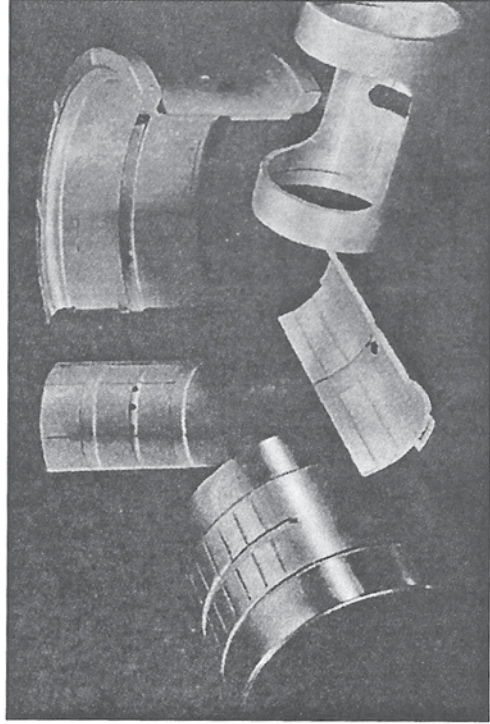
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High Temperature Thermal Stability

In many cases, excess fuel is pumped to the locomotive engine, a small portion is burned and the remaining fuel is returned to the tank – often picking up a substantial amount of heat from the trip. As such, High Temperature Thermal Stability is another key quality indicator of diesel fuel.

The test subjects fuel to a 300°F (150°C) environment for 3 hours. After which, the fuel is filtered through a Whatman #1 filter paper and the reflectance of the paper is measured. The general idea being if the fuel is stable and does not break down, the paper will be essentially the same reflectivity as new (or at least 97-99% as reflective) If the fuel does break down at high temperatures, the products of the breakdown will soil the paper reducing reflectance and indicate a thermal stability issue with the fuel.

Overall, thermal stability, as displayed in Figure 7, is noted as a rising value (more stable fuel) from 2011 to the 2018 timeframe. In early 2019 the plot begins to break up with only intermittent data and no datapoints in the 2020 / 2021 timeframe. What happened here?

The explanation is as simple as it is gratifying – throughout the latter two years of continuous testing (2017 and 2018) only 3 samples were found to fail the test out of slightly over 4,000 samples tested. Again, modern fuel production techniques and overall quality essentially eliminated the need for the test. High Temperature Thermal Stability testing was discontinued in favor of focusing effort and testing resources to other areas.

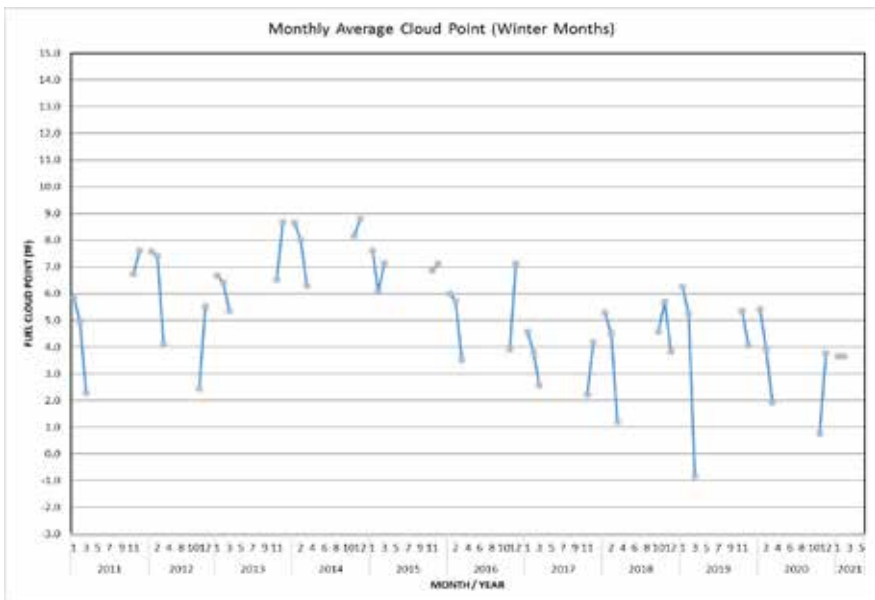


Figure 8

Cloud Point

Cloud point testing subjects the fuel to decreasing temperatures and attempts to measure the point at which wax crystals start to form – resulting in a clouding of the normally clear diesel fuel. It is at this point where filter plugging may begin to occur and as such, is of great concern during the winter months. Consequently, cloud point of the fuel is typically only measured in the winter months of the year (November – March). Given the intermittent testing, it provides somewhat of a broken / intermittent graph. Interestingly, ASTM D975 does not specifically designate maximum or minimum cloud points or other cold weather properties. It is up to the end user to specify relevant cold flow properties of the fuel for a given location.

As with many other tested parameters, cloud point, as displayed in Figure 8, indicates somewhat of an ebb and flow over the decade with somewhat higher cloud points noted during the winters of 2013-2014 and 2014-2015 timeframe and somewhat lower cloud points recorded in the 2017-2018 timeframe. Slightly lower cloud points were also noted in winter of 2020-2021.

Overall, there does not appear to be any substantial worsening (rise) in cloud points of the tested fuel samples and it may be argued that the cold flow properties are slightly better toward the end of the observed time period. One parameter not plotted/ correlated with the graph is the use of cold flow improver additives. Given the data available, it is not possible to conclude if the lowering of cloud point is due to natural characteristics of the fuel or increased use of cold flow improving additives.

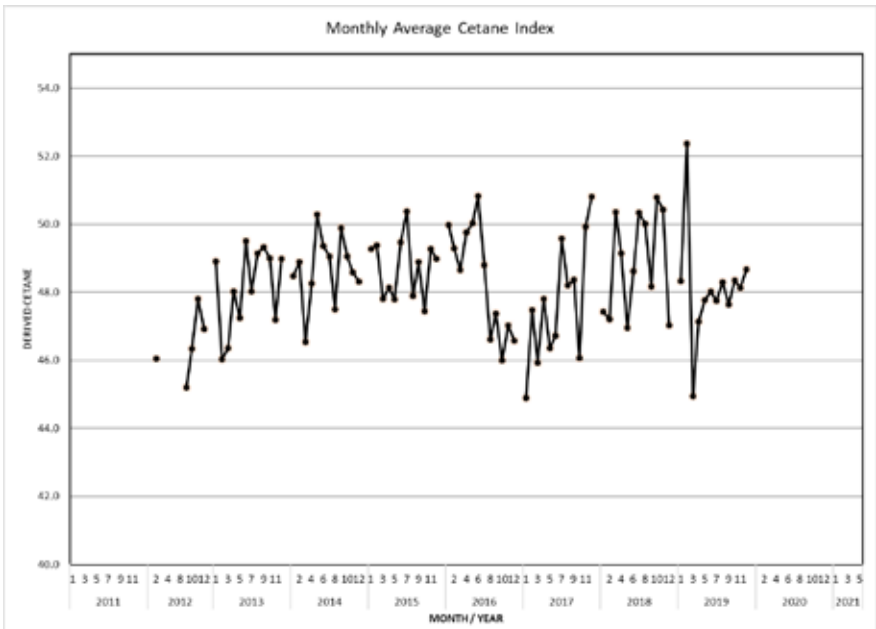


Figure 9

Cetane Index

The Cetane Index of the fuel, or alternately Derived Cetane Number, serves to indicate the ignition quality of the fuel. A high cetane fuel ignites quickly after injection in the cylinder which allows additional time for complete combustion and power extraction by the piston. This results in relatively lower emissions and elevated fuel efficiency. By contrast a low cetane fuel creates a longer ignition delay which can result in incomplete combustion and less time for the piston to extract mechanical energy from the burning fuel. This can result in higher emissions and lower fuel efficiency.

The specification for cetane has historically been set at 40.0, minimum. Indeed, in the early years of the specification, it was a struggle to keep cetane value above the minimums. However, with the advent of more modern fuel processing techniques, hydrotreating to reduce fuel sulfur, along with the introduction of biofuels and their typically high cetane values, the overall cetane value of the fuel (as Index or DCN) has experienced an increase.

With another ‘eyeball approximation’ of the chart, average cetane values appear to generally rise from the 2012 to 2016 timeframe. In mid-2016 cetane value experiences a small, but notable drop, then begins to rise again in 2017 and later years. The astute reader will note this sudden shift phenomena is quite similar to the trend noted in the API data, and indeed it has the same underlying reason – a shift in laboratory measuring technique and reporting.

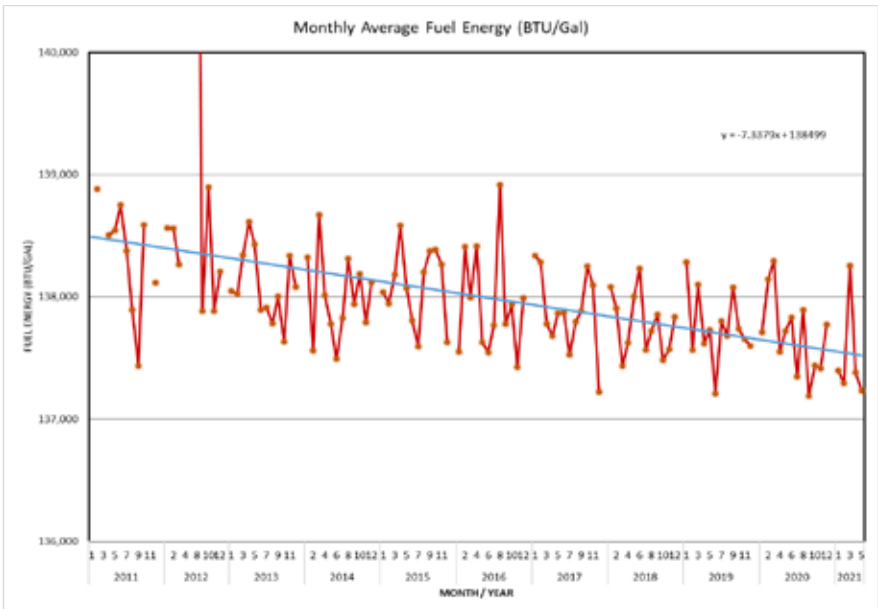


Figure 10

BTU per Gallon

Essentially all fuel transactions are conducted in ‘gallons’, although the energy content of a gallon of fuel may vary due to properties such as density (API Gravity), sulfur content, water content, biodiesel or renewable fuel content, etc. Based on this, it is important to know and track the energy content of fuel, otherwise attempts to meet fuel usage targets may suffer.

Figure 10 is drawn from testing conducted on samples obtained from a large portion of the continental United States. As such, there is a considerable spread in the data. Some locations naturally have ‘heavy’ (dense, low API gravity) fuel which typically has a higher than average energy content, while other locations naturally have a ‘light’ (less dense, high API gravity) fuel which typically has a lower than average energy content.

Applying a linear regression best fit reveals an overall downward trend in energy density. The average Gross Heating Value in 2011 was approximately 138,550 BTU/gallon. However, that value has dropped closer to 137,500 BTU/gallon in 2021. This represents a loss of slightly over 1000 BTU/gallon or approximately 0.72% of the energy in a gallon of fuel.

While 0.72% may not sound like a substantial number in itself, when multiplied by the hundreds of millions or even billions of gallons of fuel consumed by major North American railroads, then multiplied again by the \$2.00 - \$3.00+ average cost of fuel, it can still represent tens of millions of dollars in added operating cost.

Particulate Contamination

Particulate contamination will not be discussed at length in this paper. For an in-depth treatise on the subject, refer to *“Diesel Fuel Cleanliness: Application of the ISO 4406 Cleanliness Codes”*, Jonathan George, *Locomotive Maintenance Officers Association – Fuel, Lube and Environmental Committee, 2017*.

Though in summary, overall, fuel cleanliness is following the same path as many other fuel parameters explored in this paper - the path of continual improvement over the years. While older locomotives (and more correctly older injectors and fuel pumps) were able to digest a comparatively large amount of dirt, sand and other materials included in the fuel, more modern high-pressure systems are considerably less tolerant.

When the camshaft of a 3000hp engine impacted the rocker arm and ultimately drove the plunger on a mechanical injector – something was going to move, regardless of any bits of sand or grit in the way. When the low-voltage electromagnet of a modern injector politely asks the thumbtack-sized pilot valve to admit fuel and fire the injector, any small amount of debris or even a thin deposit of material derived from altered fuel chemistry can plug up the works and cause an inoperable injector.

Discussion

In brief discussion, where do the trends of the past decade point?

ASTM Fuel Specification – Relatively frequent revisions continue.

Base Fuel Properties – (Those properties which are inherent to the fuel and cannot be reasonably altered by additives)

API Gravity – Fuel has become ‘lighter’ less dense by approximately 2° API over the past decade. Fuel may continue to get lighter / less dense in the future.

Sulfur Content – Essentially all railroad diesel fuel was converted to Ultra Low Sulfur Diesel in the 2012-2015 timeframe, and sulfur has continued the decline since. Expect sulfur to continue into the low single digit ppm range.

BTU/gallon – BTU per gallon has displayed a small but steady downtrend over the past decade. On average fuel in 2021 displayed 0.72% lower BTU/gallon than fuel from 2011.

High Temperature Thermal Stability – At the beginning of the decade, multiple samples were flagged due to thermal breakdown at high temperatures. However advanced refining techniques, removal of fuel sulfur, and other changes in fuel properties mean fuel is essentially no longer subject to this issue.

Additive Impacted Fuel Properties – (Those properties which can be controlled by the addition of fuel additives)

Fuel Lubricity – Some ebb and flow over the decade, but fuel lubricity continues to be maintained well below the standard. May require increasing use of lubricity additives to maintain.

Cloud Point – Typically displayed a slight downward trend over the past decade meaning the fuel is more tolerant of cold weather.

Cetane Value – Overall, cetane value of the fuel appears to be a rising trend over the past decade, meaning a higher quality fuel.

Conclusion

Overall, changes in the past decade point toward diesel fuel being a cleaner, more environmentally sound and higher performing fuel than at any point in the past. However, these changes come at some cost as well. An overall lowering of fuel density (rising API gravity) and an overall lowering of fuel energy content (BTU/gallon) mean each gallon of fuel purchased delivers slightly less energy than it did in years past. While other fuel properties such as Cloud Point, Pour Point and Lubricity appear to remain well within specifications, it is not within the scope of this paper to determine if these properties remain in specification due to the natural fuel properties, or if increasing use of fuel additives

(read increasing cost) has been required to maintain the properties in specification. Further research along those lines may be warranted in future papers.

In conclusion, as diesel fuel progresses into the 21st century, many of these trends will continue, along with the likely introduction of new testing and parameters to insure continued development.

As the old saying goes, “The only thing that is constant is change”

— Heraclitus

Appendix A

Typical No. 2D Diesel Fuel Specifications – 2021

API GRAVITY (ASTM D7777) Minimum	30.0
FLASH POINT (ASTM D93, Procedure A) Minimum.....	125 °F
VISCOSITY @ 100 °F (ASTM D445) cSt.....	1.90 Min. – 4.10 Max.
DERIVED CETANE NUMBER (ASTM D7668).....	40.0 Min. – 52.0 Max. *
RAMSBOTTOM CARBON RESIDUE (ASTM D524) Maximum Percent	0.35
ASH (ASTM D482) Maximum Percent	0.01
SULFUR (ASTM D2622, X-ray Fluorescence) Maximum ppm	15
CORROSION TEST, COPPER STRIP (ASTM D130) Maximum.....	3A
AROMATIC CONTENT (ASTM D5186) Minimum	15% *
DISTILLATION (ASTM D86)	
90 Percent Recovery.....	282 °C Min. (540 °F) – 338 °C Max. (640 °F)
Recovery Percent, Minimum.....	98.00
STABILITY TEST (ASTM D6468, 180 Minutes with Search Unit Y) Minimum	
Percent	70
OXIDATION STABILITY (ASTM D2274) Maximum mg/100 mL	2.50
WATER AND SEDIMENT	
Water (ASTM D6304, Karl Fischer, Procedure B)	
Maximum Percent	0.05
Particulate Contaminant (ASTM D6217) Maximum mg/L.....	7.00
Appearance (ASTM D4176, Procedure 2, 25 °C) Maximum	2
POUR POINT (ASTM D5949)	Variable by Region
CLOUD POINT (ASTM D5773)	Variable by Region
COLD FILTER PLUG POINT (CFPP, ASTM D6371).....	Variable by Region
NEUTRALIZATION NUMBER (ASTM D664 or ASTM D974)	
Total Acid Number, Maximum.....	0.20
Strong Base Number.....	0.00

LUBRICITY (ASTM D6079, HFRR @ 60 °C) Maximum Micron.....	520
RED DYE (ASTM D6756) Minimum ppm.....	11.1
BIODIESEL (InfraCal Mid-IR) Maximum Percent	5.0
RENEWABLE DIESEL (aka 'HDRD', HVO, or similar, ASTM D5186) Maximum Percent	30.0
BTU PER GALLON (ASTM D4809, Gross) Minimum.....	131,000

* Unless otherwise required by CARB, TXLED or other similar emissions regulating body

Renewable Diesel Fuel Effects on Exhaust Emissions From a Tier 3 GE ES44C4 Locomotive

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ABSTRACT

This report documents the effects of renewable diesel on locomotive exhaust emissions. A total of nine emissions tests were conducted on a 4,500 horsepower (HP) US EPA Tier 3 GE ES44C4 locomotive using five different fuels or fuel blends.

The original CARB-funded project plan called for duplicate testing of CARB diesel, 100% Renewable Diesel, and a 50/50 blend of the two fuels. Based on interest from Union Pacific Railroad (UP), and BNSF Railway (BNSF), a blend of 50% CARB diesel, 30% Renewable, and 20% Biodiesel, was added to the test plan, with funding for the extra fuel blends and locomotive tests covered by UP and BNSF.

The commercially available base fuels were acquired and mixed by SwRI into the required blends for testing. The resulting fuels and fuel blends were then analyzed to determine their properties and to verify that the fuel mixtures were correct. Once the fuel analysis results were completed and approved, locomotive emissions testing began. Emissions testing was completed according to Federal Test Procedure (FTP) as defined in Title 40 of the Code of Federal Regulations (CFR), Part 1065 and Part 1033.

Carbon Intensity (CI) for the base fuels were provided by CARB and take into account the supplier and associated feed stock for the fuels. A total of eight planned FTPs were conducted in a randomized test matrix, with duplicate tests conducted on each of the first four fuel or fuel blends. One additional test was added using EPA Certification Diesel fuel as defined in 40 CFR Part 1065.703 Table 1. This test was performed by SwRI to provide a baseline for the test results back to EPA certification levels, and for baseline fuel comparisons. Table A-1 contains the test order, the fuel blends utilized in this testing, and the CI for each test fuel.

Each test was completed using the same measurement equipment and was run at similar ambient temperatures to minimize the effects that temperature has on locomotive emissions and fuel consumption. No locomotive power deration was noted on any of the fuels tested in this project.

The average results for each fuel blend over the EPA Linehaul cycle is shown in Tables A-2.

Table A-1. Test Fuels, Test Order, and Carbon Intensity

Test #	Test Date	Test Fuel	Designation	Carbon Intensity, gCO ₂ e/MJ
1	6/4/2020	100% CARB Diesel	C100	100.45
2	6/5/2020	50% CARB Diesel / 30% Renewable Diesel / 20% Biodiesel	C50R30B20	67.9
3	6/8/2020	100% Renewable Diesel	R100	35.7
4	6/9/2020	50% CARB Diesel / 50% Renewable Diesel	C50R50	69.7
5	6/10/2020	100% Renewable Diesel	R100	35.7
6	6/11/2020	50% CARB Diesel / 50% Renewable Diesel	C50R50	69.7
7	6/12/2020	50% CARB Diesel / 30% Renewable Diesel / 20% Biodiesel	C50R30B20	67.9
8	6/15/2020	100% CARB Diesel	C100	100.45
9	6/17/2020	US EPA Cert Diesel	Cert	-

Table A-2. Average EPA Linehaul Cycle Results

Test Fuel	BSFC	Vol Fuel Consumption	BSHC	BSCO	BSNO _x	BSCH ₄	BSPM	BSCO ₂
	[lb/hp-hr]	[gal/MW-hr]	[g/hp-hr]	[g/hp-hr]	[g/hp-hr]	[g/hp-hr]	[g/hp-hr]	[g/hp-hr]
US EPA Tier 3/FEL Limits	NS	NS	0.300	1.50	4.80	NS	0.090	NS
Cert	0.369	70.0	0.065	0.23	5.29	0.001	0.030	536.8
C100	0.363	69.5	0.068	0.23	4.87	0.001	0.031	521.5
C50R30B20	0.367	72.0	0.057	0.19	4.88	0.001	0.021	515.2
C50R50	0.358	70.8	0.060	0.21	4.74	0.001	0.025	512.7
R100	0.352	72.1	0.051	0.20	4.65	0.001	0.021	501.0

NS = No Standard

Over the Linehaul cycle, as the percentage of Renewable Diesel increased in the fuel blends, reductions were seen in emissions of Particulate Matter (PM), Oxides of Nitrogen (NO_x), and Carbon Dioxide (CO_2). Brake Specific Fuel consumption (BSFC) on a mass basis also showed a decreasing trend with increased Renewable fuel content. However, due to the lower density of the Renewable Diesel, volumetric fuel consumption generally got worse with increases in Renewable Diesel content.

Testing showed notable reduction in PM emissions when using the C50R30B20, C50/R50, and R100 fuel blends, compared to the other fuel mixtures tested. The increased NO_x emissions generally seen when operating on biodiesel were offset by the NO_x reductions in the renewable diesel, making the C50R30B20 fuel blend essentially NO_x neutral with the C100 fuel.

Similar trends in locomotive emissions were noted over the EPA Switch cycle, though the differences were more notable as the Renewable Diesel's impact was more pronounced at the lower load points. The following report provides further details on the results of this testing.

1.0 INTRODUCTION AND BACKGROUND

California's Low Carbon Fuel Standard is designed to decrease the carbon intensity of California's transportation fuel pool and provide an increasing range of low-carbon and renewable alternatives, which reduce petroleum dependency and achieve air quality benefits. It is important to understand the effects these fuels have on vehicle emissions and fuel consumption. To determine how renewable diesel affects locomotive emissions, locomotive exhaust emissions testing was completed on various fuels and fuel blends at the Southwest Research Institute's (SwRI) Locomotive Technology Center (LTC) in June 2020.

The information detailed in the following report is the result of emissions testing performed for the California Air Resources Board (CARB), BNSF Railway Company (BNSF), and Union Pacific Railroad (UPRR) by Southwest Research Institute (SwRI).

The emissions testing was performed at the SwRI Locomotive Technology Center (LTC) in San Antonio, Texas.

This report includes the description of the locomotive tested, the test equipment and test fuels used, the procedures followed, and the results of the emissions testing. These topics are discussed in more detail in the following sections of the report.

2.0 TECHNICAL APPROACH

2.1 Test Engine



Figure 1. Test Locomotive, BNSF 7934

Testing was performed using BNSF 7934, a 4,500 HP Tier 3 GE ES44C4 locomotive. BNSF provided the locomotive for testing and made arrangements to move it to San Antonio. The Tier 3 GEVO engines are equipped with high pressure common rail (HPCR) fuel injection systems. The details of the test locomotive are listed in Table 1. The EPA useful life for this locomotive engine is 33,750 MW-hrs, and BNSF 7934 had accumulated 21,852 MW-hrs at the time of testing, or approximately 65 percent.

Table 1. Test Locomotive Details

Road Number	BNSF 7934
Manufacturer	GE
Model	ES44C4
EPA Tier	3
Loco Build Date	12/2014
Engine Build Date	11/2014
Engine Model	GEVO12LDC12
Engine SN	G442140997
Locomotive SN	63016
Lifetime MW-hrs	21,852
Lifetime Mileage	625,296

2.2 Test Fuels

The original CARB-funded project plan called for duplicate testing of CARB diesel, 100% Renewable Diesel, and a 50/50 blend of the two fuels. Based on interest from Union Pacific Railroad (UP), and BNSF Railway (BNSF), a blend of 50% CARB diesel, 30% Renewable, and 20% Biodiesel, was added to the test plan, with funding for the extra fuel blends and locomotive tests covered by UP and BNSF.

Procurement of the CARB diesel fuel turned out to be very challenging, as the goal was to obtain commercially available fuel from California, but before it was blended with either Biodiesel or Renewable Diesel. Ultimately, SwRI procured 2,500 gallons of CARB diesel fuel from the PBF Energy refinery in Martinez, California.

Renewable Diesel was purchased from Renewable Energy Group, Inc. (REG), and was produced at their Geismar, Louisiana biorefinery. This plant uses a wide variety of feedstocks to produce approximately 75 million gallons of high-quality renewable diesel, renewable naphtha, and renewable autogas annually. The largest feedstock components at the time the test fuel was produced were likely animal fat (mostly beef tallow), used cooking oil (UCO), and distillers corn oil (DCO). The most conservative approach for the Renewable Diesel carbon intensity (CI) would be to assume it was made from 100% animal fat. SwRI purchased 2,200 gallons of Renewable Diesel from REG.

Biodiesel was donated to the project by REG, and was produced at the Albert Lea, Minnesota plant from a mixture of DCO and UCO. The REG Albert Lea plant has been in operation since 2005 with numerous upgrades over the years, including the addition of a distillation unit for the biodiesel product in 2014. The original nameplate production volume for the plant was 30 MMGPY but its current operating volume is more than 40 MMGPY. The exact CI of the biodiesel depends on the feedstock mix at the time (per CARB methodology), but it is

generally less than 30 gCO₂/MJ. The most conservative approach would be to assume it is made from 100% DCO. REG provided 240 gallons of B100 to SwRI for this project.

The bulk CARB Diesel and Renewable were delivered to SwRI and transferred into temporary 4,000-gallon diesel tanks shown in Figure 2, that were steam-cleaned prior to use. The Neat Biodiesel was provided in its own 330-gallon shipping tote. Before blending, detailed fuel analyses of each fuel were performed by SwRI to make sure the fuels were as expected. Specifically, we wanted to ensure that the CARB diesel did not contain any Biodiesel or Renewable Diesel, and that the Renewable Diesel and Biodiesel were nearly 100 percent Bio Carbon, per ASTM D6866-20, using radiocarbon analysis.



Figure 2. Fuel Storage Tanks

Fuel analyses results are summarized in Table 1. All fuel property testing was completed at SwRI, with the exception of ASTM D6866-20 Bio-Carbon analysis, which was performed by Beta Analytic Testing Laboratory in Glenvar Heights, Florida. The ASTM D6866-20 results for the base fuels showed that the CARB diesel (C100) was 0.6 percent Bio Carbon, the Renewable Diesel (R100) was 100 percent Bio Carbon, and the Biodiesel (B100) was 95.7 percent Bio Carbon. REG reported that the small level (4.3 percent) of non-Bio Carbon was from the methanol used to convert the fat/oil into FAME (fatty acid methyl esters) and was an expected result. SwRI provided test results for the base fuels to CARB for review and approval prior to blending. SwRI received CARB approval to blend,

and the 550-gallon stainless steel totes shown in Figure 2 were used for blending and storage of blended fuels.

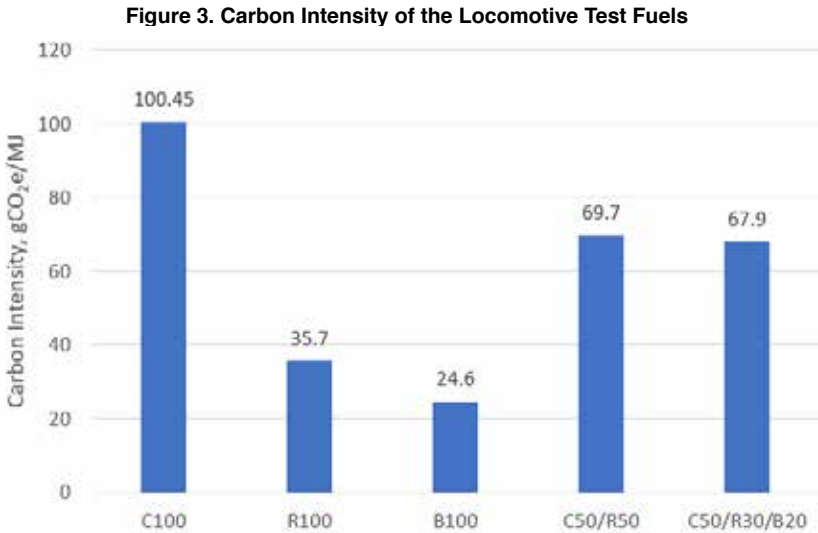
Two fuel blends were prepared; a 50/50 volume mix of C100 and R100 (assigned a test code of C50/R50), and a blend of 50 percent C100, 30 percent R100, and 20 percent B100, and assigned the code C50/R30/B20.

Fuels were blended on a volumetric basis, using a volumetric flowmeter dispensing nozzle and cross-checked with fuel level strapping charts for the 550-gallon totes. After the appropriate amount of each fuel was added to each tote, they were mechanically mixed with a propeller-type mixer powered by an air motor for 30-minutes each. Samples were then drawn from the blended and mixed totes for blended fuel analyses. These results are also given in Table 2, along with properties of the current batch of EPA Certification Diesel fuel (as defined in 40 CFR Part 1065.703 Table 1). The fuel properties were also used to verify that the fuel mixtures used in testing were correctly blended. SwRI sent the fuel analysis results table, now updated with the blended test fuel results, to CARB for review and approval to proceed with testing. CARB approved the blended fuel results, and SwRI then proceeded with BNSF Railway to coordinate delivery to the test locomotive.

Table 2. Test Fuel Properties

ASTM	Property	Units	C100	B100	R100	C50/R50 A	C50 R30 B20 A	EPA Cert.
D240G	BTUHeat	BTU/lb	19,792	17,186	20,297	20,020	19,560	19,652
D240N	BTUHeat	BTU/lb	18,534	16,090	18,922	18,702	18,270	18,445
	HHV	BTU/gal	137,800	126,562	132,296	134,897	132,760	138,108
	HHV % change from C100		***	-8.2%	-4.0%	-2.1%	-3.7%	0.2%
	LHV	BTU/gal	129,041	118,491	123,834	126,016	124,004	129,621
	LHV % change from C100		***	-8.2%	-4.4%	-2.3%	-3.9%	0.4%
D405.2	API@60F		37.94	28.69	49.49	43.58	42.31	36.40
	SP@60F		0.835	0.883	0.782	0.808	0.814	0.843
	Dens@15C	g/ml	0.835	0.883	0.782	0.808	0.814	0.842
	density	lb/gal	7.0	7.4	6.5	6.7	6.8	7.0
D445 40c	Viscosity	cSt	2.2	4.1	3.1	2.6	2.8	2.3
D4629	Nitrogen	ppm	21.7	<1.0	<1.0			ND
	Nitrmass	mass %	0.0022	0.0001	0.0000			ND
D4737A	Cetane Index		45.3	NA	95.5	66.6	69.2	46.1
D4737B	Cetane Index		45.1	NA	79.9	61.7	64.3	ND
D5186	Total Aromatics	Mass%	9.1	NA	0.2	5.0	3.3	29.8
	Mono Arom	Mass%	8.6	NA	0.2	4.6	3.2	22.8
	Poly Arom	Mass%	0.5	NA	ND	0.4	0.1	7.0
D5291 CH	Carbon	wt%	85.92	76.96	84.96	85.90	83.96	86.46
	Hydrogen	wt%	13.80	12.01	15.07	14.44	14.14	13.12
	Oxygen	wt%	0.28	11.03	-0.03	-0.34	1.90	0.42
	H/C		1.95	1.89	2.15	2.00	2.01	1.81
D5453	Sulfur	ppm	2.2	1.6	<0.5	0.9	0.7	8.1
D613	Cetane Number		48.1	51.9	>74.8	64.5	69.5	44.6
D86	PCorrIBP	degF	338.1	NA	287.8	334.0	344.7	333.0
	PCorrFBP	degF	663.2	NA	611.8	631.5	633.4	653.0
	PCorrD05	degF	373.6	NA	461.4	390.7	409.0	382.0
	PCorrD10	degF	383.3	NA	502.6	411.7	440.1	399.3
	PCorrD15	degF	392.9	NA	522.4	430.3	464.0	412.5
	PCorrD20	degF	401.4	NA	533.0	445.4	483.8	425.3
	PCorrD30	degF	419.6	NA	543.2	474.2	514.7	446.8
	PCorrD40	degF	438.0	NA	548.8	499.3	537.0	466.8
	PCorrD50	degF	456.9	NA	553.5	520.7	552.7	485.6
	PCorrD60	degF	477.8	NA	556.9	537.4	564.9	505.5
	PCorrD70	degF	502.6	NA	560.7	550.8	575.7	527.8
	PCorrD80	degF	534.6	NA	565.5	562.6	588.2	554.6
	PCorrD90	degF	583.3	NA	572.5	578.7	609.2	595.4
	PCorrD95	degF	628.1	NA	585.9	606.7	632.6	632.5
	UCorRcvd	mL	98.3	NA	97.6	97.3	97.9	97.8
	UCorLoss	mL	0.4	NA	1.1	1.1	0.6	0.9
D93	Flash	degF	145.0	353.0	133.0	137.0	143.0	153.0
D976	Cetane Index		44.4	NA	77.5	63.2	64.3	46.2
EN14078	FAME	volume %	0.3	100.0	<0.1	<0.1	19.5	0.1
D6866-20	% Bio Carbon	volume %	0.6	95.7	100	48.21	67 / 57 / 48	ND

The carbon intensity (CI) of the base fuels and fuel blends are summarized in Figure 3. The CI for the base fuels were provided by CARB and take into account the supplier and associated feed stock for the fuels¹.



2.3 Instrumentation and Data Acquisition

All emissions testing was performed at the SwRI Locomotive Technology Center. All tests were conducted using the measurement equipment described below.

2.3.1 Fuel Measurements

Diesel fuel consumption was measured on a mass basis. The mass measuring device used by SwRI is a Micro Motion® CMF-25. Before testing, the Micro-Motion calibration was verified and compared to a calibrated scale. The Micro-Motion measures the makeup fuel supplied to a closed loop system, which is kept at a constant pressure that supplies fuel to the locomotive lift pump.

The SwRI fuel cart is equipped with heat exchangers and a chilled water system to regulate the fuel supply temperature to the locomotive at a target of 27°C (±6°C). The fuel supply temperature is measured at the outlet of the fuel cart, just after the heat exchanger.

¹ CARB LCFS Pathway Table https://ww2.arb.ca.gov/sites/default/files/classic/fuels/lcfs/fuelpathways/current-pathways_all.xlsx

2.3.2 Power Measurements

Traction power is measured on the direct current (DC) electrical bus within the locomotive. Voltage was measured directly, and current was measured using a DaniSense DS5000 current transformer. The output of the DaniSense and the voltage were sent to a Yokogawa WT3000E power analyzer.

Accessory power was measured at 3-phase AC output of the auxiliary alternator. It was measured using a pair of current transducers, direct voltage measurements, and the Yokogawa WT3000E Power Analyzer.

Gross power was calculated using alternator efficiencies provided to SwRI by WABTEC.

2.3.3 Emissions Measurements

Gaseous emissions were sampled from within an exhaust stack extension using a Horiba MEXA7100 emissions bench. A heated line was used to transfer the raw exhaust sample to the emission instruments for analysis. Measured gaseous emissions included hydrocarbons (HC), carbon monoxide (CO), carbon dioxide (CO₂), oxygen (O₂), oxides of nitrogen (NO_x), and methane (CH₄). Measurements were taken for each discrete mode listed in the EPA locomotive duty cycles.

Total hydrocarbon concentration in the raw exhaust was determined using a Horiba heated flame ionization detector (HFID), calibrated on propane. NO_x concentration in the raw exhaust was measured with a heated chemiluminescent detector (HCLD). NO_x correction factors for ambient air humidity were applied as specified by EPA in 40CFR1065.670. Concentrations of CO and CO₂ in the raw exhaust were determined by non-dispersive infrared (NDIR) instruments, and O₂ concentrations were measured using a magneto-pneumatic analyzer. Raw exhaust methane (CH₄) concentration was measured using a non-methane cutter (NMC) and a dedicated heated flame ionization detector (NMC-HFID) as outlined in 40CFR1065.365(d).

Particulate emissions were measured at each test point with a Sierra Instruments BG-3 Particulate Partial-Flow Sampling System. This “mini-dilution tunnel” device employs a partial flow dilution technique that can be characterized as the “split then dilute” technique, in which a portion of the raw locomotive exhaust is “split” from the total flow and mixed with filtered air in a micro dilution tunnel.

The Sierra BG-3 sampling system used a single ended probe facing upstream in the exhaust to extract a fraction of the raw exhaust. The diluted exhaust was then pulled through a Sierra Heat-Pak before being routed through a single 47 mm diameter TX40 sample filter. The Sierra Heat-Pak is a heated enclosure (target temperature of 47°C) that contains a stainless-steel cyclonic separator and a residence chamber. This is an optional BG-3 accessory offered by Sierra Instruments as a tool for sampling under 40CFR1065 criteria. The BG-3 measured

the dilution air flow using a laminar flow element (LFE), and the total dilute sample was measured by a positive displacement roots meter. The difference between the two measurements is defined as the raw exhaust sample volume, which was used along with the filter mass increase and the calculated engine exhaust flow rate to calculate the PM mass emission rate of the locomotive.

2.4 Common Test Parameters

During testing, the locomotive was provided with compressed air from an outside source, such that the air compressor remained unloaded throughout the test. All auxiliary cab loads (such as headlights, cab lights, and air conditioners) were turned off. The same measurement devices were used during each test. The locomotive was self-loaded on its own grids.

2.5 Test Sequence

Upon delivery to SwRI, the locomotive was subjected to an inbound inspection for obvious mechanical or electrical problems. This inspection also consisted of recording part numbers and serial numbers for key components (including photographs of the EPA compliance sticker and EPA Engine Compliance tag).

Testing was done in accordance with the Federal Test Protocol (FTP), as defined by the Code of Federal Regulations (CFR), Title 40, Part 1065 and Part 1033. A single FTP was run each day, targeting similar ambient temperature conditions. In total, 9 individual tests were run over the course of this project.

The test order of the first eight tests was generated randomly using Microsoft Excel. The order and the date that each test was completed are listed in Table 3. FTP 9, which was run on US EPA Certification Diesel, was not originally included in the test matrix and was therefore not included in the randomized test matrix. It was added to the end of the project as a reference point, to put the other tests into a common context.

Table 3. Test Fuels and Test Order

Test #	Test Date	Test Fuel	Designation
1	6/4/2020	100% CARB Diesel	C100
2	6/5/2020	50% CARB Diesel / 30% Renewable Diesel / 20% Biodiesel	C50R30B20
3	6/8/2020	100% Renewable Diesel	R100
4	6/9/2020	50% CARB Diesel / 50% Renewable Diesel	C50R50
5	6/10/2020	100% Renewable Diesel	R100
6	6/11/2020	50% CARB Diesel / 50% Renewable Diesel	C50R50
7	6/12/2020	50% CARB Diesel / 30% Renewable Diesel / 20% Biodiesel	C50R30B20
8	6/15/2020	100% CARB Diesel	C100
9	6/17/2020	US EPA Cert Diesel	Cert

SwRI utilizes a closed loop system for fuel measurement and temperature control. It is not possible to fully drain this system when switching fuels due to issues with air entering the system so testing was performed on the system before this project began to determine the time necessary to fully purge the remaining fuel in the system. This was completed right at 2 minutes. When switching fuels during this project, an extra minute was added to that purge time to make certain that all previous fuel was purged from the system before the next test began.

2.6 Duty-Cycle Weighting Factors

The US EPA Linehaul and Switch duty-cycles were used to determine the fuel consumption values reported in this project. Table 4 lists the EPA Linehaul duty-cycle weighting factors, and Table 5 lists the EPA Switch duty-cycle.

Table 4. Linehaul Duty-Cycle Weighting Factors

Locomotive Notch	Weighting factor, %
Notch 8	16.2
Notch 7	3.0
Notch 6	3.9
Notch 5	3.8
Notch 4	4.4
Notch 3	5.2
Notch 2	6.5
Notch 1	6.5
DB-2 (580 RPM)	12.5
Idle (300 RPM)	38.0
Total	100.0

Table 5. Switch Duty-Cycle Weighting Factors

Locomotive Notch	Weighting factor, %
Notch 8	0.8
Notch 7	0.2
Notch 6	1.5
Notch 5	3.6
Notch 4	3.6
Notch 3	5.8
Notch 2	12.3
Notch 1	12.4
DB-2 (580 RPM)	-
Idle (300 RPM)	59.8
Total	100.0

3.0 TEST RESULTS

This section includes emissions and fuel consumption results from all testing performed. Detailed test summaries are available in the SwRI Final Report submitted to CARB.²

3.1 Test Conditions

Ambient conditions have some influence on locomotive emissions, smoke opacity, and fuel consumption. To minimize the impact of these effects, similar ambient temperatures were targeted for each test. Engine intake air temperature, intake air humidity, and barometric pressure throughout each test are shown in Figures 4-6 below.

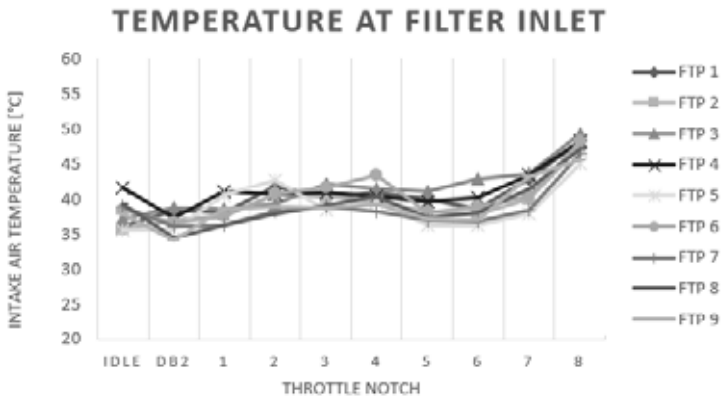


Figure 4. Intake Air Temperatuues at Air Filter Inlet During Each Test

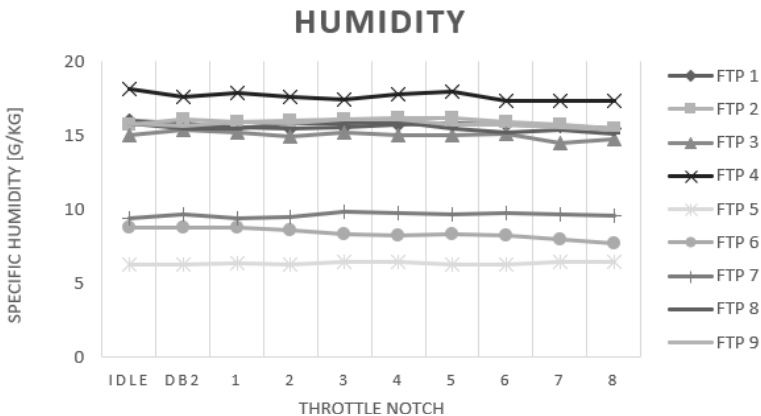


Figure 5. Intake Air Humidity During Each Test

² Stoops, C., "Renewable Diesel Fuel Effects on Exhaust Emissions from a Tier 3 GE ES44C4 Locomotive," SwRI Final Report 03.25756, CARB Agreement No. 19ISD009, April 2021.

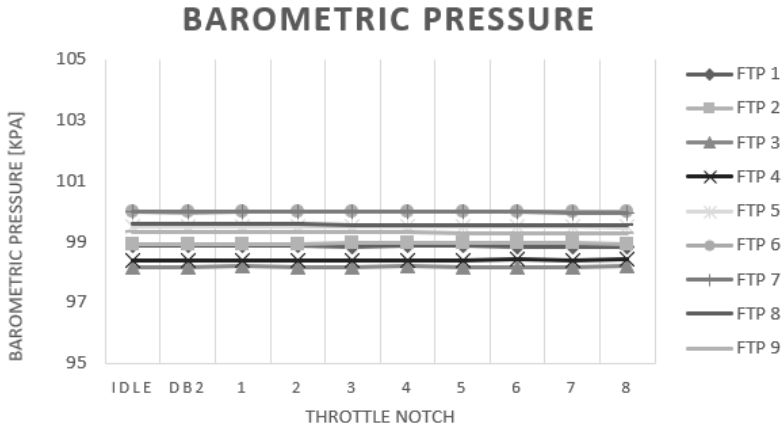


Figure 6. Barometric Pressure During Each Test

While similar ambient temperatures and barometric pressure were seen during each test, humidity changes did occur. There was slightly higher humidity for FTP 4, and notably lower humidity for FTPs 5-7. Note that, while humidity has a large effect on NO_x emissions, correction factors for ambient humidity are specified in 40 CFR Part 1065. All NO_x reported herein are corrected for ambient humidity.

3.2 Duty Cycle Weighted Emissions Results

The duty cycle results for each test run over the linehaul and switch cycles are listed in Tables 6 and 7, respectively. The average emissions test results for each fuel mixture are shown in Tables 8 and 9.

Table 6. Linehaul Cycle Emissions Result

Test #	Test Fuel	BSHC	BSCO	BSNO _x	BSCH ₄	BSPM	BSCO ₂
		[g/hp-hr]	[g/hp-hr]	[g/hp-hr]	[g/hp-hr]	[g/hp-hr]	[g/hp-hr]
1	C100	0.068	0.24	4.85	0.000	0.033	521.3
2	C50R30B20	0.056	0.20	4.87	0.001	0.023	515.0
3	R100	0.051	0.21	4.58	0.001	0.024	504.1
4	C50R50	0.061	0.22	4.68	0.001	0.027	513.4
5	R100	0.051	0.18	4.72	0.001	0.018	497.9
6	C50R50	0.060	0.19	4.79	0.001	0.022	512.1
7	C50R30B20	0.058	0.18	4.89	0.001	0.020	515.4
8	C100	0.068	0.23	4.89	0.001	0.028	521.8
9	Cert	0.065	0.23	5.29	0.001	0.030	536.8

Table 7. Switch Cycle Emissions Results

Test #	Test Fuel	BSHC	BSCO	BSNO _x	BSCH ₄	BSPM	BSCO ₂
		[g/hp-hr]	[g/hp-hr]	[g/hp-hr]	[g/hp-hr]	[g/hp-hr]	[g/hp-hr]
1	C100	0.092	0.34	6.84	0.001	0.047	557.1
2	C50R30B20	0.073	0.28	6.70	0.002	0.030	550.1
3	R100	0.059	0.31	6.22	0.002	0.029	540.0
4	C50R50	0.077	0.33	6.44	0.002	0.033	553.4
5	R100	0.061	0.26	6.45	0.002	0.023	536.4
6	C50R50	0.077	0.29	6.55	0.002	0.029	549.7
7	C50R30B20	0.076	0.26	6.76	0.002	0.028	551.9
8	C100	0.092	0.34	6.88	0.002	0.035	562.7
9	Cert	0.096	0.35	7.60	0.002	0.041	597.7

Table 8. Average Linehaul Cycle Emissions Results

Test Fuel	BSHC	BSCO	BSNO _x	BSCH ₄	BSPM	BSCO ₂
	[g/hp-hr]	[g/hp-hr]	[g/hp-hr]	[g/hp-hr]	[g/hp-hr]	[g/hp-hr]
Cert	0.065	0.23	5.29	0.001	0.030	536.8
C100	0.068	0.23	4.87	0.001	0.031	521.5
C50R30B20	0.057	0.19	4.88	0.001	0.021	515.2
C50R50	0.060	0.21	4.74	0.001	0.025	512.7
R100	0.051	0.20	4.65	0.001	0.021	501.0

Table 9. Average Switch Cycle Emissions Results

Test Fuel	BSHC	BSCO	BSNO _x	BSCH ₄	BSPM	BSCO ₂
	[g/hp-hr]	[g/hp-hr]	[g/hp-hr]	[g/hp-hr]	[g/hp-hr]	[g/hp-hr]
Cert	0.096	0.35	7.60	0.002	0.041	597.7
C100	0.092	0.34	6.86	0.002	0.041	559.9
C50R30B20	0.075	0.27	6.73	0.002	0.029	551.0
C50R50	0.077	0.31	6.49	0.002	0.031	551.5
R100	0.060	0.29	6.33	0.002	0.026	538.2

Using the test on the US EPA Certification fuel (Cert) as the baseline, Tables 10 and 11 show the percent change for each emission. Negative numbers imply a reduction from the baseline in the given emission, while a positive number is an increase.

Table 10. Percent Change From Baseline - Linehaul

Test Fuel	BSHC [% change]	BSCO [% change]	BSNO _x [% change]	BSCH ₄ [% change]	BSPM [% change]	BSCO ₂ [% change]
Cert	-	-	-	-	-	-
C100	3.9%	1.0%	-8.0%	-8.9%	1.5%	-2.8%
C50R30B20	-12.5%	-19.6%	-7.8%	-3.4%	-29.2%	-4.0%
C50R50	-8.1%	-10.6%	-10.5%	-4.2%	-18.1%	-4.5%
R100	-21.6%	-15.6%	-12.1%	4.5%	-30.4%	-6.7%

Table 11. Percent Change From Baseline - Switch

Test Fuel	BSHC [% change]	BSCO [% change]	BSNO _x [% change]	BSCH ₄ [% change]	BSPM [% change]	BSCO ₂ [% change]
Cert	-	-	-	-	-	-
C100	-4.0%	-3.7%	-9.7%	-7.8%	-0.9%	-6.3%
C50R30B20	-22.0%	-23.0%	-11.4%	-5.1%	-29.5%	-7.8%
C50R50	-19.9%	-12.5%	-14.5%	-3.6%	-24.2%	-7.7%
R100	-37.0%	-19.0%	-16.6%	7.4%	-35.9%	-10.0%

3.3 Duty Cycle Weighted Fuel Consumption Results

The fuel consumption results for each test are listed below in Table 12. Fuel consumption results are displayed in brake specific fuel consumption (BSFC), which is a mass-based value. In addition, a volumetric fuel consumption was also calculated based off the density of each fuel mixture, expressed in gallons per Megawatt-hour (gal/MW-hr). Average fuel consumption results for each fuel blend are in Table 13.

Table 12. Fuel Consumption Results

Test #	Test Fuel	Line Haul Cycle		Switch Cycle	
		BSFC [lb/hp-hr]	Volumetric Fuel Cons [gal/MW-hr]	BSFC [lb/hp-hr]	Volumetric Fuel Cons. [gal/MW-hr]
1	C100	0.363	69.5	0.387	74.1
2	C50R30B20	0.367	72.0	0.391	76.8
3	R100	0.355	72.6	0.379	77.6
4	C50R50	0.358	70.9	0.385	76.3
5	R100	0.350	71.6	0.376	77.0
6	C50R50	0.357	70.7	0.383	75.7
7	C50R30B20	0.367	72.1	0.392	77.0
8	C100	0.363	69.5	0.391	74.8
9	Cert	0.369	70.0	0.410	77.8

Table 13. Average Fuel Consumption Results

Test Fuel	Line Haul Cycle		Switch Cycle	
	BSFC [lb/hp-hr]	Volumetric Fuel Cons. [gal/MW-hr]	BSFC [lb/hp-hr]	Volumetric Fuel Cons. [gal/MW-hr]
Cert	0.369	70.0	0.410	77.8
C100	0.363	69.5	0.389	74.5
C50R30B20	0.367	72.0	0.392	76.9
C50R50	0.358	70.8	0.384	76.0
R100	0.352	72.1	0.378	77.3

3.4 Emissions Trends

Some overall emissions trends were noted during this testing. In general, as the fraction of renewable diesel was increased, overall emissions trended downward.

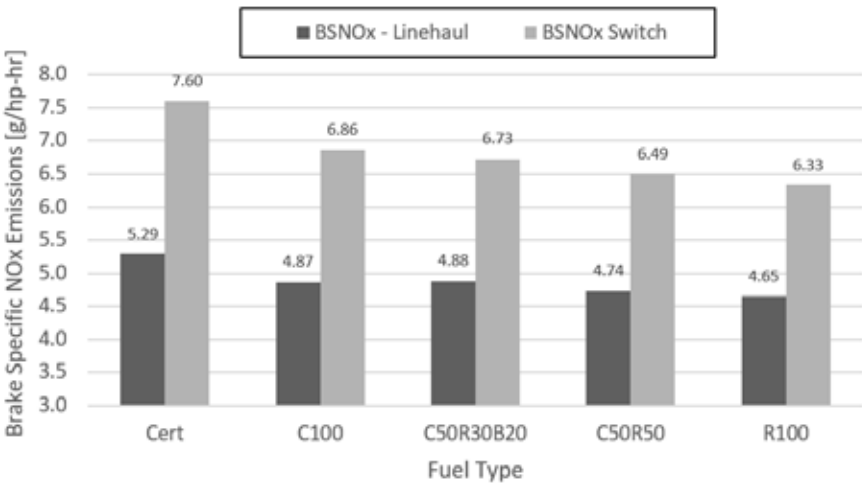
**Figure 7. Brake Specific NO_x Average by Fuel Type**

Figure 7 shows the average brake specific NO_x emissions for each fuel type. NO_x trended slightly lower as the percentage of renewable diesel increased, showing a 2.7% decrease in NO_x from the C100 average with the C50R50 blend, and a 4.4% reduction using R100. EPA Cert diesel had NO_x emissions that were 8.7% higher than the C100 average. The C50R30B20 fuel blend showed NO_x equivalence with C100, implying that the NO_x reduction from the renewable diesel balanced the NO_x increase that is often associated with Biodiesel.

Particulate matter emissions for both EPA Cert Diesel and C100 were essentially equivalent over the linehaul and switch cycles. Over the linehaul cycle C50R50 and R100 showed reductions in PM of 19.3% and 31.4%, respectively. The C50R30B20 mixture also showed a 30.3% reduction in PM. Figure 8 shows the brake specific PM emissions averages for each test fuel.

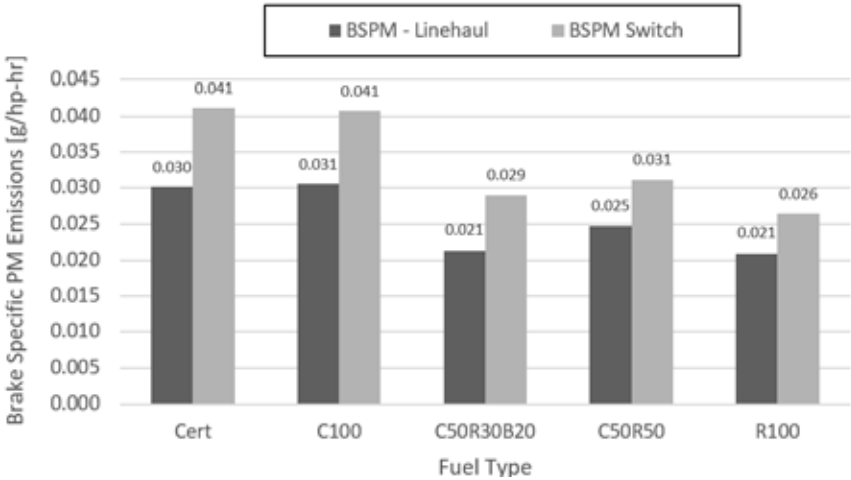


Figure 8. Brake Specific PM Average by Fuel Type

As seen in Figures 9-11, other regulated emissions showed similar trends to those discussed above. Reductions in CO₂, CO, and HC were seen as the percentage of renewable diesel in the fuel was increased.

Overall, renewable diesel showed reductions in all regulated locomotive emissions with reductions generally increasing as the percentage of renewable diesel increased. The addition of biodiesel in the C50R30B20 mixture did not decrease BSNO_x emissions compared to C100, but showed larger decreases in PM, HC, and CO emissions.

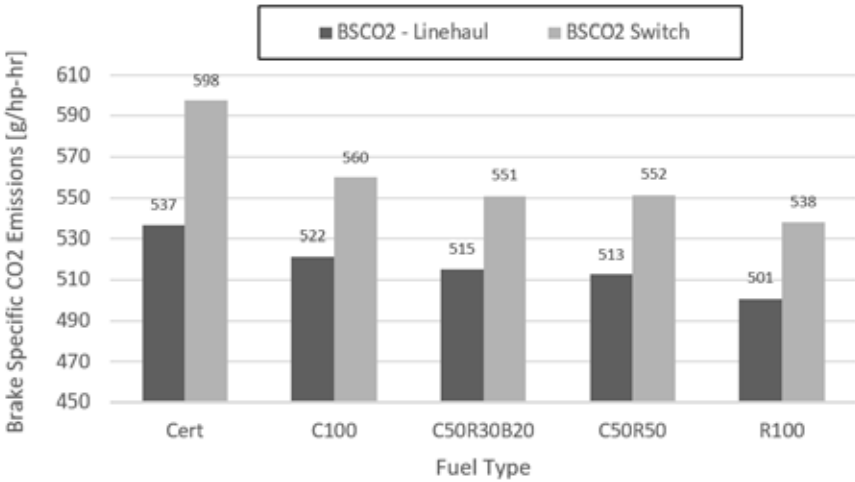


Figure 9. Brake Specific CO₂ Average by Fuel Type

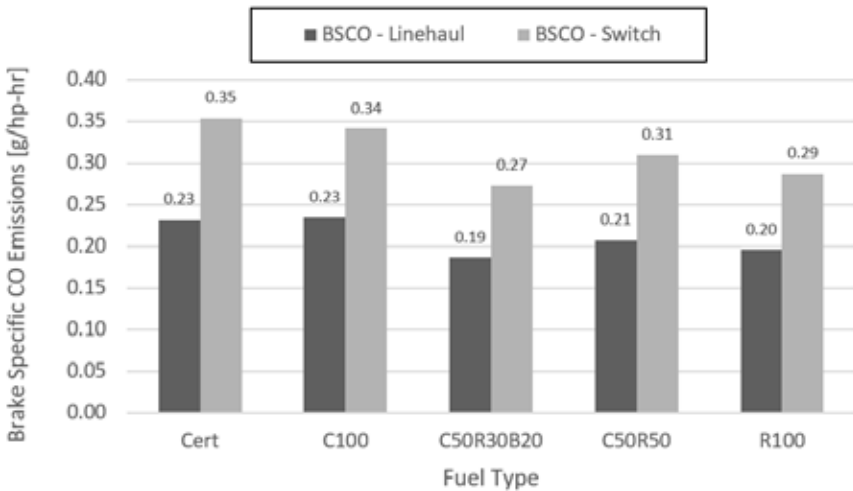


Figure 10. Brake Specific CO Average by Fuel Type

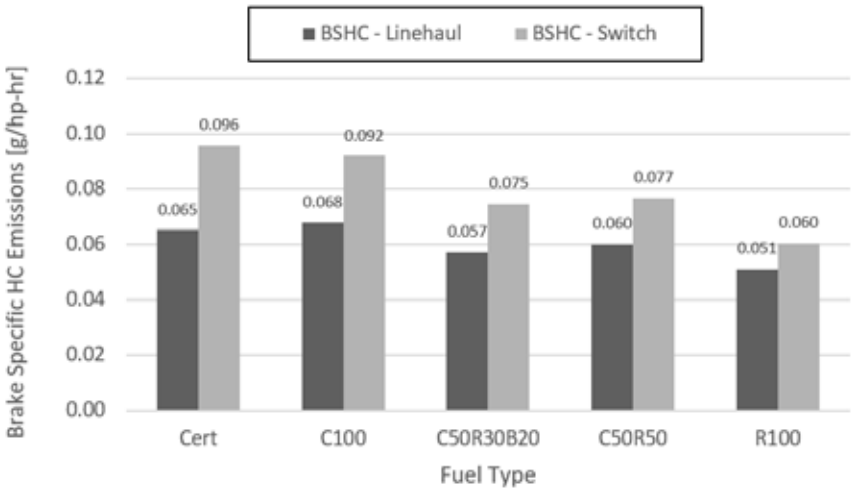


Figure 11. Brake Specific HC Average by Fuel Type

The various fuel blends had very limited effect on locomotive smoke opacity. The average smoke opacity results for each fuel blend are shown in Figure 12. Overall, the locomotive was well below the allowable smoke opacity limits on each test fuel.

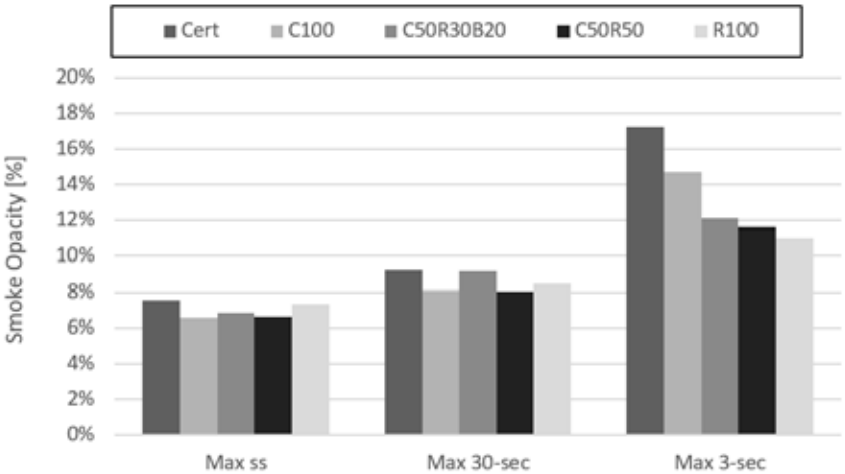


Figure 12. Smoke Opacity Average by Fuel Type

Acknowledgement

Acknowledge the SwRI Locomotive Technology Center team of Southwest Research Institute.

Funding for the Biodiesel blends tested as part of this project was provided by BNSF Railway and Union Pacific Railroad. BNSF Railway also provided the test locomotive, BNSF 7934.

The Renewable Energy Group (REG) donated the neat Biodiesel (B100) used for the biodiesel blend tests at no cost to the project.

This Report was submitted in fulfillment of ARB Agreement #19ISD009 for “Renewable Diesel Fuel Effects on Exhaust Emissions from a Tier 3 GE ES44C4 Locomotive” by Southwest Research Institute under the sponsorship of the California Air Resources Board. Work was completed as of June 17, 2020. Ms. Danielle Magadia, Air Resources Engineer, was the ARB Project Manager overseeing this work.

Glossary of Terms, Abbreviations, and Symbols

AAR – Association of American Railroads

AC – Alternating Current

BSFC – Brake Specific Fuel Consumption

C100 – 100% CARB Diesel

C50R30B20 – 50% CARB Diesel, 30% Renewable Diesel, 20% Biodiesel

C50R50 – 50% CARB Diesel, 50% Renewable Diesel

CARB – California Air Resources Board

CH₄ – Methane

CO – Carbon Monoxide

CO₂ – Carbon Dioxide

DC – Direct Current

EPA – Environmental Protection Agency

HC – Hydrocarbons

hp – Horsepower

lb – Pounds mass

MW – Megawatt

NO_x – Oxides of Nitrogen

PM – Particulate Matter

R100 – 100% Renewable Diesel



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Sustainable Fuel Constraints and the Necessity of Alternative Propulsion

Prepared by:

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Abstract

The railroad industry has long been a leader in sustainable transportation, but with the creation and growing acceptance of the Paris Climate Agreement and a drive to long-term carbon neutrality, the inherent efficiencies of a diesel-electric locomotive pulling a heavy train aren't enough. The U.S. railroads, on average, move one ton of freight over 480 miles on a gallon of fuel (Association of American Railroads), but it is still a gallon of carbon intensive diesel. This paper will review the current landscape of diesel fuel, biomass-based diesels (HDRD and FAME), hydrogen, and electricity and evaluate the possible constraints on those fuels and energy sources that could limit the ability of a railroad to meet sustainability targets. These limitations could put more focus on alternative propulsion to meet long-term sustainability goals.

Greenhouse Gas Reduction in the Transportation Sector

Sustainable transportation is a hallmark of the railroad industry, but relying on the inherent efficiencies of diesel-electric locomotives pulling heavy trains isn't enough anymore. The Paris Climate Agreement aims to limit global warming to well below 2 degrees Celsius compared to pre-industrial levels, ideally staying below 1.5 degrees Celsius. Greenhouse gasses must be reduced over time to achieve the Paris Climate Agreement temperature goal, essentially aiming to reach the global GHG emissions peak as soon as possible.

With the United States in a transition period around emissions reduction, this introduction will focus on Canadian climate commitments and actions needed by railroads to meet these commitments. Under the Paris Agreement, Canada committed to a 40-45% GHG emissions reduction from 2005 levels by 2030 (Prime Minister Trudeau announces increased climate ambition, 2021). At the same time, the Clean Fuel Standard (CFS) requires diesel suppliers to gradually reduce the Carbon Intensity (CI) of the fuel they produce and sell for use in Canada by 13% (84 gCO₂e/MJ from a baseline of 96) in 2030 (Canada Gazette, Part I, Volume 154, Number 51: Clean Fuel Regulations, 2020). The long-term Canadian goals move towards achieving net-zero emissions by 2050.

From a North American railroad perspective, Canadian National has a Science Based Target initiative (SBTi)-approved target to reduce Scope 1 and 2 GHG emissions 43% per gross ton mile by 2030 from a 2019 base year (Science Based Target initiative, 2021). In addition, CN is committed to reduce Scope 1 locomotive emissions 6% by 2022 from a 2017 baseline in alignment with the Memorandum of Understanding between Transport Canada and the Railway Association of Canada (RAC) (Rail Association of Canada, 2018). CSX set a SBTi-approved target to reduce Scope 1 and 2 GHG emissions intensity 37% per million gross ton miles by 2029 from a 2014 base year (CSX, 2020), and Union Pacific's science-based target was approved at a 26% reduction of absolute Scope 1 and 2 GHG emissions on a well-to-wheel basis from locomotive operations by 2030 from a 2018 baseline (Union Pacific Railroad, 2021). Kansas City Southern has a SBTi-approved target to reduce Scope 1 and 2 GHG emissions intensity 42% per million gross ton-miles by 2034 from a 2019 base year (Kansas City Southern, 2021). Canadian Pacific and BNSF are committed to setting science-based targets to reduce emissions to support global climate change goals, but the targets are not yet approved (SBTi, 2020).

Current Diesel Engine Fuels and Alternative Propulsion Landscape

While looking at the variety of options in alternative fuels and propulsion that will be needed to meet sustainability targets, it's important to understand fuel pricing, supply and demand, infrastructure needs and more. This paper will consider the following sources of fuel: petroleum diesel (#2 diesel / ASTM D975), biodiesel (Fatty Acid Methyl Esters or FAME), renewable diesel (Hydrogenation-Derived Renewable Diesel or HDRD), hydrogen, and electricity. The fuels in Table 1 fall into two main categories: diesel engine fuels and alternative propulsion. On the path to sustainability, both will be needed due to the fact that locomotives are a long-life asset expected to last 40-60 years. Diesel engine fuels such as biodiesel and renewable diesel will be needed to meet short- and medium-term sustainability targets as hydrogen and electric propulsion locomotives are developed and tested to meet long-term goals.

Table 1: Typical Properties of ULSD, FAME, HDRD, Hydrogen, and Electricity

Property	ULSD #2 Diesel	Biodiesel (FAME)	Renewable Diesel (HDRD)	Hydrogen	Electricity
Fuel Material	Crude Oil	Fats and oils from sources such as soybeans, waste cooking oil, animal fats, and rapeseed	Fats and oils from sources such as soybeans, waste cooking oil, animal fats, and rapeseed	Natural gas, methanol, and electrolysis of water	Natural gas, coal, nuclear, wind, hydro, solar, and small % of geothermal and biomass
Chemical Structure	C ₈ to C ₂₅	Methyl esters of C ₁₂ to C ₂₂ fatty acids	Saturated straight chain C ₁₂ -C ₁₈ hydrocarbons	H ₂	-
Carbon, wt%	86.8	76.2	84.9	0	-
Hydrogen, wt%	13.2	12.6	15.1	100	-
Oxygen, wt%	0	11.2	0	0	-
Specific Gravity	0.85	0.88	0.78	-	-
Cetane No.	40-50	45-55	70-90	-	-
Energy Content	43 MJ/kg 18,500 BTU/lb 130,000 BTU/gal	39 MJ/kg 16,600 BTU/lb 121,000 BTU/gal	44 MJ/kg 18,900 BTU/lb 122,000 BTU/gal	120 MJ/kg 61,000 BTU/lb	3414 Btu/kWh
Diesel Gallon Equivalent (DGE)	1 gal = 1.00 DGE	1 gal = 0.93 DGE	1 gal = 0.94 DGE	1 lb = 0.40 DGE 1 kg = 0.9 DGE	1 kWh = 0.027 DGE
Cloud Point (°C)	-10	-7 to 16	-10 to -5	-	-
Sulfur (ppm)	<15	<2	<2	-	-
Aromatics (vol %)	< 12	N/A	0	-	-

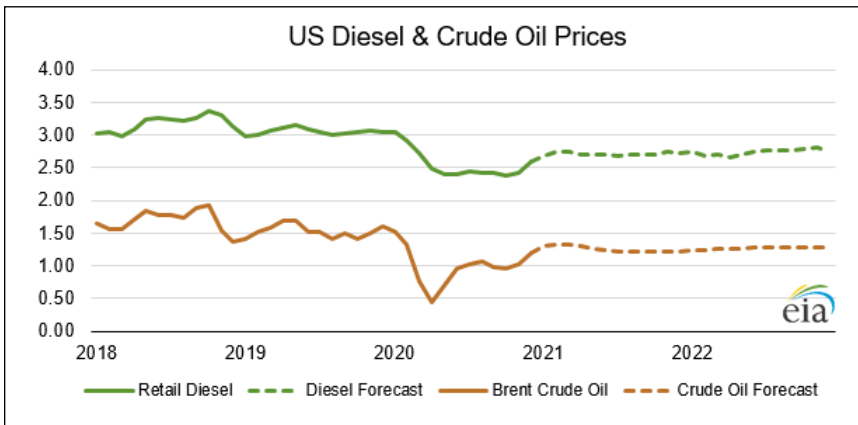
Sources: (ECO Resources Consultants, 2012) (Canada's Biojet Supply Chain Initiative, 2019) (US Dept of Energy, 2020) (Beta Analytic Testing Laboratory, 2020) (National Biodiesel Board, 2014)

DIESEL ENGINE FUELS

Petroleum Diesel

Petroleum diesel is the most common type of fuel for diesel engines. It is produced from the distillation of crude oil and falls under the ASTM D975 standard. Petroleum diesel is widely available, so the main constraint is pricing. Prices dropped from 2018 to 2019 due to increases in U.S. petroleum production that offset the production cuts from OPEC. Prices plunged in 2020 due to COVID-19, but they have since leveled off with forecasts in both oil and diesel pricing staying relatively level as shown in Figure 1 below. Predictions from the U.S. Energy Information Administration suggest that crude oil production will plateau after 2030, but there is significant uncertainty around the long term future of oil price, production, and throughput that would effect petroleum diesel pricing.

Figure 1: US Diesel & Crude Oil Prices



Source: (US Energy Information Administration, 2021)

While the availability of petroleum diesel will not be limited in the coming decades, the implications of carbon taxes may have a significant effect on the transportation industry’s willingness to use it. Canada’s new climate plan proposal would have GHG pricing rise by \$15 CAD per year starting in 2023 to \$170 CAD per ton of CO₂e in 2030 (Environment and Climate Change Canada, 2020). Current pricing for 2021 is set at \$40 CAD per ton. The United States Environmental Protection Agency (EPA) is expected to create carbon tax proposals that match or exceed the Canadian plan. The restoration of an Obama-era calculation valuing the social cost of carbon (SCC) at \$51 USD/ton is just one indication of such policies (Rozen, 2021). According to the Bureau of Transportation Statistics, the North American Class I railroads burned nearly 3.5 billion gallons of diesel in 2019 (Bureau of Transportation Statistics). That fuel burn generated around 44

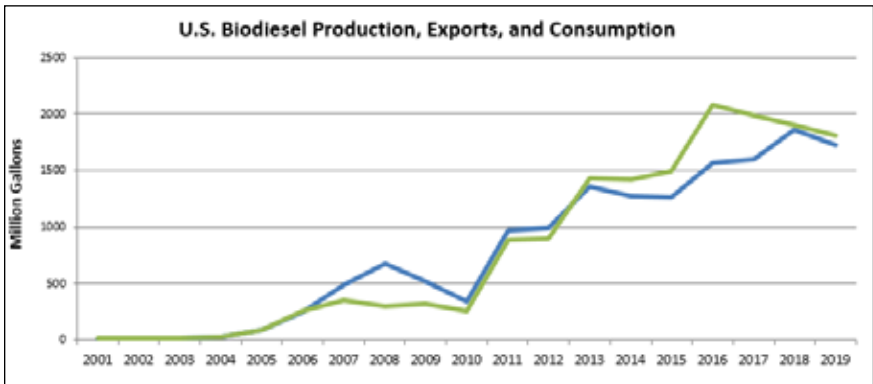
million tons of CO₂e, which at current Canadian GHG emissions pricing would be \$1.76B CAD, and would increase to nearly \$7.48B CAD in GHG taxes spread throughout the Class I railroads per year.

Biodiesel (FAME)

Biodiesel, also known as FAME (Fatty Acid Methyl Esters), is created by transesterification of the feedstock fat to remove the glycerol and by-products. Typical feedstocks are fats and oils from sources such as soybeans, canola, waste cooking oil, and animal fats. A blend of petroleum diesel with up to 5% biodiesel (B5) still meets the same specifications as petroleum diesel under ASTM D975.

The Renewable Fuel Standard (RFS) in the U.S. sets renewable fuel volumes such that even when fuel demand drops, consumption remains steady by maintaining appropriate percentages of renewable fuels. As shown in Figure 2 below, consumption of biodiesel in the US outpaces production, requiring import from foreign sources. Biomass-based fuels usage is expected to increase over the long term with rates in proportion to the cost of petroleum diesel. Higher prices of petroleum diesel make biomass-based fuels more competitive, driving up demand especially in applications such as trucks, heavy machinery equipment, and other applications that may already be incentivized to use biomass-based fuels.

Figure 2: U.S. Biodiesel Production, Exports, and Consumption

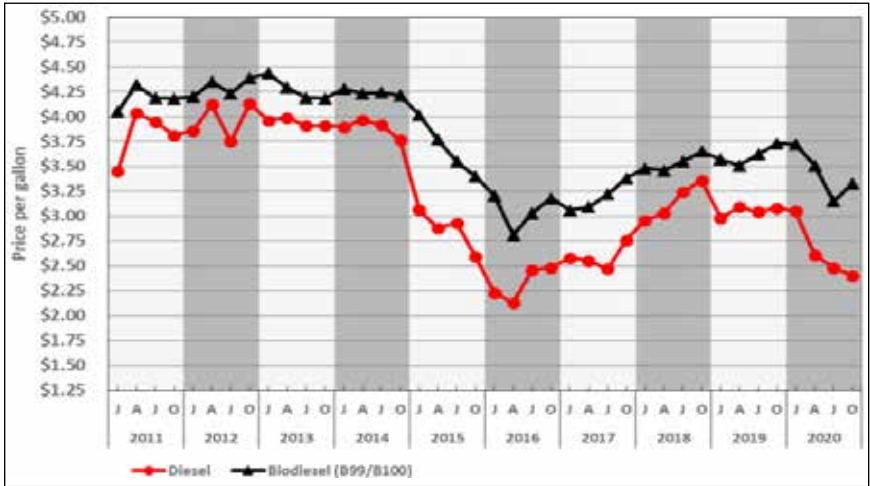


Source: (US Dept of Energy, 2020)

Neat biodiesel (B100 as listed in ASTM D6751) is used primarily as a blend stock, but tends to be more expensive than petroleum diesel as shown in Figure 3 below (without accounting for any available credits). In October of 2020, the U.S. national average for B100 was 39% higher than diesel at \$3.33 USD for B100 and \$2.40 USD for petroleum diesel (US Dept of Energy, 2020). Prices are dependent on location and the associated taxes, with the New England and

Central Atlantic regions retailing B100 \$0.12 USD to \$0.48 USD cheaper than diesel and the Lower Atlantic and Gulf Coast regions retailing B100 \$1.29 USD to \$1.48 USD more expensive than diesel.

Figure 3: Biodiesel and Petroleum Diesel Prices



Source: (US Dept of Energy, 2020)

Biodiesel has a number of technical disadvantages when compared to petroleum diesel. A couple of the most important ones are cold flow properties, oxidation stability, and energy content. The cloud point (when a cloud of wax crystals first appears in a liquid when cooled) of biodiesel is a challenge in northern climates where fuel lines and filters can become plugged in temperatures as high as -4°C to 12°C, depending on feedstock (M Canakci, 2008). Oxidation can be a challenge with biodiesel as six to twelve months of storage can deteriorate the fuel and form gums that cause carbon deposits in the combustion chamber. Similar effects can occur with petroleum diesel storage, though, and these issues can be mitigated with fuel monitoring, proper storage conditions, and additive use. Finally, the lower volumetric energy content compared to petroleum diesel means that to generate the same amount of horsepower, a locomotive engine must consume more biodiesel increasing the effective operating cost of pulling freight and reducing the locomotive’s range.

The feedstock constraints of biodiesel are also shared by renewable diesel as both are produced with the same supplies of waste cooking oil, animal fats, and plant oils. Feedstock constraints will be addressed in the HDRD section of this paper, but one important biodiesel specific constraint is that the drive towards HDRD as a one-size-fits-all solution will likely mute interest in new biodiesel plants. As of December 2020 there were 85 biodiesel production facilities in the

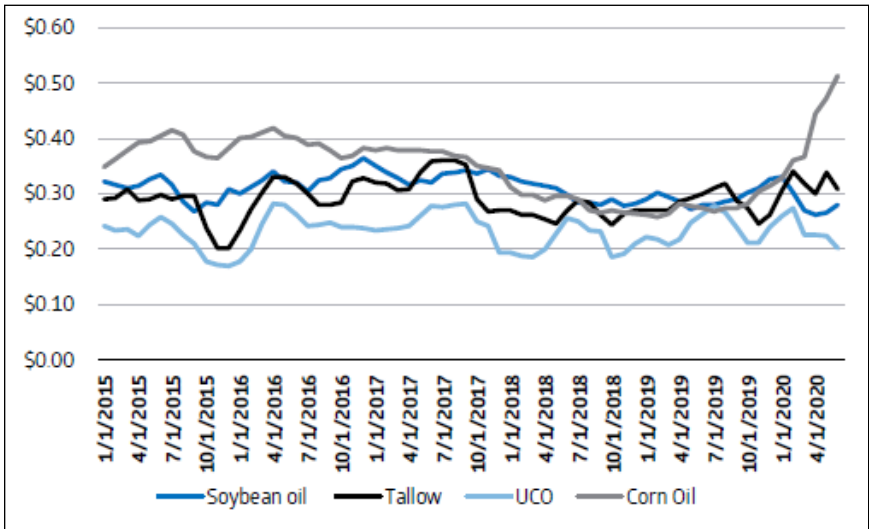
US producing 1.817 billion gallons of biodiesel versus a capacity of 2.476 billion gallons per year (US Energy Information Administration, 2020). Some biodiesel producers operate at a loss and depend on the Blenders Tax Credit (BTC) of \$1 USD/gal to make their operations profitable (RBC Capital Markets, 2020). With very few new plants being planned or built in the U.S., any more than a 25% increase in demand of biomass-based diesel will have to be handled by importing biodiesel or using existing and planned HDRD facilities. As further incentive, HDRD has a 13% higher value of Renewable Identification Numbers (RINs)—the tradeable credits used to track and enforce mandates set by the RFS—pushing new producers into HDRD rather than biodiesel.

Hydrogenation-Derived Renewable Diesel (HDRD)

Hydrogenation-Derived Renewable Diesel (HDRD), also known simply as renewable diesel, is created by hydrotreating animal fats or vegetable oils under elevated temperatures and pressures in the presence of a catalyst. The hydrotreating process is similar to the process to produce petroleum diesel from oil so the fuel output is chemically similar to petroleum diesel falling under the same ASTM D975 standard. Blends of up to 30% (R30) are currently supported under warranty agreements by Wabtec, while Progress Rail sets requirements by a specific Maintenance Instruction (MI). The main challenges with HDRD include a lack of aromatics that may cause elastomer issues, lower fuel lubricity, a higher cetane number that may cause damage to older engine technologies, and, on average, a higher cloud point than petroleum diesel. These challenges aren't overwhelming, but the possible engine parts life cycle reduction and operational impacts should be studied and considered in total cost of ownership calculations going forward.

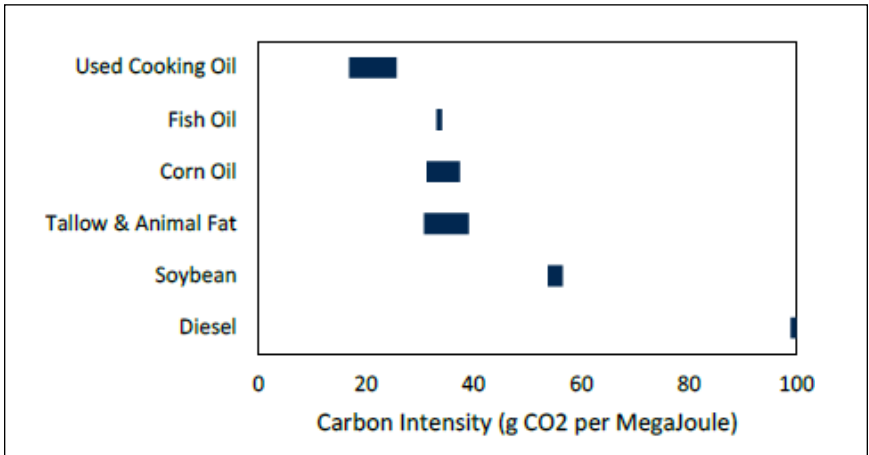
Unfortunately, this early in the growth of HDRD, there are not sufficient volumes of HDRD in physical market trading to support spot price assessments in the United States. S&P Global Platts has begun publishing pricing under the *Platts US West Coast RD* name starting December 1, 2020 that will reflect the cost of renewable diesel produced from tallow via hydro-processing (S&P Global Platts, 2020). Feedstock pricing shown in Figure 4 varies with Used Cooking Oil (UCO) being the cheapest and having the lowest CI (Figure 5). It is the most attractive feedstock, but is inherently limited by available supply. From there, CI and pricing increase in tandem with animal fats generally being lower in price and CI than plant crops.

Figure 4: Feedstock Pricing (USD/lb)



Source: (Cowen and Company, 2020)

Figure 5: Renewable Diesel Feedstock CI Scores



Source: (ESG Stratify, 2020)

Most of the HDRD currently produced for North America goes to California due to the Low Carbon Fuel Standard (LCFS) credit, Renewable Identification Numbers (RINs) cost mitigation, and the Blender's Tax Credit (BTC) (McGurty, 2020). Demand for HDRD in California is expected to be around 1B gal/yr in 2021. Of that 1B gallons, most is imported from other US states or from abroad. Neste is the largest producer of HDRD with plants located in Finland, the Netherlands, and Singapore producing around 950 mgal/yr in total. The next closest producer is Diamond Green Diesel producing roughly 275 mgal/yr (ESG Stratify, 2020).

While HDRD has few technical limitations on how much can be blended into petroleum diesel, there are still constraints regarding feedstock supply and transportation industry demand. On the feedstock side, UCO and animal fats supplies are unlikely to increase significantly. This puts the pressure on plant oil crops to handle the demand. Soybeans will likely become the most common feedstock for short- to medium-term HDRD production due to the high volume of supply in both the US and worldwide. Unfortunately, nearly 50% of U.S. soybean production is exported and 68% of soybean oil is used for food (Cowen and Company, 2020) putting HDRD in competition with food supplies, animal feed, and a demanding global market.

The crushing of a bushel (60 lbs) of soybeans typically generates 11-12 lbs of soybean oil, and a gallon of HDRD requires ~7.5 lbs of soybean oil (RBC Capital Markets, 2020). Doing the math finds that 1 billion gallons of HDRD would require 667 million bushels of soybeans, and at prices at the time of writing this paper results in a feedstock cost of roughly \$2.50 USD/gal reducing competitiveness with petroleum diesel. US soybean production in 2020 was at 4.135 billion bushels with 2.25 billion of those exported (USDA, 2021), so growing HDRD production would require reducing exports, causing an increase in prices of soybeans, and therefore HDRD. There are also a number of social and environmental challenges with soybean production from monoculture farming causing soil erosion and nutrient depletion to ongoing deforestation and ecosystem conversion in the Amazon rainforest (Vivek Voora, 2020). From a Canadian perspective, there's a desire to move away from soybeans by creating HDRD plants with canola as a feedstock and using locally sourced hydrogen as a means of boosting the economies of Alberta and Saskatchewan (Pratt, 2020).

There is a long list of proposed HDRD plant projects in the US that could increase the supply of renewable diesel from 450 million gallons per year to around 4.3 billion gallons per year if all of the projects were built (ESG Stratify, 2020), but some projects are likely to be cancelled, so total capacity is likely to fall short of that estimate (RBC Capital Markets, 2020). Theoretically, the demand for HDRD from Class I railroads alone could eat up nearly all the U.S. capacity. One should also keep in mind that renewable blends are already being used in the trucking industry at ever increasing rates. In 2015, 39 billion gallons of diesel fuel were used in trucks for business purposes in the United States (Brandon Schoettle, 2016).

Low-Carbon Fuel Standard (LCFS) rules currently exempt conventional jet fuel and keep demand for Sustainable Aviation Fuel (SAF) low allowing for the HDRD that is produced in the same facilities to flow to railroads and trucking. This could change with the passage of the Sustainable Aviation Fuel Act that was recently reintroduced to establish a national goal for the U.S. aviation sector to achieve a net 35% reduction in GHG emissions by 2035 and net zero emissions by 2050. U.S. jet fuel consumption in 2019 (pre-COVID) was 18.3 billion gallons (Bureau of Transportation Statistics, 2021), significantly higher volume than the roughly 3.5 billion gallons of diesel that the Class I railroads consume annually. A change in the LCFS rules to include jet fuel could introduce a massive new demand to the limited feedstock and production of HDRD/SAF making it difficult for railroads to obtain as much HDRD as needed to meet sustainability goals in the short- or medium-term. This demand could also drive up prices making blending a more expensive proposition.

Alternative Energy and Propulsion

Alternative propulsion technologies will likely be needed to meet drastic carbon reductions in the railroad industry due to the diesel engine fuel constraints listed above. There will be a glide path where biomass-based fuels such as FAME and HDRD can carry the load, but at some point the railroads will likely need to invest in locomotives with more environmentally friendly propulsion technology. Alternative propulsion technologies still rely on a traction motor driven by electricity, but the source of the electricity generation changes from the current diesel engine to less carbon intense sources. The main alternative propulsion technologies currently being considered by the industry are hydrogen fuel cells, battery-electric, and full-electric driven off of a catenary. The early stages of alternative propulsion development won't have the flexibility afforded by diesel in operations and interchange at first, and for this reason hybrid options such as a diesel-electric/battery or diesel-electric/catenary hybrid may be good first steps.

Hydrogen Energy Storage and Propulsion

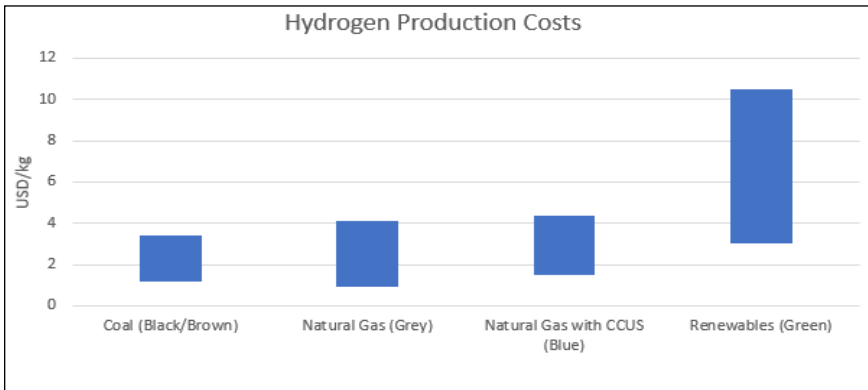
Hydrogen is the most abundant element on earth with nearly three times the energy content of diesel per kg. That high energy per mass number is balanced by low volumetric density that makes distribution and storage a challenge. While hydrogen is the simplest molecule, the manufacturing process is not. There are a variety of ways to manufacture hydrogen that each have a color designation based on the carbon intensity of that process.

Brown and black hydrogen are produced through a gasification process of fossil-based carbon materials. Brown hydrogen starts as lignite coal while black hydrogen starts as bituminous coal (Giovannini, 2020). Both types result in the release of CO₂ and carbon monoxide. Grey hydrogen is the most widely produced type of hydrogen and is created through a process called steam-methane

reforming. This technique creates about 9.3 kg of CO₂ per kg of hydrogen production (compared to 9.1 kg of CO₂ with gasoline combustion) (Rapier, 2020). Blue hydrogen has the same production process as grey but with 90% of the CO₂ captured using Carbon Capture, Utilization and Storage (CCUS) (Liebreich, 2020). Finally, green hydrogen is produced from water by electrolysis using renewable electricity sources such as hydroelectricity, wind, or solar with no resulting CO₂ created (Natural Resources Canada, 2020).

The current pricing for hydrogen aligns with the production costs shown in Figure 6. The ease of production of the black, brown, and grey types of hydrogen lowers production costs, but with an increase in the release of CO₂. As the cost of carbon increases through federal and state credits or taxes, the less carbon intensive blue and green hydrogen will become relatively more affordable and demand should rise.

Figure 6: Hydrogen Production Costs



Source: (International Energy Agency, 2020)

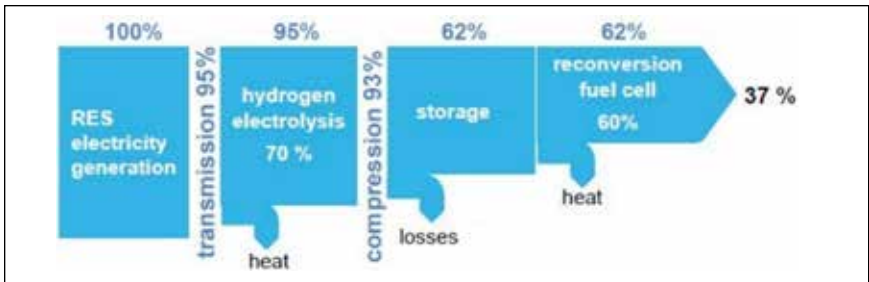
Hydrogen fuel cells as a source of electrical energy for locomotive propulsion has the support of many governments around the world, but especially in Canada. Canada's Minister of Natural Resources stated in the 2020 *Hydrogen Strategy for Canada* that "by 2050, clean hydrogen can help us achieve our net-zero goal—all while creating jobs, growing our economy, and protecting our environment. This will involve switching from conventional gasoline, diesel, and natural gas to zero-emissions fuel sources, taking advantage of new regulatory environments, and embracing new technologies to give Canadians more choice of zero emission alternatives." Two of the major hydrogen fuel cell manufacturers are based in Canada; Ballard in Vancouver, BC and Hydrogenics (now Cummins) in Mississauga, ON. Hydrogen from natural gas (grey and blue) is currently produced in Alberta, while the renewable grids of BC and Quebec allow for potential future production of green hydrogen.

The most likely choice of hydrogen fuel cell for locomotive use is the Proton-Exchange Membrane (PEM) fuel cell. It is also sometimes referred to as a Polymer Electrolyte Membrane (PEM) fuel cell. Hydrogen (H_2) is split into protons ($2H^+$) and electrons ($2e^-$) using a catalyst at the anode side of the fuel cell. The protons are able to pass through the membrane, while the electrons are forced through a load circuit to the cathode side where the hydrogen protons and electrons are combined with oxygen ($\frac{1}{2}O_2$) to create water as an output. The electrons in the load circuit are used for propulsion either directly or from a battery charged from the fuel cell. PEM fuel cells operate around $120^\circ C$ with around 60% efficiency (US Department of Energy, 2015) and have increased reliability compared to a diesel engine due to fewer moving parts.

Hydrogen as a source of energy for locomotive propulsion does have some downsides to consider; low volumetric density requiring frequent fueling or tender cars and inefficiency of production, packaging, and distribution. A typical 4,400 horsepower (hp) diesel electric locomotive with 38% efficiency at the rail would convert 190 MWh of energy in ~5,000 gallons of ULSD to about 72 MWh of energy providing around 24 hours at Notch 8 between refueling. If the diesel engine was swapped for a PEM fuel cell operating at 60% fuel cell efficiency and 47% efficiency at the rail, ~15,000 gallons of liquid H_2 would be needed for the same range as the diesel electric locomotive. A single cryogenic tender could provide this amount of liquid H_2 . While cryogenic tenders were developed to maintain Liquid Natural Gas (LNG) at $-163^\circ C$, further work will be required to maintain temperatures of $-253^\circ C$ required of liquid H_2 . For this reason, projects such as the 200 kW Sierra Northern Railway (Progressive Railroading, 2021) hydrogen fuel cell prototype locomotive are being developed with onboard gaseous H_2 fuel storage with power and range matching a current diesel switching locomotive.

The inefficiencies of green hydrogen production, packaging, and distribution can stack up to require a significantly higher amount of energy used than will ultimately be delivered to the locomotive. There are projects to improve this efficiency, but for the whole process shown in Figure 7, the output energy of the gaseous hydrogen by electrolysis is around 37% of the input energy (Bernholz, 2018). With the North American electrical grid already strained, this amount of waste is a concern. On the other hand, generation of hydrogen from renewable sources, also known as power-to-gas or P2G, is an excellent way to balance demand on the grid with plants able to run at steady state and off-peak hours. This is in contrast with short bursts of demand that would happen when rapidly charging a battery-electric locomotive (discussed in the next section).

Figure 7: Hydrogen Production to Use Efficiency



Source: (Bernholz, 2018)

Fueling infrastructure for a hydrogen locomotive can vary in size and complexity. There are three main fueling station types shown in Figure 8: gaseous delivery, liquid delivery, and onsite production. The gaseous delivery consists of transporting tube trailers of hydrogen holding roughly 200-600 kg at 200-450 bar via truck or pipeline transportation using modified existing natural gas infrastructure. The hydrogen can be transferred directly into storage tanks for dispensing to the locomotive. Liquid hydrogen transportation can be used to transfer more hydrogen in a smaller volume. Four tons of liquid hydrogen can be stored in a cryogenic trailer, but vaporization equipment is needed to dispense the hydrogen as a gas. Finally, onsite production using locally available renewable energy and electrolysis can be used for fueling stations with higher volume requirements. Cost estimates for a fueling station producing thousands of kg/day of hydrogen needed to refuel locomotives are not yet available, but one study found cost for a 300kg/day facility ranged from \$1.36M-\$4.43M USD (Ethan S. Hecht, 2017).

Figure 8: Hydrogen Fueling Station Examples

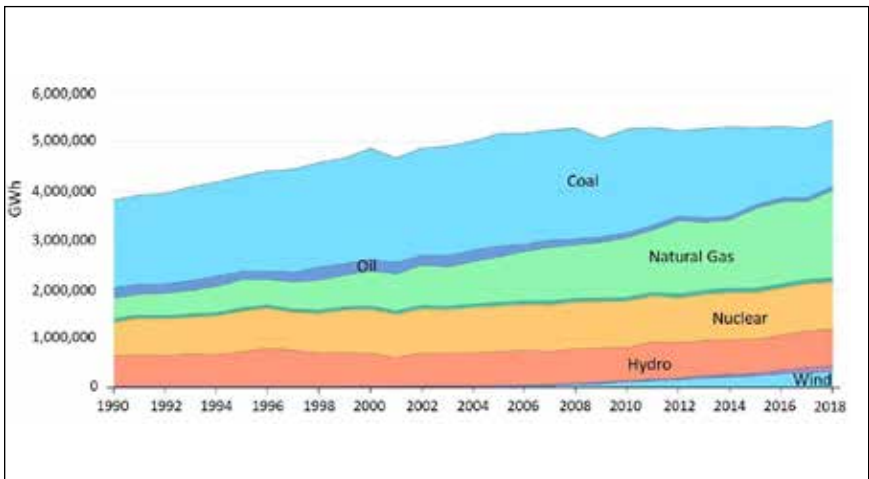


Source: (California Fuel Cell Partnership)

Electrical Energy Storage and Propulsion

Electricity generation has been changing over time to less carbon intensive sources making it a good option for sustainable propulsion technologies. Coal has been gradually replaced with natural gas, and the fastest rising source of electricity is wind as shown in Figure 9. These cleaner, renewable sources have also steadily dropped the cost of electricity. Retail prices of electricity for the transportation sector have not been tracked as far back as residential or industrial sectors, but from 2003 to 2020, the average price paid in the US was \$0.097 USD/kWh with a high of \$0.107 USD/kWh in 2008 and low of \$0.072 USD/kWh in 2004 (US Energy Information Administration, 2021).

Figure 9: Electricity Generation by Source, N. America 1990-2018



Source: (International Energy Agency, 2021)

Production costs in the U.S. vary based on source with nuclear power averaging \$0.025/kWh over the last decade with a relatively narrow range of \$0.022-0.027/kWh each year (Federal Energy Regulatory Commission, 2020). Fossil fuel driven steam varied from \$0.035-0.040/kWh each year with an average of \$0.037/kWh (Federal Energy Regulatory Commission, 2020). Hydroelectric power comes in the cheapest at \$0.008-0.013/kWh each year with an average of \$0.011/kWh. Finally, the grouping of gas turbine, photovoltaic, and wind have been steadily dropping from \$0.058/kWh in 2009 to \$0.028/kWh in 2019.

Battery Electric

Battery electric cars have made inroads with many consumers now that they are able to achieve 200-300 miles in range, but the energy needs of a locomotive are

significantly higher. Current range limitations of a Battery-Electric Locomotive (BEL) place the technology purely in a supplemental role in line-haul operations. An example of this supplemental role is Wabtec's 2.4 MWh BEL that was tested on BNSF. The next generation of Wabtec's BEL is planned for 6 MWh (Fretty, 2021) with that nameplate capacity limited to about 80% useable capacity to ensure battery health and longevity. While the efficiency of a battery-electric locomotive is relatively high (~90%), this amount of energy storage only provides 1.5 hours of Notch 8 compared to the 24 hours (72 MWh) of a diesel locomotive. So, while a line-haul BEL can't stand alone until battery technology advances significantly, the supplemental application is expected to provide 10-30% fuel savings depending on operation (Fretty, 2021).

Battery-electric locomotives do have promise as a replacement for yard switchers and other short distance captive fleets. Much like an electric car is ideal when you charge it every night at home, a yard switcher can function in the same way. An assessment of requirements for a hydrogen-powered switcher found that the duty cycle of a switcher had short peak power demands of 1,600 kW with an average of 71 kW and a total energy demand over a 16-hour period of 1,131 kWh (Change Energy Services, 2020). This energy profile would be satisfied by a locomotive such as Progress Rail's EMD Joule with 3,200 hp (2,386 kW) peak output and 2.4 MWh of nameplate battery capacity (Progress Rail, A Caterpillar Company, 2020). A charging station in the yard could be used to recharge the locomotive during off hours or shift changes with only localized charging infrastructure needed.

Charging a BEL does present some challenges around infrastructure and rate of charge. Support structure for heavy duty vehicle charging generally consists of an AC breaker off of the distribution power lines, a large transformer, a DC rectifier, and positive/negative DC breakers to bring the high voltage AC down to a manageable DC voltage. All of this equipment can run in the range of \$1M USD to charge only a couple battery electric locomotives. The EMD Joule is expected to charge at up to 700 kW in order to be fully charged in under 4 hours, and while charging one BEL would certainly draw a lot of power, a fleet of BELs could drastically change infrastructure needs and electricity charges. Electrical utilities are known to use demand charges based on peak power usage as a tool for managing energy needs during high-demand periods and to provide compensation for the additional infrastructure and capacity needed to provide variable rates of high power (US Department of Energy, 2017). These demand charges would affect a railroad trying to charge multiple BELs at once and possibly require more strategic operational changes to balance charging, maximize off-peak charging times, or create local energy storage options.

Electric Catenary

The last sustainable locomotive propulsion solution to be addressed in this paper is full electric locomotives running on electrified sections of rail (most likely catenary). The North American freight network is the largest in the world with very little, if any, electrification. This is in comparison to the next three largest networks—China, India, and Russia—that have 30-65% electrification with the stated goal of going to full electrification of all major corridors in their respective networks (Blomerus, 2019). The railroads in these three countries are state-owned, with electrification programs using public-private partnerships or direct government funding. This puts them in a different situation regarding funding for these projects than the privately-owned railroads in North America that are responsible for maintaining reasonable capital investment levels to satisfy shareholders. For example, China's investment in railway fixed assets exceeded \$150B USD in each of the past five years (Blomerus, 2019) compared to the combined \$28B USD of capital spent per year by the North American railroads according to the AAR and RAC.

While the investment to electrify an entire Class I railroad meets both financial and interchange challenges, there is a return on investment (ROI) to be had by electrifying strategic portions of the North American network. Part of this ROI relies on the advantages of full electric locomotives over diesel. Modern high horsepower diesel locomotives generate around 3,200 kW of power vs 4,600 kW of available power in an electric 6-axle, and the absence of the diesel engine and generator reduces the need for maintenance and fuel (the highest cost of a diesel locomotive) at a lower overall acquisition cost due to less locomotives being needed to move a given amount of freight. The negative side, of course, is the infrastructure cost. The expected cost for new construction would likely fall in the \$1M USD/km range depending on a range of factors (Blomerus, 2019), which is a large investment for any North American Class I railroad with only a couple billion dollars in total capital investment per year. For this reason, public-private partnerships would likely be needed to finance the electrification of a section of the network.

Summary

There is a lot to consider in moving the railroad industry to a zero carbon future, with many options available in the short-, medium-, and long-term. There is also quite a lot of urgency to do it quickly to limit global warming to well below 2 degrees Celsius compared to pre-industrial levels. Sustainable fuels can take a railroad a long way in reducing carbon emissions, but there may be higher fuel costs or supply constraints as more industries share the limited feedstock resources needed to produce HDRD and FAME. This means that sustainable fuels are a good solution in the short- to medium-term, but the long-term solution should consider a gradual retirement of diesel burning assets for more sustainable

means of propulsion. There won't be a one-size-fits-all approach in the North American rail network, but focusing on hybrid and modular solutions will provide a pathway to zero carbon emissions while still maintaining operational flexibility. Perhaps diesel-electric/battery hybrid locomotives are the next step followed by an overhaul option to replace the diesel engine with more batteries of higher energy density or a hydrogen fuel cell after a decade of operation. Only time will tell, but the work must begin now.

References

Association of American Railroads. (n.d.). *Freight Railroads are Addressing Climate Change*. Retrieved from <https://www.aar.org/climate-change>

Bernholz, J. (2018, September). *RWE's former, current and possible future energy storage applications*. Retrieved from <https://www.group.rwe/-/media/RWE/documents/01-der-konzern/rweti/rwe-ti-MUC-Workshop-2018-IERE-Energy-Storage.pdf?la=en>

Beta Analytic Testing Laboratory. (2020). *Hydrogenation-Derived Renewable Diesel (HDRD)*. Retrieved from <https://www.betalabservices.com/biofuels/renewable-diesel-hdrd.html>

Blomerus, P. (2019). *Electrification of the Freight Rail Sector in Canada: Review of the Feasibility, Costs and Benefits*.

Brandon Schoettle, M. S. (2016). *A Survey of Fuel Economy and Fuel Usage by Heavy-Duty Truck Fleets*. University of Michigan - Sustainable Worldwide Transportation.

Bureau of Transportation Statistics. (2021, January). *Airline Fuel Cost and Consumption*. Retrieved from <https://www.transtats.bts.gov/fuel.asp>

Bureau of Transportation Statistics. (n.d.). *Class I Rail Freight Fuel Consumption and Travel (Metric)*. Retrieved from <https://www.bts.gov/content/class-i-rail-freight-fuel-consumption-and-travel-metric>

California Fuel Cell Partnership. (n.d.). *Costs and Financing*. Retrieved from <https://h2stationmaps.com/costs-and-financing>

Canada's Biojet Supply Chain Initiative. (2019). *HEFA Production and Feedstock Selection*.

Change Energy Services. (2020, June). *Assessment of the Design, Deployment Characteristics and Requirements of a Hydrogen Fuel Cell Powered Switcher Locomotive*. Retrieved from Environment & Climate Change Canada: <https://tdocs.ingeniumcanada.org/>

Cowen and Company. (2020). *A Primer on US Renewable Diesel*. Cowen Equity Research.

CSX. (2020). *CSX Leads North American Rail Industry with Most Ambitious GHG Emissions Intensity Reductions Goal*. Retrieved from <https://www.csx.com/index.cfm/about-us/media/press-releases/csx-leads-north-american-rail-industry-with-most-ambitious-ghg-emissions-intensity-reductions-goal/>

ECO Resources Consultants. (2012). *Study of Hydrogenation Derived Renewable Diesel as a Renewable Fuel Option in North America*. Natural Resources Canada.

Environment and Climate Change Canada. (2020). *A Healthy Environment and A Healthy Economy*.

ESG Stratify. (2020). *Renewable Diesel: If You Build It, They Will Come*. RBC Capital Markets.

Ethan S. Hecht, J. P. (2017). *Comparison of conventional vs. modular hydrogen refueling stations, and on-site production vs. delivery*. Sandia National Laboratories.

Federal Energy Regulatory Commission. (2020). *FERC Form 1, "Annual Report of Major Electric Utilities, Licensees and Others"*.

Fretty, P. (2021, January). *Wabtec Putting EV Locomotive on Rails*. Retrieved from Industry Week: <https://www.industryweek.com/technology-and-iiot/article/21152590/wabtec-putting-ev-locomotive-on-rails>

Giovannini, S. (2020, November). *50 Shades of (Grey and Blue and Green) Hydrogen*. Retrieved from Energy Cities: <https://energy-cities.eu/50-shades-of-grey-and-blue-and-green-hydrogen/>

Government of Canada, Dept. of the Environment. (2020). *Canada Gazette, Part I, Volume 154, Number 51: Clean Fuel Regulations*. Retrieved from <http://gazette.gc.ca/rp-pr/p1/2020/2020-12-19/html/reg2-eng.html>

International Energy Agency. (2020, March). *Hydrogen production costs by production source, 2018*. Retrieved from <https://www.iea.org/data-and-statistics/charts/hydrogen-production-costs-by-production-source-2018>

International Energy Agency. (2021). *Data and statistics*. Retrieved from IEA: <https://www.iea.org/data-and-statistics/?country=WEONAM&fuel=Electricity%20and%20heat&indicator=ElecGenByFuel>

Kansas City Southern. (2021, May). *Kansas City Southern's Emissions Reduction Targets Approved by Science Based Targets initiative*. Retrieved from <https://www.kcsouthern.com/media/news/news-releases/kansas-city-southern-s-emissions-reduction-targets-approved-by-science-based-targets-initiative>

Liebreich, M. (2020, October). *Separating Hype from Hydrogen – Part One: The Supply Side*. Retrieved from BloombergNEF: <https://about.bnef.com/blog/liebreich-separating-hype-from-hydrogen-part-one-the-supply-side/>

M Canakci, H. S. (2008). Biodiesel production from various feedstocks and their effects on the fuel properties. *Journal of Industrial Microbiology and Biotechnology*, Volume 35, Issue 5.

McGurty, J. (2020, November). *Evolve or die: US refiners grasp renewables lifeline to stay viable*. Retrieved from <https://www.spglobal.com/platts/en/market-insights/podcasts/focus/020921-us-battery-storage-strategies-opportunities-barriers>

National Biodiesel Board. (2014). *Biodiesel Fact Sheets*. Retrieved from Biodiesel: <https://www.biodiesel.org/what-is-biodiesel/biodiesel-fact-sheets>

Natural Resources Canada. (2020). *Hydrogen Strategy for Canada: Seizing the Opportunities for Hydrogen*.

Patrick Miller, A. K. (2014). Techno-economic Assessment of Hydrogenation-derived Renewable Diesel Production from Canola and Camelina. *Sustainable Energy Technologies and Assessments* 5.

Pratt, S. (2020, January). *Canola growers see opportunity in biofuel option*. Retrieved from The Western Producer: <https://www.producer.com/news/canola-growers-see-opportunity-in-biofuel-option/>

Prime Minister of Canada. (2021, April 22). *Prime Minister Trudeau announces increased climate ambition*. Retrieved from <https://pm.gc.ca/en/news/news-releases/2021/04/22/prime-minister-trudeau-announces-increased-climate-ambition>

Progress Rail, A Caterpillar Company. (2020, November). *Progress Rail and Pacific Harbor Line Sign Agreement*. Retrieved from <https://www.progressrail.com/en/Company/News/PressReleases/ProgressRailAndPacificHarborLineSignAgreementForBatteryLocomotive.html>

Progressive Railroading. (2021, March). *Sierra Northern Railway obtains funding to build, test hydrogen switcher locomotive*. Retrieved from https://www.progressiverailroading.com/short_lines_regionals/news/Sierra-Northern-Railway-obtains-funding-to-build-test-hydrogen-switcher-locomotive--62988

Rail Association of Canada. (2018). *Rail Association of Canada*. Retrieved from <https://www.railcan.ca/wp-content/uploads/2019/07/TC-RAC-MOU-2018-22.pdf>

Railway Technology. (2021, March). *CP to deploy Ballard fuel cells in its Hydrogen Locomotive Program*. Retrieved from <https://www.railway-technology.com/news/cp-ballard-hydrogen-locomotive-program/>

Rapier, R. (2020, June). *Estimating The Carbon Footprint Of Hydrogen Production*. Retrieved from Forbes: <https://www.forbes.com/sites/rpapier/2020/06/06/estimating-the-carbon-footprint-of-hydrogen-production/?sh=6af63c8024bd>

RBC Capital Markets. (2020). *Renewable Diesel: If You Build It, They Will Come*. Royal Bank of Canada.

Rozen, S. L. (2021, February). *Biden Turns Back to Obama-Era Method of Valuing Climate Change*. Retrieved from Bloomberg Green: <https://www.bloomberg.com/news/articles/2021-02-26/biden-turns-back-to-obama-era-method-of-valuing-climate-change>

S&P Global Platts. (2020, December). *S&P Global Platts Launches Renewable Diesel Values in United States*. Retrieved from <https://www.spglobal.com/platts/en/about-platts/media-center/press-releases/2020/12012020-renewable-diesel-launch>

SBTi. (2020). Retrieved from Science Based Targets: <https://sciencebasedtargets.org/companies-taking-action>

Science Based Target initiative. (2021). *Companies Taking Action*. Retrieved from <https://sciencebasedtargets.org/companies-taking-action#table>

Union Pacific Railroad. (2021, February). *News Releases - Environment*. Retrieved from Union Pacific: <https://www.up.com/media/releases/210210-SBTi.htm>

US Department of Energy. (2015, November). *Fuel Cells Fact Sheet*. Retrieved from https://www.energy.gov/sites/prod/files/2015/11/f27/fcto_fuel_cells_fact_sheet.pdf

US Department of Energy. (2017). *Enabling Fast Charging: A Technology Gap Assessment*.

US Dept of Energy. (2020). *Alternative Fuels Data Center*. Retrieved from <https://afdc.energy.gov/fuels/properties>

US Dept of Energy. (2020, May). *Alternative Fuels Data Center*. Retrieved from <https://afdc.energy.gov/data/?q=biodiesel>

US Dept of Energy. (2020, October). *Clean Cities Alternative Fuel Price Report*. Retrieved from <https://afdc.energy.gov/fuels/prices.html>

US Energy Information Administration. (2020). *Form EIA-22M "Monthly Biodiesel Production Survey"*. Retrieved from <https://www.eia.gov/biofuels/biodiesel/production/>

US Energy Information Administration. (2021). *Annual Energy Review*. Retrieved from EIA: <https://www.eia.gov/totalenergy/data/annual/index.php>

US Energy Information Administration. (2021, January). *Short-Term Energy Outlook*. Retrieved from <https://www.eia.gov/outlooks/steo/data.php>

USDA. (2021, March). *Soybeans & Oil Crops - Related Data & Statistics*. Retrieved from Economic Research Service: <https://www.ers.usda.gov/topics/crops/soybeans-oil-crops/related-data-statistics/>

Vivek Voora, C. L. (2020). *Global Market Report: Soybeans*. International Institute for Sustainable Development.

Report on the Committee on Locomotive Software and Systems

MONDAY, OCTOBER 4, 2021

10:45 AM



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Director-Strategic Business

ZTR Control System

London, Ontario

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PERSONAL HISTORY

Viktor Gvelesiani

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Viktor Gvelesiani is a Director of Strategic Business Development at ZTR. He has been working in the railroad industry for 25 years. His extensive work experience has been primarily focused on locomotive modernization, such as diesel-electric and electric locomotive overhauls, modernization of electrical and control systems on locomotives, manufacturing and field service.

Viktor has worked with major railroads all over the world and has in-depth understanding of challenges railroads are facing in today's world. He is actively involved with the AAR Locomotive Committee and Railway Electronics Standards Committee and various task force groups.

Born in Georgia, Viktor obtained Bachelor's Degree in Engineering at Kiev Polytechnical Institute (Ukraine) and Master's Degree in Business Administration at Laurier University (Canada). He is a registered Professional Engineer currently residing in London Ontario, Canada with his wife Gillian and daughter Anna. His son Dennis works as a marketing team lead in Toronto, Ontario. Viktor enjoys being outdoors, especially camping, hiking, biking and golfing.

Improving Locomotive Cab Comfort with a new generation of HVAC systems

Prepared by:

David Caron, Vice-President Sales & Marketing, Ekyrail Enterprises Inc.

Preface

For the past 50 years, the rate of global warming has been very alarming. With temperatures increasing year after year, it is getting more and more difficult to perform any task in a non-controlled environment including crews responsible for handling trains. As a result, offering a comfortable cab temperature to crew members is becoming a priority for Railroads Operators. The HVAC system onboard a locomotive is now a critical component to keep the crew comfortable, alert, safe and productive.

This paper discusses options and maintenance for an HVAC system.

Background

Across the different OEMs, there are several solutions for cooling and heating locomotive cabs. The cab is fully exposed to direct sunlight, usually very badly insulated and house equipment such as Positive Train Control electronics, Radio Transmitters and Digital video recorder which generate large amounts of heat. Keeping the cab at a comfortable temperature is not just beneficial for the crew, but also helps increase the useful life of the equipment installed in that part of the locomotive. Considering that an HVAC system is now a critical component for the operation of a locomotive, it comes with operational challenges since it is also a single point of failure.

Type of HVAC Systems

An HVAC system dedicated for locomotive applications should be engineered to withstand extreme conditions such as high and low temperatures, shocks & vibrations, and electromagnetic interferences. A locomotive is definitely a harsh environment for any type of equipment. In the newest locomotive manufactured by OEMs, HVAC units are now considered standard equipment, which was not the case several years ago. Low horsepower locomotives such as the GP38 were manufactured with no provision for HVAC installation. Some railroads still do not require HVAC units, but others have added HVAC systems to their mandatory equipment list in lead locomotives. To achieve such requirements, railroads

decided to use the roof of locomotive to install an HVAC System. In today's market, there are very few models fully engineered for roof mounting, so many railroads decided to install products that were not originally manufactured for locomotive applications, such as systems built for camper applications. These low-cost HVAC units are not designed for such operating conditions and will last only a few years before failure. When calculating the Life Cycle Cost (LCC) of this type of equipment, including shopping events, equipment cost and labor for installation, the LCC becomes greater than a system designed for locomotive applications.



Picture 1: Camper Type HVAC Unit

For the last few years, railroads have started the integration of Positive Train Control systems (PTC) onboard their fleet. One of the challenges associated with those new systems is the antenna associated with the PTC. It needs to have the shortest cable length as possible and must be located at the highest point of the locomotive. Also, the antenna needs to be as close as possible to the equipment it is cabled to. The issue that arises is that the area of the roof where camper HVAC units are located is also the place of choice for installing the antenna farm.



Picture 2: PTC and latest electronic hardware installed in a short nose

The options for clearing the roof are limited so Railroads have become creative in finding real-estate for the antenna farm. HVAC manufacturers are working hard to address this problem by offering alternate solutions to the roof mounted HVAC units.



Picture 3 (L): Creative solution by railroads to accommodate antenna farms
Picture 4 (R): New generation of HVAC for Low Horsepower Locomotives

With all the new electronic equipment, the number of hours spent in the cab to maintain such systems is also increasing drastically. With temperatures in the shop usually very high, maintenance teams are using any methods to keep the cab comfortable. Offering a system that can be in operation while the locomotive is shut down is even more interesting, not just from a comfort standpoint but also for safety reasons.



Picture 5: Artisan cab cooling system

Newer locomotive by Progress Rail (EMD) have been engineered with HVAC integration in mind and have opted for a system that is located in the sub-base area of the cab. Alternatively, GE decided to use the running board behind the cab on some models for HVAC installation. In their newer locomotive, GE has also chosen the sub-base area as the best location for an HVAC unit.



Picture 6: GE Side Mounted HVAC



Picture 7: Progress Rail (EMD) Sub-Base HVAC Type

Maintenance & Overhaul of an HVAC System

HVAC equipment requires regular maintenance for optimal operations. Dirty and/or clogged filters are the leading cause of systems underperforming. At every 184-day-inspection, the filters must be replaced or cleaned. The cabin filter (evaporator side) is a type of filter that is thrown away as opposed to the exterior filter (condenser side), which is typically a hog-hair filter that can be cleaned with water and reused over and over again.

A system that has been designed for railroad operation will require an overhaul at about every 6 to 8 years (typically 50,000 hours of operation). Such overhauls are required to maintain all components in optimal condition. Before an overhaul, increasing noise level, abnormal vibrations, and frequent interruption of service of an HVAC system are all indicators of a system in need of maintenance or cleaning. This will also result in an increase of complaints regarding the HVAC system from train crews.

A typical overhaul will consist of a complete recovery and recycling of the refrigerant, which needs to be performed according to local regulations and industry best practices. All rotating equipment such as evaporator and condenser fans should be dismantled, cleaned, and all bearings replaced. Newer generations of HVAC units are using fans that are packaged in a way that are not serviceable. In that case maintenance is not possible and they will be replaced by new fans. The entire HVAC frame will be cleaned using chemical agents or by a dry ice cleaning process that leaves no residue. The evaporator and condenser coils should also be cleaned with a chemical solution to ensure an unrestricted airflow through the fins of the coils. When the system is ready to be reassembled, all components should first go through a quality check process before they can be reassembled in the main frame. Then harnesses and piping are reinstalled and secured by vibration resistant clamps which helps to ensure good operating conditions for the components to increase their useful life.

The first step after reassembling the unit consists of a leak check by charging the system with nitrogen at a fixed pressure level. By monitoring the pressure, the technician will be able to confirm that the system is not leaking. Following the initial leak check, the unit will be connected to a vacuum pump for several hours. The objective is to completely remove any trace of humidity and air within the system before the system is charged with refrigerant.

When the vacuum process is complete, the unit will be powered and preliminary checks for the rotating equipment will be performed. This includes inspecting the direction of rotation of the fans, validating the electrical consumption, and balancing the fan blades to avoid any vibrations that lead to premature bearing damage. The next step consists of starting the compressor and charging the unit with a specific quantity of refrigerant. This quantity is measured in real-time by weight, by placing the tank of new refrigerant on a scale. The technician constantly monitors the value on the scale until the desired amount of refrigerant is introduced into the freshly remanufactured HVAC unit.

Obsolescence of Refrigerant

The U.S. Environmental Protection Agency (EPA) has set January 1st, 2020 as the date when R22 becomes unavailable for purchase in the United States. This refrigerant was the most popular across the HVAC industry because of its performance. Indeed, R22 was one of the best performing refrigerant, offering great heat transfer properties and efficiency. However, it is an important ozone-depleting substance with a very high ozone depletion potential.

Since then, several other replacements have been developed; some, such as R407C, even as a direct drop-in replacement for R22. Unfortunately, other refrigerants have no substitute and systems using them will require extensive work to make the compressor and other peripherals compatible with new refrigerants. The oil type within the compressor is an important point to consider while upgrading an HVAC system that was originally designed for operating with R22, as it will need to be replaced with POE oil.

The newer HVAC systems are mainly operating with R410A. This offers a great alternative to R22, as it is more energy efficient and not an HCFC (hydro-fluoro-chloro-carbon). Across the HVAC industry, the ASHRAE association is the main body that guides the best practices for HVAC system manufacturers. Each recipient of refrigerant is color coded to easily identify the product in a specific container and thus helps prevent the use of a wrong refrigerant in a system or simply mixing refrigerants.



Picture 8: R410A tank, Pink color-coded

The next generation of HVAC is talking

The newest locomotives manufactured by the OEMs are fully equipped to transmit massive quantities of vital information that are processed with the objective of offering predictive failure of equipment data. At the moment, HVAC systems for locomotives are not designed to communicate any information to the locomotive other than basic data such as the operating mode and temperature.

The next generation of HVAC will be able to manage in a more efficient way the components' behaviors by using different sensors and setting optimal operating parameters. This will be done according to real-time information captured by the unit. In addition, the unit will be able to communicate its complete status information to the locomotive system. Maintenance crew will be alerted of upcoming failures, as well as being guided in the troubleshooting process for any components within the system. The objective is to reduce the maintenance time as much as possible.

Conclusion

With increasing temperatures around the globe, HVAC systems are becoming a critical component aboard locomotives. Operating crews must be able to work in a comfortable environment which helps them to stay alert, safe and productive.

With proper maintenance, an HVAC system will be able to deliver the performance expected by the crew with minimal down time. The next generation of HVAC will lead to an industry change within our railroads by providing strategic information for maintenance but also for operation.

For more information about the future HVAC systems, do not hesitate to contact your locomotive HVAC solutions provider.

Battery Energy Management on Locomotive

Prepared by:

*Viktor Gvelesiani, ZTR, Locomotive Software
and Systems Committee, 2021*

Batteries have been used in locomotives since the beginning of the diesel-electric era, where their primary purpose was to provide energy to crank the engine. Without a properly charged battery it is not possible to start a locomotive. Therefore, the topic of the “dead batteries” is synonymous to the topic of “dead locomotives”.

Given the importance of a healthy charged battery to locomotive operation and widespread use of this technology since the early 50’s it is rather surprising how little consideration was really given to the state of charge and the overall health of the battery in the design of locomotive electrical systems.

One of the most obvious reasons was how locomotives were typically used. Until the beginning of the 21st century, a typical locomotive duty cycle consisted of a fairly large idle time component (40-80%) and practically non-existent engine shutdown time. Just about the only time an engine would be shut down was to go into a shop. This provided more than enough time to charge batteries and very little need to actually use them, since the engines were running most of the time. There was no need to worry about state of charge of batteries because they were simply always charged.

Rising fuel prices and tightening environmental regulations brought out numerous technologies focused on reducing fuel consumption and idling locomotives were an obvious target. Automatic Engine Start Stop (AESS) technologies are now standard feature in all new locomotives and the vast majority of older locomotives are equipped with products like ZTR’s SmartStart. This resulted in a significant change in locomotive duty cycle –longer and more frequent engine shutdown periods allowing deeper drain of the battery. At the end of the shutdown period, the locomotive needs a healthy charged battery to restart.

There is no question that idle reduction technologies bring substantial benefits in reducing railroad operating cost and improving environmental footprint. The problem is that traditional methods of controlling locomotive battery energy and its flow are no longer adequate.

Battery Charge/Discharge Cycle

A typical operating cycle of a battery consists of the Charge Period (when the engine is running), a Slow Discharge Period (the engine is shut down, and

A DEAD LOCOMOTIVE BATTERY WILL AFFECT UTILIZATION



Extended locomotive battery life.

Batteries are costly to install and replace, but KickStart reduces battery drain during start to improve life by up to 50%.



Increased locomotive availability.

KickStart ensures that your locomotive performs when it is most critical by significantly enhancing starting reliability in all weather conditions.



Easy installation and zero maintenance.

The light and compact design provides for safer installation and allows KickStart to be installed in a variety of locations, with no regular maintenance required after installation.

A simple change can make a big difference.



NOT

WHEN YOU HAVE KICKSTART.



battery is supplying energy to other electrical equipment) and a Crank Period (high energy discharge is required to turn over the engine to start).

If battery is not at an adequate State Of Charge (SOC) level at the time of the Crank Period, the engine most likely will not start and locomotive will not perform its primary function of moving freight. Therefore, the most important aspect of battery energy management should be focused on achieving the appropriate SOC at the time of the engine crank.

State Of Charge

The measurement of the SOC of a Lead Acid (LA) battery is complex. It cannot be directly measured without completely draining the battery and measuring the energy output; we have to use estimation techniques to determine the SOC. One of the most commonly used methods of estimation of the SOC of a single cell lead acid battery is by measuring it's voltage (Figure 1)

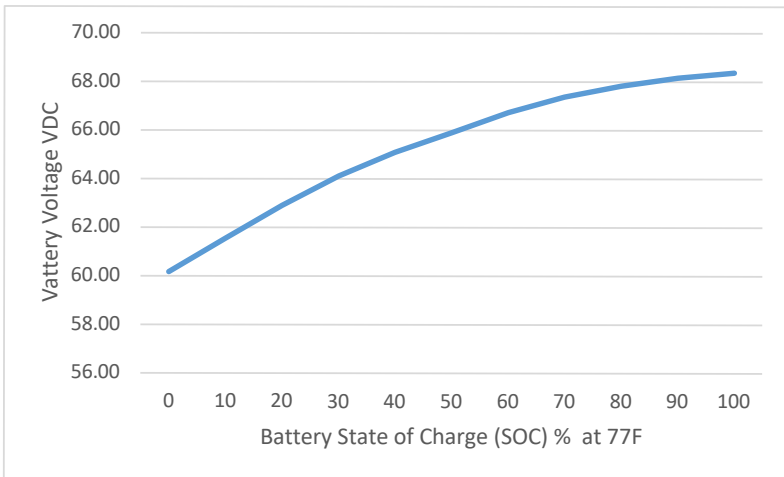


Figure 1: LA Battery Voltage vs SOC

While the battery voltage provides a fairly accurate indication of the SOC in ideal temperature conditions, lead acid battery performance (both the ability to accept the charge as well as the discharge) is considerably affected by the temperature of the electrolyte (Figure 2):

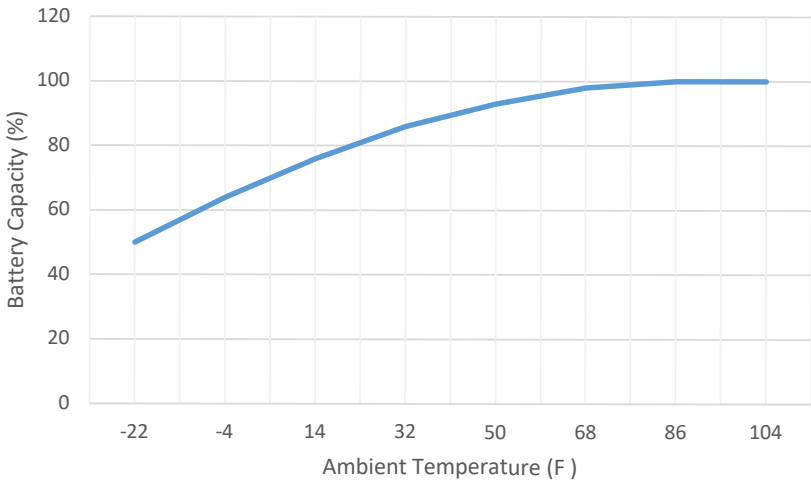


Figure 2: LA Battery Available Capacity (%) vs Ambient Temperature (F)

The effects of temperature and deficit charging are superimposing. For example, if a battery is at 80% SOC and ambient temperature is 32F, the overall battery capacity of 80% is reduced by the temperature factor of 85%, therefore resulting in an overall available capacity of $0.8 \times 0.85 = 68\%$.

Another important factor is the quality of electrolyte. The accuracy of any method of estimating SOC is based on the assumption that batteries have undergone the proper maintenance and have the correct quality of electrolyte in them.

Achieving any practical accuracy of the SOC of a battery requires reliable and accurate measurement of voltage, internal electrolyte temperature and electrolyte quality. A continuous measurement of these parameters is highly impractical and extremely costly, especially considering the need to monitor 32 active cells on any given locomotive.

Another possible method of measurement of the SOC is direct energy measurement. Battery energy level (and consequently, its SOC) can be assessed by measuring energy flow in and out of the battery. This method, however, has its own complications. It is susceptible to error accumulation over time and requires periodic recalibration. It does not automatically work if the battery is replaced and it is affected just as much by the temperature and quality of the electrolyte.

As a result, the most practical method currently used is based on the terminal voltage measurement of the entire battery and temperature measurement in the battery compartment. This method assumes that battery has been properly maintained and quality of the electrolyte is within the manufacturer's specifications.

Battery Charge

One of the most important aspects of managing battery energy and health is to have a fully charged battery at the time of engine shutdown. A deficit charging scenario, when batteries do not achieve a fully charged state before engine shutdown, can lead to significant deterioration in performance of the batteries and permanent internal damage (Figure 3).

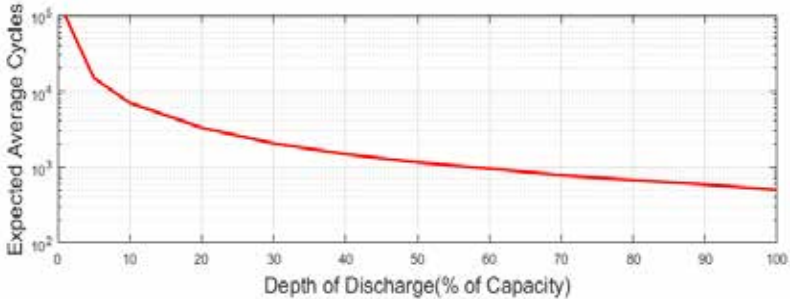


Figure 3: Life expectancy (number of cycles) vs. Depth Of Discharge¹

Continuous operation of the battery at SOC below 80% can lead up to 50 times shorter life span of the battery and possible irrecoverable damage to the battery plates. However, extending engine idle to ensure proper battery charge without knowing when it is fully charged would lead to unnecessary and excessive fuel burn.

New emerging technologies, such as ENERPRO 3-stage battery charging controller and ZTR REMEDY, provide optimum charging sequence for the battery. This ensures that the battery reaches its full charge in the fastest possible time, therefore improving battery performance and reducing the need for unnecessary idle.

And this is the pinnacle of the problem – battery health (and availability of the locomotive) and fuel conservation are at odds. Solving this problem will require a compromise, a trade-off between fuel savings and battery health. It is possible to calculate loss of fuel savings and plot them against life span of the battery (or the cost of ownership of the battery), but such analysis will have to be specific to the operating environment and conditions.

A more generic approach to solving this problem could be based on common sense. A good balance between fuel savings and battery life span could be achieved by reducing Depth Of Discharge during discharge periods, and by shortening the amount of time that is required to reach full SOC.

¹ An Overview of Different Approaches for Battery Lifetime Prediction, P. Zhang, F. Zhang, J. Liang, May 2017, IOP Conference Series Materials Science and Engineering

New sophisticated 3- or 4-stage battery charging technologies, such as ENERPRO LVR31/VR31 modules, provide optimal battery charge control based on a multitude of various parameters. These technologies can achieve up to 40% reduction in charging time while ensuring batteries are charged in the most optimal way.

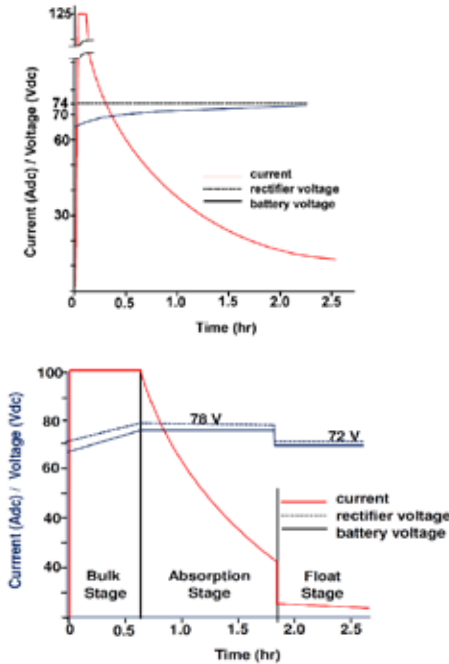


Figure 4: Charging Profile Single Stage (top) vs Three-Stage (bottom)²

Slow Discharge

While the engine is off conserving fuel, the battery is supplying energy to a variety of circuits on the locomotive, such as lights, headlights and other equipment. While some of the loads can be disconnected, as it is being done by stand alone products like Load Shedder and Battery SAVER, some loads have to be powered due to operational or safety requirements. With the addition of PTC equipment and data off-boarding devices, these “hotel” loads on average reach 15-20 A and peak at 50A of continuous current. Although it does not sound like much, the consequences of it are much greater at the starting and charging periods.

2 Source: ENERPRO Inc

The dependence of the lead acid battery voltage on the SOC creates a non-linear relationship between SOC and battery's ability to perform necessary work. As seen in Figure 1, as the battery voltage is approaching 62 V (a common re-start point for AESS systems) the battery SOC is becoming dangerously low and the battery can no longer overcome the impedance of the loads and deliver the necessary current to turn over the engine. In some cases, battery voltage drops far enough during crank that other electrical and electronic equipment resets, leading to a crank failure.

A deeper discharge of the battery during engine shut down also means it will need longer time to re-charge after engine re-start. This can significantly increase the idle time increasing fuel usage even more.

To provide solid engine crank, the engine should be restarted at the point where the SOC of battery is in it's upper levels of the SOC. The actual optimal re-start point will depend on several factors, such as battery overall health and ambient temperature (Figure 2).

Reducing battery discharge during engine off time, therefore, plays a very significant part in maintaining engine shutdown time.

Engine Crank

Engine crank is the primary purpose of the battery on diesel electric locomotives. It is also the most stressful time for the batteries in every possible way. Extremely high current demands potentially at lower temperatures after a prolonged drain is about as bad as it can be for a battery. Given the criticality of the engine crank to locomotive operation, reducing peak energy draw from batteries could allow batteries to reach lower SOC before requiring a re-start.

Supercapacitor crank assist technologies, such as ZTR KickStart, store substantial amount of electrical energy while the engine is running in its supercapacitor bank. This energy is then supplied to the starting system in the initial and most demanding phase of the engine crank to reduce stress on the battery and provide higher performance at the acceleration stage (Figure 5).

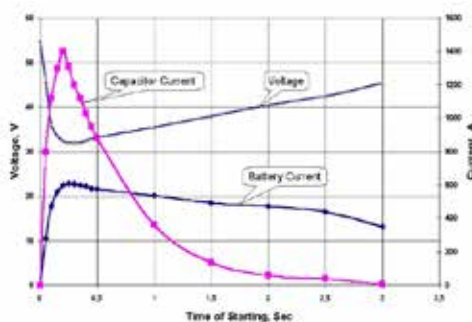


Figure 5: Supercapacitor Assisted Start (right) vs Battery Only Start (left)

This achieves several goals. As seen in Figure 5, the peak current load on the battery is reduced by approximately 30%, which allows the battery to maintain higher voltage during crank and deliver the energy to the starting system. This also reduces depletion of the battery and allows multiple cranking attempts even with a battery with low SOC. Engine Idle required to recharge the battery is also reduced. The supercapacitor bank gets recharged at the same time as the battery and does not require any additional idle time.

Emerging Technologies

Today's world runs on batteries, and new technologies are constantly emerging. It is a very vibrant and dynamic field of research, sponsored by major transportation industries. However, very few of the new technologies are focused on the particular needs of freight locomotives in terms of operating temperature range, maintenance cycles and specific engine crank requirements.

Supercapacitor technologies are also rapidly evolving constantly increasing energy density. Some of these technologies are promising higher energy density than most Li-Ion batteries.

There is also an emerging field of blended technologies combining batteries and supercapacitors into one power storage and delivery system. The aim is to leverage the advantages of each of the technologies and mutually offset their disadvantages.

Recommendations

Managing batteries on locomotives is a complex problem. Battery preservation can negatively affect fuel consumption, environmental impact and railroad operating costs. Therefore, the best approach would be to use a combination of various technologies to achieve the most optimum performance from the critical asset such as a battery without increasing operating costs and fuel consumption.

It is also important to continue investing in the development of new technologies, as they can potentially bring additional performance and cost saving benefits to the railroads.

Report on the Committee on Electrical Maintenance

MONDAY, OCTOBER 4, 2021

2:15 PM



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Amarjit Soora

Senior Manager of Engineering
ZTR, London, Ontario

Vice Chair

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PERSONAL HISTORY

Amarjit Soora, P. Eng

Senior Engineering Manager, R&D and Project Management
ZTR, London Ontario

Amarjit (Am) was born in London England but has spent most of his life in London Ontario, where he went to the University of Western Ontario. After obtaining a Bachelor of Science degree in Electrical Engineering in 1996, Am went to work with the Electromotive Division (EMD) in London. While there he had roles within the Engineering team, including Manufacturing Engineering and the Controls Group.

After three years Am joined ZTR, with whom he has been with for the past 20 years. While at ZTR Am has had several roles within engineering including R&D, Applications Engineering and Product Management. For the past ten years Am has managed various teams for domestic and export development projects, and has also led several long term control system programs.

Am currently lives in London with his wife Kulvinder of 24 years, and his daughter Parveen and son Amit. His passions outside of family and engineering include fitness, photography, soccer and the Indian Classical Instrument the Tabla.

**THE ELECTRICAL MAINTENANCE COMMITTEE
HELD A ZOOM CALL ON JULY 20, 2021
HOSTED BY AMARJIT SOORA
OF ZTR CONTROL SYSTEMS.**

EMD DC Traction Motors – Past to Present

Prepared by:

Randell L. Honc – Southwest Research Institute (SwRI)

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Introduction

DC traction motors were first introduced in diesel-electric locomotives in the 1940s. DC traction motors can provide full rated torque at 0 rpm which was a big improvement over steam locomotives. Many improvements have been made over the years that have increased performance as well as reduce maintenance and operating costs. It is important to understand these changes when replacing traction motors so that locomotive performance is not compromised.

DC Traction Motor Construction

A DC traction motor is composed of a stator and an armature. The stator is the stationary part that does not rotate and the armature is the rotary part that does rotate. Electrical contacts called “brushes” complete the circuit between the armature and the stator.

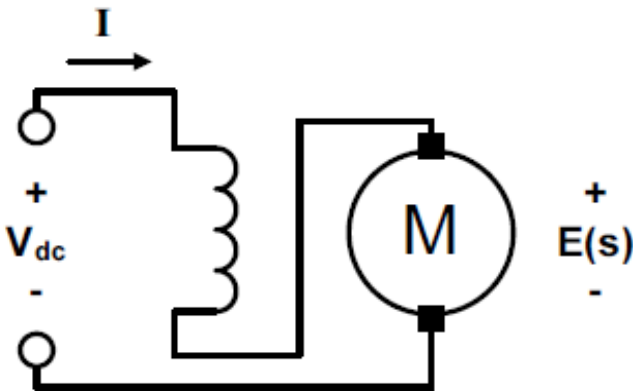


Figure 1. Series Wound DC Motor

Locomotives utilize series-wound brushed DC traction motors. In a series wound motor, the field coils are connected electrically in series with the armature (via the brushes). A diagram of a series-wound DC motor is presented in Figure 1. The field coils can be reversed by switching a contactor to allow the traction motor to spin in the opposite direction.

The field coils and interpoles make up the stator circuit that is presented in Figure 2. The field leads (F and FF) are connected to the field coils. The armature leads (A and AA) wrap around the interpoles and connect to the brush holders. The interpoles are intermediate magnetic poles connected in the armature circuit to offset the effects of armature flux.

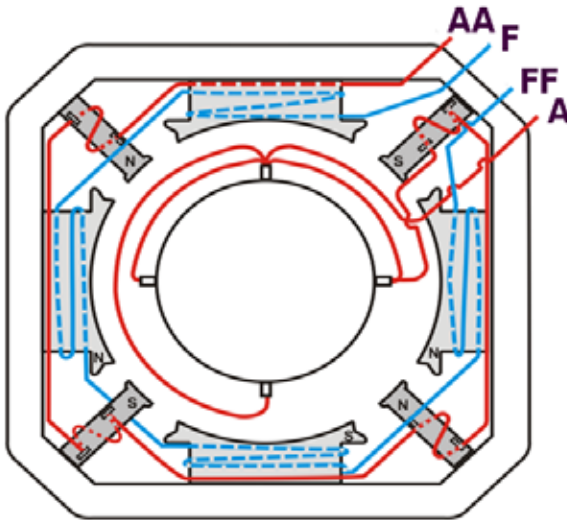


Figure 2. Series Wound DC Motor Stator Circuit

The interpoles aid commutation by:

- Nullifying the effect of armature reaction by creating a compensating electromagnetic force in the interpolar zone, proportional to the armature current.
- Reducing (cancel) sparking between brushes and commutator, thus extending the motor's life.
- Reducing heat developed in the short-circuited coils.
- Reduce damaging back emf that can adversely affect the switch gear and power supply.

The brushes are the interface between the armature and stator circuit. The armature utilizes a rotary electrical switch called a commutator, which reverses



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the current direction between the rotor and the stator circuit. Springs are used to maintain contact between the commutator and brushes. Figure 3 shows the commutator circuit; the lines on the brushes are a wear indicator. The brushes should be replaced when no wear lines are visible in the brush box slot. Brush grades in a motor should not be mixed.

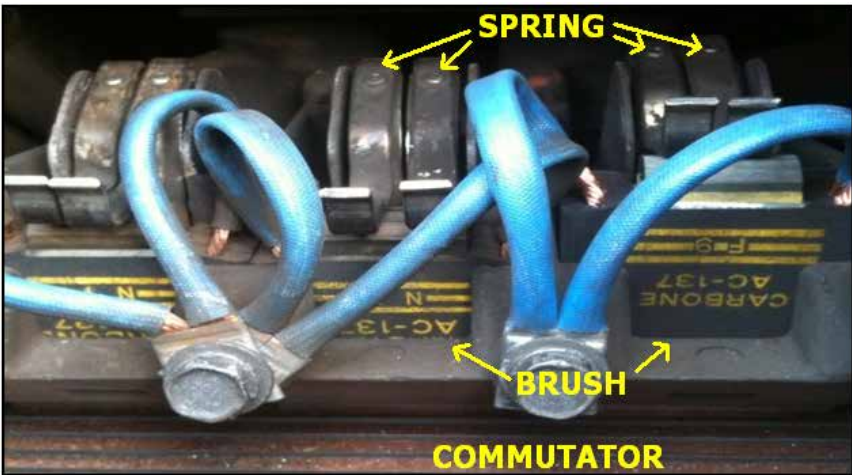


Figure 3. D78 Traction Motor Commutator Circuit

Traction motors are force air cooled by means of an external blower which is typically mechanically driven by the engine. The maximum continuous current ratings of the traction motor are based on throttle N8 engine speed operation. The continuous motor rating is the power and current the motor can steadily produce without overheating. The current should be reduced at speeds below throttle N8 for locomotives with a mechanically driven blower because traction motor cooling air flow decreases as engine speed decreases.

EMD DC Traction Motor History

The development and production of higher horsepower locomotives over the years created the demand for higher and higher horsepower traction motors. The development of the D87B motor, with its high continuous current capability and peak power rating of 623 kW from the early 1940's D7 motor with its 260 kW peak power rating, were accomplished within the same physical dimensions. Today's D87B motor is similar in appearance and of the same general size of the 1940's D7 traction motor. The D87B motor, first used in the SD60 locomotive, in fact will fit physically into the first FT locomotives as well as in-between locomotives. The EMD DC traction motor history is presented in Table 1.

Table 1. EMD DC Traction Motors

Traction Motor	Continuous Rated Current (Amps)	Continuous Rated Power (kW)	Locomotive Type	Cooling Air Requirements (CFM)	Years
D7	700	260	FT	1900	1940-45
D17	700	284	F3	2100	1946-49
D27	825	284	F7, GP7	2400	1954-60
D37	900	310	F9, GP9	2600	1959-63
D47	900	317	GP18	2600	1959-63
D47	900	350	GP20	2600	1959-62
D57	980	350	GP30	2800	1962-63
D67	1000	357	GP35	2800	1963-65
D77	1050	357	GP40+	2800	1965-
D78	1050	357	Backward Compatible	2800	1980-
D87	1170	364	GP/SD50	2800	1980-85
D87B	1206	379	SD60	2800	1984-95
D90	1230	535	SD70/M	2800	1993-2004
D100	1230	535	SD70M-2	2800	2005-11

D77 Traction Motor

The D77 traction motor was first produced in 1965 in conjunction with continued development of higher horse power locomotives. With the introduction of Polyimide thin film as high temperature insulation for the armature coils, the armature coil cross-sectional area was increased by 18%. This increase in armature coil copper, coupled with other improvements increased the peak power of this motor to 534 kW versus 435 kW rating of the previous D67 motor. The peak power is what the motor will produce if connected directly to rated voltage. The continuous motor rating is the power and current the motor can steadily produce without overheating. The continuous current rating was also increased by 5% to 1050 Amps from 1000 Amps.

D87 Traction Motor

The D87 traction motor was first introduced in 1980 for GP-50 and SD-50 locomotives. Significant changes were made to the previous model D77 motor to increase the current capability and horsepower rating. The most significant change

to the armature was the use of so called 'Transposed' coils. The armature coil conductor is made up of two parallel coated straps 'transposed' at the center of the armature core slot. In this 'transposed' construction, each strap is at the bottom of the coil for half of the slot length and at the top of the coil for the remainder of the slot length. This type of coil arrangement reduces the copper eddy current losses and hence the reduction in total armature temperature which could be up to 25°C under certain conditions and thereby increase insulation life. The transposed coil arrangement is shown in Figure 4.

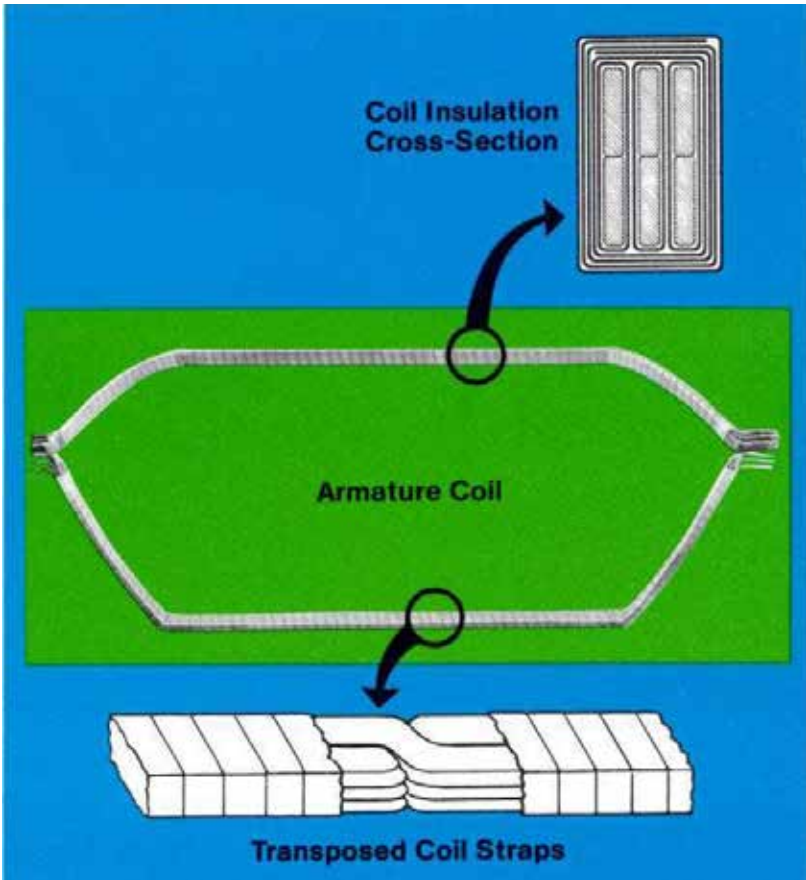


Figure 4. Transposed Coil Arrangement

The series main field coil of this motor contain 16% more copper than the D77 field coil. To reduce the excessive temperature rises due to high current levels, the D87 main field coil is redesigned into a two layer 'step' configuration where the bottom layer has nine turns while top layer has 7 turns of copper conductors. This 'step' configuration produces a large exposed coil surface for efficient heat transfer from the copper to the cooling air. The commutating field coil is also redesigned to have 17 turns instead of 14 turns of the previous D77 coil to improve the commutation at high current levels. This design also results in a more even brush current distribution and longer brush life even at high current and high horsepower condition.

Due to the higher current capacity and higher horsepower rating, the operating load of this motor also became heavier. To accommodate the heavier operating loads and to increase the bearing fatigue life, the pinion end bearing of this traction motor was changed to 150mm from 130mm in the D77 traction motor. The dynamic load rating of this motor is 35% more than that of a D77 traction motor bearing. The Pinion End of the armature shaft was redesigned to accommodate this bigger bearing. The Pinion End bearing assembly parts were also redesigned to suit this bearing.

With these changes in motor design and construction, it was possible to increase the continuous current rating to 1,170 Amps and peak power rating to 623 kW.

D78 Traction Motor

The D78 traction motor is same in design and construction as a D77 traction motor except the armature is wound with a D87 style 'Transposed' coils. Use of 'transposed' coils in this motor enables the armature to operate at lower temperature and a cooler running armature extends the insulation life. It has the same continuous and peak ratings as the D77 and the same 130mm pinion end bearing. The D78 armature should be stamped "D78" on the core at the commutator end and marked with a 2" wide green stripe around the center of the core. The D78 armature identifiers are shown in Figure 5.

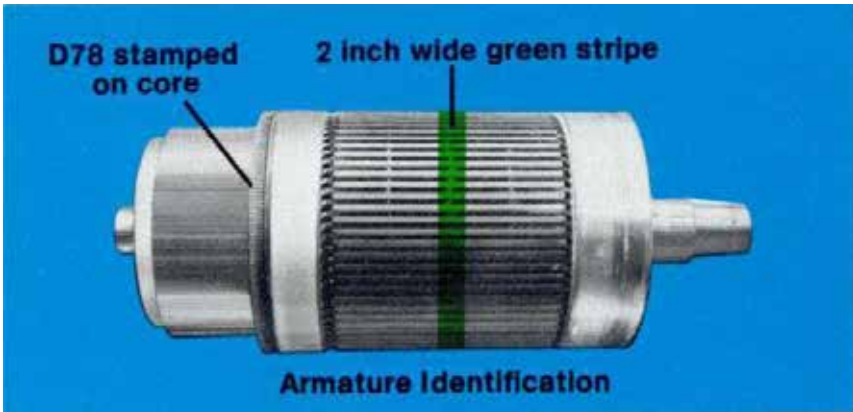


Figure 5. D78 Armature Identification

D87B Traction Motor

With the continued development and production of higher horsepower locomotives, the need for higher horsepower traction motors increased. The D87B traction motor was first introduced in 1984 for SD60 locomotives. This motor is the same as the D87 motor in design and construction except for some changes in armature construction. To accommodate the higher continuous current rating, the cooling air flow was redistributed and more air flow was diverted towards the armature. The air vent holes in the armature core were increased to 56 holes from 32 holes in the D87 and the diameter of the vent holes was reduced from 7/8" in the D87 to 5/8" in the D87B. The quill fit diameters and hence the quill bore were increased to minimize the shaft deflection due to higher loading. This also eases the transition of the shaft diameter to a larger bearing journal on the pinion end. The D87B axle caps were redesigned to increase the suspension bearing lubricant cavity to increase the maintenance interval.

The brush holders in the D87B were redesigned to receive four brushes instead of the three brushes in the D87 traction motor. The brush sizes are also dimensionally different. The continuous current rating of this motor was increased by 3% to 1,206 Amps. The peak power rating remained the same at 623 kW. A comparison of the various traction motors is presented in Table 2.

Table 2. Traction Motor Specifications

	D77	D78	D87	D87B
Continuous Rated Current (A)	1050	1050	1170	1206
Continuous Rated Power (kW)	357	357	364	379
Peak Power (kW)	534	534	623	623
Resistance @ 75°C				
Stator Field Coils (Ω)	0.00876	0.00876	0.00799	0.00799
Commutator Field Coils (Ω)	0.00652	0.00652	0.00642	0.00642
Armature Coils (Ω)	0.0123	0.0120	0.0120	0.0120
Armature Coil Type	Split Conductor	Split Conductor Transposed	Split Conductor Transposed	Split Conductor Transposed
Turns of Stator Field Coil	16 Turns 8 Top 8 Bottom	16 Turns 8 Top 8 Bottom	16 Turns 7 Top 9 Bottom	16 Turns 7 Top 9 Bottom
Turns of Commutator Field Coil	14 Turns	14 Turns	17 Turns	17 Turns
Pinion End Bearing Size (mm)	130	130	150	150
Number of Brushes	3	3	3	4
Size of Brushes	2 7/16 × 2 × 5/8 "	2 7/16 × 2 × 5/8 "	2 7/16 × 2 × 5/8 "	1 11/16 × 2 × 11/16 "

D90/D100 Traction Motor

The D90 and D100 traction motors were introduced in the DC versions of the SD70 series locomotives. The SD70 series locomotives produced 4,000 to 4,300 horse power versus the 3,800 horse power of the SD60 locomotive. The D90 traction motor was introduced in the SD70 and SD70M locomotives. The D100 traction motor was used later in the SD70M-2 locomotives. Both the D90 and D100 traction motors are rated for 1230 amps of continuous current and 535 kW of continuous power. The D100 has an improved armature over the D90 that provides better cooling.

Traction Motor Replacement

Beginning with the SD60 and introduction of the D87B traction motors, EMD implemented a computer controlled traction control system. The EM2000 locomotive control system was introduced in the SD70 series locomotives. The computer monitors traction motor current and throws a fault when exceeded. The engine is also derated to prevent damage to the traction motor. However, individual traction motor control is unavailable in dc locomotives so all the traction motors are derated. So a weaker traction motor can affect the operation of the other traction motors as well. So a certain amount of caution should be used when replacing a traction motor.

Table 3 contains a conservative approach to which traction motors should be used in different locomotives. This is especially the case for the SD60 and SD70 locomotives with computer controlled traction motor control systems. While the case could be made that the SD50 locomotives could use either the D87 or D87B traction motors, it should be noted that the brushes are totally different for these two traction motors which could present logistical problems.

Table 3. Traction Motor Replacements

	D77	D78	D87	D87B	D90	D100
Earlier	X	X				
GP/SD50			X			
SD60				X		
SD70/M					X	
SD70M-2						X

However, upgrading Dash 2 and earlier to a more powerful traction motor may be an option especially if the locomotive does a lot of dynamic braking. The D78 traction motor has the same ratings as the D77 but runs a lot cooler as shown in Figure 6. This is the result of the transposed coils introduced in the D87 traction motors and retro fitted into the D87s.



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Locomotive Battery Maintenance Best Practices

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Introduction

The railroad industry has experienced an increase in locomotive no starts, line of road failures, increased spending on batteries, and reduced life cycles. Proper maintenance and operating practices can help alleviate these conditions. Understandably, the human factor can also influence, but this paper focuses on the best battery maintenance practices and operational practices that have proven to increase battery life and performance. These efforts have a direct correlation with the performance and availability of locomotives. Today's demand for horsepower is quickly changing for network planning teams. Mechanical fleets need to be able to respond to the changes and demand for network horsepower. Some railroads experience battery failure as a secondary failure to another issue, but for others, it is a primary failure mode; both of which impact battery life cycle and locomotive availability. Railroads have had success in implementing these best practices resulting in properly maintained locomotive batteries.

This paper identifies two main practices that impact battery life and performance. 1) Material management and maintenance from the receiving dock to installation onto the locomotive; 2) locomotive operational practices at yards. As a result of these practices, railroads have realized three key factors that can be measured and monitored for further success. Lastly, this paper will focus on common higher horsepower locomotives. All practices can be applied in part or in full for all locomotive battery manufactured types. We recommend consulting with the battery manufacturer for more detailed specific parameters or criteria.

Overview:

- Receiving dock practices
- On-board / yard practices
- Conclusions
- Recommended actions

Acronyms and Definitions

AESS	Automatic Engine Stop Start
SOC	State-of-Charge
FIFO	First In First Out
OCV	Open Circuit Voltage
SPWS	Single Point Watering System
LUGO	Laid Up Good Order
EC	Engine Control
EFCO	Emergency Fuel Cut Out

Receiving Dock and Warehouse Practices

Locomotive batteries can be received as new or repaired. Visual inspections should be conducted to ensure the battery has not been damaged in transit. Once qualified as a good battery, all batteries should be handled with a FIFO process. First in, first out process allows the oldest batteries to be applied first vs applying batteries that are newer, while older batteries remain in the warehouse. This practice requires zero investment, but also requires process awareness or sometimes changes to a process.

Opportunity charging of batteries upon arrival is another way to ensure quality batteries are applied to locomotives in the shop. Applying a float charge after visual inspection ensures the battery is being maintained regardless of duration at the warehouse. Battery manufacturers have parameters for charging recommendations depending on number of days and environmental temperatures.



Fig 1

Figure 1 above- this railroad applies a float charge upon arrival - the batteries are kept at optimal SOC intended for install.

Another best practice to maintain batteries is to rotate batteries through a system designed to determine the health of the battery off the locomotive. These systems are designed to determine the health of the battery and will be discussed later in this paper.

Lastly, the locomotive batteries should be stored with protection from excessive high temperatures. Storing locomotive batteries outdoors in high temperatures will decrease the life of your investment. Figure 2 and 2a below, show an example of proper storage inside and protected from the sun.



Fig 2



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RBS sales are managed by Transportation Products Sales Company (TPSC).



Fig 2a

Locomotive On-board and Yard Practices

The locomotive is quite the investment for a railroad and one of the areas for damage is the battery box tray and enclosure. Figure 3 depicts the common occurrence of improper watering and results of improper watering. Rust and corrosion is accelerated by the over spill of acid that can occur while adding water to the cell of a locomotive battery. While this condition is not desired for the locomotive, it also presents a list of hazards associated with acid, specifically with craft personnel coming in contact with the acid themselves. Furthermore, improper watering has a negative impact on the health and life of the battery.



Fig 3

Locomotive inspections schedules include watering the battery. Modern locomotives are designed with a hatch in the floor of the carbody to access each battery.

Even with these designed carbody openings, it is cumbersome to water each cell properly. The best practice for modern six (6) axle locomotives is to access the top of the battery through the carbody hatch. If the locomotive is not designed with this access point the battery side cover can be removed to access the top of the battery and utilize the single point watering system connection point. A single point watering system uses valving on all 16 cells to ensure each cell receives only the prescribed amount of water the battery was designed for. (Figure 4) The safety benefit is that the risk of craft potentially overfilling a cell and spilling acid is greatly reduced.



Fig 4

The single point watering system can be easily installed on a service track or can be installed at the battery manufacturer. Railroads have found battery watering and maintenance records are conducted with higher success rates because it is easy to do compared with the traditional method. Once SPWS is installed on the battery it remains on the battery, as part of the locomotive battery system. Railroads have learned that despite shop records showing a watering event was completed, in reality this was that it was not occurring. This was due to the added work of watering a battery manually. The SPWS requires the battery box covers to be removed for those locomotive models without carbody access provisions. For those locomotive models with carbody provisions to access the battery the battery

box panels do not need to be removed to water the battery. As a result, the battery can be properly watered with the SPWS installed on the battery.

Service Track inspections can also offer opportunities to water batteries in the correct fashion. It is recommended that watering take place after the charge. Opportunity charging should also take place for unscheduled maintenance in the shops. For example, if the locomotive is shopped for turbo change out, the batteries should be charged and isolated from the locomotive for safety reasons. This practice fosters healthier batteries when the locomotive is released. Releasing a locomotive with a higher known SOC is better than releasing a locomotive that starts with an unknown or low SOC.

Once the locomotive has been released to the yard or regular service, various unrelated conditions can require the locomotive to be shut down. These conditions could include line of road failure not related to batteries, requiring the locomotive to be shut down. The process of shutting a locomotive down can play an important role in whether or not the batteries will be heavily discharged by the time it arrives at the shop. Improper shutdowns are a high frequency reason for heavily discharged batteries.

Education and training for all departments potentially required to shut down a locomotive is one way to communicate the process. Below describes common procedures for 6 axle locomotives. The detail is included here to illustrate the standard known to all potential departments. Disclaimer: this process shows one version of locomotive. Consult with the manufacturer for proper procedure specific to the locomotive and consider any modifications that might have been added to the locomotive. Fig 5 illustrates a typical EC panel.

Sample Locomotive A

1. Place EC switch in the start position.
2. Press EFCO until engine shuts down.
3. Open all uncovered breakers on bulkhead.
4. Open Battery Knife switch.

Sample Locomotive B

1. If engine is running, press “Engine Stop” button under clear protective cover on EC panel. Verify that Engine RPM has reached 0 RPM on screen.
2. Set EC Switch to ‘Start’.
3. Lower all uncovered breakers on Engine Control (EC) panel.
4. Open battery knife switch compartment.
5. Open battery knife switch.

**Fig 5**

On EMD model locomotives that are equipped with Intellitrain, the end user can elect to be notified should the locomotive be shut down manually and the knife switch is in the closed position. By only shutting down the locomotive via the EC panel ECFO or other means and not opening the knife switch, the batteries will be depleted soon. Often when this occurs the locomotive is slated to be moved to shop for diagnostic work or failed component. The problems can cascade quickly if the batteries are depleted upon arrival at the service track and shop. In some cases this will prevent the capability to obtain a download on the locomotive to aid in diagnostic work. This results in higher materials costs because the locomotive needed an unrelated part but now the locomotive also requires new batteries.

Fig 6 illustrates the messaging system. Parameters such as duration of alarm in hours can be adjusted by the end user. This feature has been valuable for the railroads as an aid to educate other departments on the proper shutdown process.

ENGINE DEAD WITH AESS DISABLED KNIFE SWITCH UP FOR THE LAST 6 HOURS
ENGINE DEAD WITH AESS DISABLED KNIFE SWITCH UP FOR THE LAST 3 HOURS

Fig 6

Our industry requires a flexible fleet of locomotives that are able to meet network demand for horsepower. Often, we are forced to store locomotives that may not be in service for months or years after they are in storage. Battery manufacturers recommend to store locomotives without batteries. For today's railroad networks, the reality is somewhere between storing some locomotives without batteries and storing locomotives with batteries. Over time, even without parasitic loads, the batteries will discharge and become fully depleted. In winter months these batteries can freeze and become a hazard when thawed out. Best practice for LUGO locomotives is to store the locomotive without batteries. It has been realized that portable power source can be utilized to check locomotive functions and predetermine locomotive health when returning locomotives to service from storage.

Conclusion

The best practices outlined in this paper are known to maximize battery health and reliability. They are, however, not as effective if implemented as standalone practices. For example, only performing opportunity charging in the shops during non-scheduled maintenance will not have the same impact as the entire program working together and all departments being involved. It is our conclusion that no start events will be reduced, along with reduction in material battery costs and realized increase in battery life cycles.

Recommendations

Cross functional departments and collective awareness can have significant influence on the outcome of any battery program. These departments include Mechanical, Transportation, Sourcing, and joint reliability/utilization teams.

Future recommendation for On-board/yard practices, and prior to releasing the locomotive is to determine a process to identify and remove batteries from entering service on a locomotive prior to returning to service.

1. Good battery with good OCV.
2. Good battery with poor OCV.
 - a. This battery only needs to be charged locally.
3. Bad Battery not suited for service.
 - a. Railroads can elect for repair.

Special Thanks

- LMOA Electrical Committee
- Shane Sledge -NS
- Steve Alessandrini – CN
- Saad Bendriss- Amtrak
- Henry Schafer - BNSF

Remote Control Technology Enhancements

Prepared by:

Rodney Myers – Wheeling & Lake Erie Railway

Mike Fitzpatrick – Making Tracks Media

Jeremy Jovenall – Cattron

Contributions by:

Adam Franco – LocoTrol® Technologies/Wabtec Companies

Dan Sipko – Control Chief Corporation

Remote control had a positive response in crane operation and eventually the technology expanded to locomotives and other machines. General acceptance of this technology increased in the 1970's and 1980's. We, as an industry, have come a long way since then. Remote control has paralleled that advancement.

A major advantage of RCL (Remote Control Locomotive) operation is that the person at the point of movement is the person that is controlling the movement.

Current Year

Fast forward to present year and there are new features available with the advanced technology. For example, GPS location, feedback from the LCU (Locomotive Control Unit) to the OCU (Operator Control Unit), distance of radio signal strength, size and weight of the OCU, just to name a few. There are many other advancements but this paper will cover those listed above. Each vendor has specific options that can be chosen to accommodate the buyer's operations.

GPS Location

GPS based location of the OCU can provide many useful benefits, some of which are:

- Troubleshooting (distance from the locomotive, location of operator)
- Productivity information (used for training purposes, yard layout & improvements)
- Continuously improving to enhance operator safety (training reviews, incident recreation)



Figure 1

Feedback

There are OCU's available that receive feedback from the LCU for the operator to use for their benefit. This can be either an LED light on the OCU or a digital message across the LED screen.

When the operator requests a BP (Brake Pipe) command (for instance), the LED is yellow on the OCU. When the LCU completes the command the OCU LED turns green.

Some OCU's offer a readout of key status values such as speeds, pressures, brake pipe air flow, etc. (Figure 2)

- As an example, viewing brake pipe air flow in Cubic Feet per Minute (CFM) allows you to do an initial terminal air brake test via the Air Flow Meter method as prescribed in CFR 232.205

Most RCL systems provide feedback information to the crew through recorded messages over the locomotive cab radio.

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Figure 2

RSSI (Receive Signal Strength Indication)

Remote control mainly works off radio signals from the OCU to the LCU and from LCU to OCU. The strength of this signal will determine how far away the RCO (Remote Control Operator) can be from the locomotive they are controlling. There are some factors that can hinder this communication:

- Low RSSI readings (faulty equipment)
- Obstructions (buildings, stone piles, cars)
- Weather (storms, cloudy)

Installation of repeaters can help with most of these. Repeaters are antennas placed strategically in areas that take the signal from the OCU and amplify it and pass it along to the LCU.

With the new technology available the signal strength can be stronger without making the equipment larger.

RSSI vs. Distance example:

- Although many variables affect RSSI, a general range of values can be established for a radio system.
- RSSI can be monitored at a receiver, which is part of the LCU and most OCU's.
- An abnormally low RSSI reading for a given range is a sign of obstructions, equipment tuning problems or hardware failure.
 - RSSI can be a critical piece of data when monitoring RF performance.
 - RSSI paired with equipment location through GPS coordinates can be even more valuable

OCU's – various brands and sizes



The size and weight of OCU's has greatly improved throughout the years. The newer OCU's are approximately half the weight (or more) than OCU's from 20 years ago. Along with that comes improved reliability.

Vendor #1 OCU

Recent Model Hardware Improvements

- Reduced to nearly half the weight of original models
- Ergonomic and designed for harsh rail yard environment
- OCU tracks activations of individual switches for reliability monitoring and preventative maintenance purposes.
- Modern battery technology increases run time
- Modern radio technologies such as Bluetooth and WiFi are available
- Newer model OCU has shown increased mean time between failures
- When possible, based on RF band, internal antenna reduces failure points and potential catch hazards
- RF performance increase over previous models
- Embedded GPS receiver enables OCU to send its position to RCL system
- Internal archive logs all internal events, switch changes, inputs and outputs, which can be accessed over Bluetooth
- Requests and feedback shown through LEDs or multiline OLED screen
- OCU can be temporarily 'locked' to prevent accidental movement commands, while retaining tilt protection and other key safety features
- Most software updates occur over Bluetooth connection, but minor changes can occur during IR assignment to RCL

Vendor #2

Recent Enhancements

- 2021 Software: Speed Controller enhancement: Automatic Direct Throttle Control to improve responsiveness
- Next Generation RCL Platform: Alt/Dual Locomotive to OCU communication with LXA (Locotrol eXpanded Architecture) based yard RCL LTE, Bluetooth, WiFi (LTE cellular, Bluetooth, WiFi)
- 2021 Software Feature: Event logging, GPS man down, One button software download
- 2021 Software features: 24hr unlink timer extension, Maintenance Mode
- Next Generation RCL Platform: Improved reliability less than 1 FLY (Failure per Locomotive Year) on LXA
- OCU-3: Enhanced display



OCU-3: Asset Management-through the Zebra device**Shipping cases to prevent damage in transit**

- Common OCU for both yard and road RCL
- Software for Remote Maintenance Mode
- Software for Brake Test for RCL
- Software feature: manual bail
- RCL enhanced speed controller is designed for long heavy trains with the incorporation of proprietary auto DB

Safety over the last 10 years

YEAR	CAUSE CODE	OCCURRENCES	Estimated Hours of Usage (one vendor reporting, Class 1 only)
2020	E76L	0	1,765,000
2019	E76L	1	1,840,000
2018	E76L	0	1,571,000
2017	E76L	0	
2016	E76L	2	
2015	E76L	2	
2014	E76L	0	
2013	E76L	2	
2012	E76L	0	
2011	E76L	0	

- FRA Accident Cause Code E76L – remote control equipment inoperative
- Most faults were induced by brake application during a push move which caused derailment
- <https://safetydata.fra.dot.gov/OfficeofSafety/publicsite/FormsPub.aspx>
- (the last column was added by 1 vendor to show how many hours of operation per year for a Class 1)

Conclusion

Technology improvements have provided RCL operation enhancements in safety, productivity, ease of use and maintenance. OCU technology growth will continue this enhancement trend.



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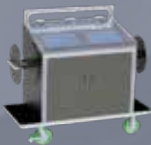
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Report on the Committee on Facilities, Material & Support

TUESDAY, OCTOBER 5, 2021
8:30 AM



Chair

Bob Harvilla
(LMOA Past President)
Vice President- Sales
PowerRail Incorporated
Duryea, PA

Committee Members

Dustin Berndt	VP of Motive Power	Reading and Blue Mountain Railroad	Port Clinton, PA
Ron Delevan	Technical Manager-Traction	Morgan Advanced Products	Greenville, SC
Brian Gessel	Supply Chain Manager	CSX Corporation	Huntington, WV
Michael Hartung	Supt of Locomotive Material	Norfolk Southern Corporation	Roanoke, VA
Robert Hodge	Plant Manager	Industrial Maintenance & Engineering	Nashville, TN
Steve Hulshizer	Manager Loco. Material Quality	BNSF Railway	Fort Worth, TX
Craig Opacic	Sales & Business Development	R&W Machine	Bedford Park, IL
Bill Peterman	Director-Operations	BP Railway Services	Pierrefonds, Quebec
Brandon Teal	Product Mgr-Wheel Truing and Reprofiling Machines	NSH USA Corporation	Albany, NY
Tad Volkmann	Chief Consultant	TADCO Railroad Consultants, LLC	Omaha, NE
Michael Zerafa	VP-Business Process	PowerRail, Incorporated	Duryea, PA

NOTE: Brandon Teal took over as new chairperson of this committee on May 2021.

PERSONAL HISTORY

Bob Harvilla

Bob Harvilla started his career with General Electric in 1973, and had a total of 22 years with GE in various Management and Sales capacities. He is currently the Vice President of Sales for PowerRail Inc., responsible for Account Management and Sales at select Class 1 and Shortline Railroads.

Bob and his wife Barb have been married for 44 years. They have two sons (Rob and Ryan) and two grandsons (Max who is 10 and Griffin who is 7). They have one granddaughter (Mirabel) who is almost one year old.

A Comparison of UTEX, Repair & Return, and Fleet Maintenance Process Flows

Prepared by:

*Craig Opacic – Sales & Business Development
R&W Machine Company*

On the surface, the supplier customer relationship is simple. The customer has a requirement for parts or services necessary to support their operation. The supplier has the capability to provide a product or service that fulfills this need. The transaction is initiated by a request for a quotation that contains basic information including price, delivery, and payment terms. Any applicable technical specifications or drawings are provided and taken into consideration when formulating the quote. The customer deems the quotation acceptable and issues a purchase order. The supplier manufactures the items or provides the service required and delivers the component(s). It seems pretty simple.

The complexity comes from which of a number of options the transaction is based. This is especially true for more complicated components. The options include Outright Purchase, Repair & Return, UTEX (Unit Exchange), and Fleet Maintenance, which is sometimes referred to as Core Component Management. Each indicates a distinct expectation on behalf of both the customer and supplier and contributes greatly to customer's satisfaction and supplier performance.

Individual customer requirements dictate best approach. What type of product or service is required? What type of railroad does the customer operate? The needs of a Class I can differ greatly from a Short Line due to differing operating conditions. Are the parts or service for a long-haul application or a yard locomotive? In what type of environment does the locomotive operate? Does the railroad have a core pool to draw from?

Economic considerations are tied into some of the above considerations. What cost to the customer is appropriate for the application? Is the locomotive part of a newer fleet in long haul service that is critical to the railroad's operating plan and therefore quality and life span are key or is it an aging yard locomotive that is used infrequently? What is the railroad's cost of having the locomotive out of service compared to the initial savings of a lower priced product with a lower level of quality?

Communication is key from the inception of the relationship. My comments regarding requirements and economics are stated in the form of questions. This is intentional. It is critical that the supplier understands and the customer communicates their expectations from the outset. Can the transaction be fulfilled without a clear understanding of the situation? Yes, it can. Does the relationship between the customer and supplier benefit from mutual knowledge afforded by open communication? Most certainly.

Diving deeper into the type of railroad the customer operates can further determine best approach. Class I, Regional, Short Line, and Passenger present different scenarios. Some of the differences include:

- Size of locomotive fleet
- Locomotive mix
- Available resources – shops, personnel, time, expertise
- Geography: Depending on the type of product or service, freight costs can be significant and proximity to the supplier can to a certain extent mitigate this expense.

Communication is a two-way street, and it is important that the supplier provides critical information that can affect their ability to perform to the customer's expectations. This information includes:

- Capacity
- Quality Certifications
- Expertise
- Access to required components

The focus of this paper is on rotatable parts. By definition, a rotatable part is:

A component or inventory item that can be repeatedly and economically restored to a fully serviceable condition. Servicing method in which an already-repaired equipment is exchanged for a failed equipment, which in turn is repaired and kept for another exchange.



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Engine Protectors

Fuel Pumps

Pumps

Water Pumps

Oil Pumps

Lube Oil Pumps

Scavenging Pumps

Air Compressors

Shaft Driven

Motor Driven

Intercoolers

Aftercoolers

Blowers/Coolers

Roots Blowers

Cooling Fans

Turbochargers

Governors

Generators/Alternators

Four unique ways of constructing the transaction between the customer and supplier exist. They are:

- Outright Buy
- UTEX
- Repair & Return
- Fleet Maintenance

Options are always beneficial, unless a lack of understanding creates confusion. The expectations and conditions mentioned earlier determine which approach will work best. The following explores what each option offers.

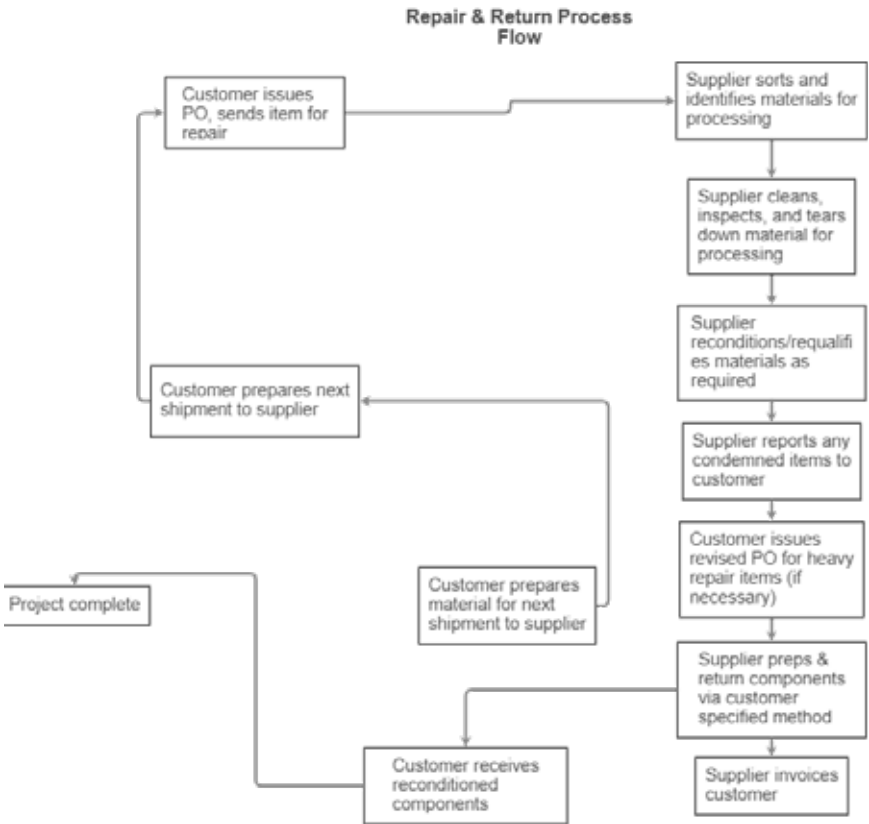
Outright Buy

This is the simplest transaction. Product can be new or remanufactured. All replacement parts are either new or requalified. 100% of the responsibility for quality and delivery is on the supplier. The product should be fully warranted. Core material not necessary. The lead time is dependent on the supplier's shop load and access to material.

The other three options provide scenarios with increased complexity but also increased flexibility that eliminates downtime and lost revenue. The flow charts presented offer an idea of how the organization that I work for handles the process flow.

Repair & Return

This, like outright buy, is a straightforward transaction. The customer's knowledge of the items maintenance history (traceability) and, unlike some of the concerns that customers have with UTEX, is not inheriting someone else's problems. The level of repair can be specified, through either providing a detailed technical specification or agreeing to a level of repair with the supplier. The age of the locomotive and type of service in which the locomotive is used can also be taken into consideration. The allowable lead time should also be considered when determining if Repair & Return is the best fit. The selling price from the supplier is a simple calculation of time and material.





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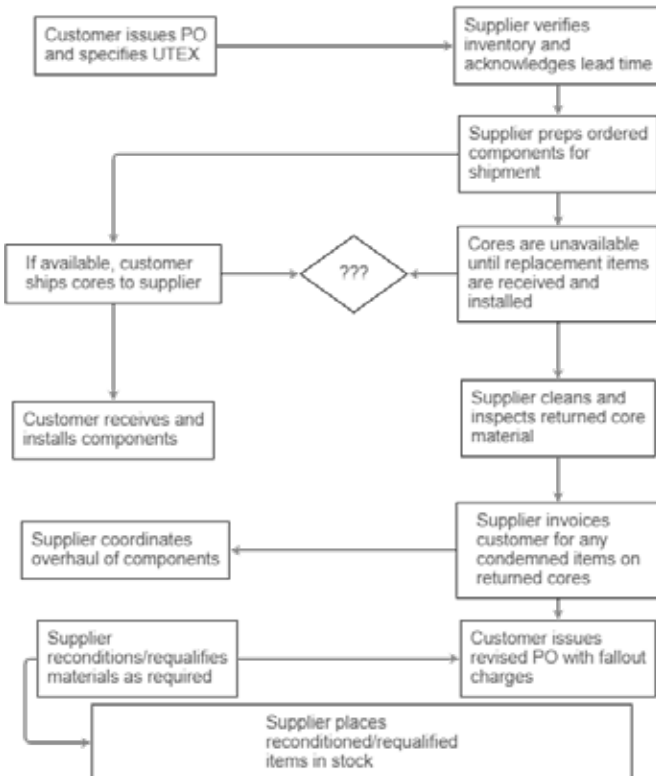
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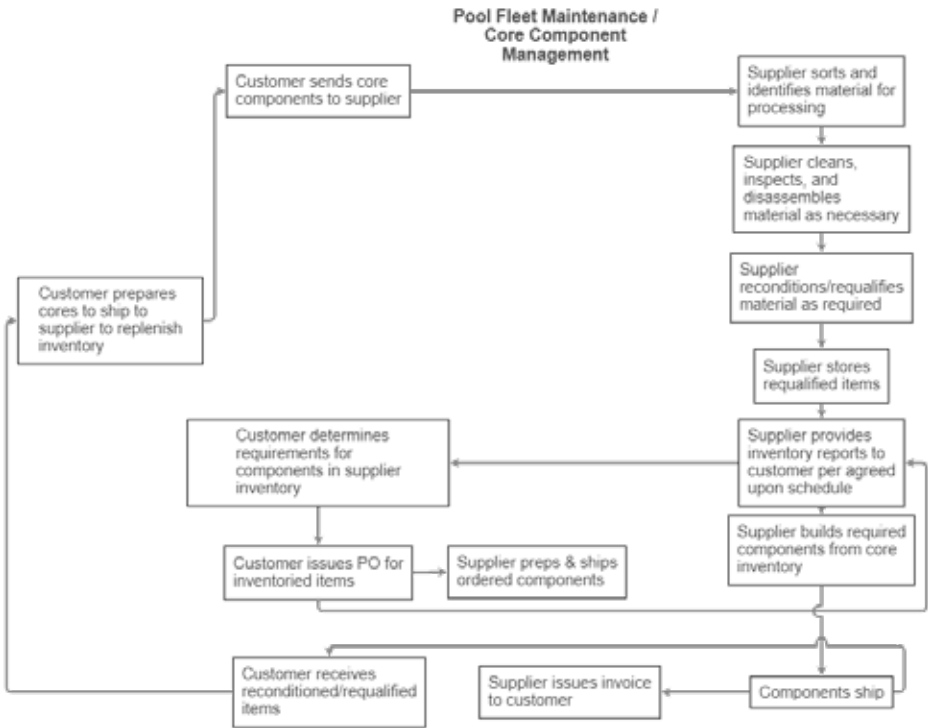
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UTEX

Unit Exchange (UTEX) is applicable when replacements are required and waiting for repair is not an option. In this approach the supplier is responsible for establishing/maintaining core pool. This can be accomplished either by receipt of similar cores from ongoing business with other customers or the purchase of cores from industry sources. While there is some flexibility on the level of repair to be performed by the supplier, the nature of a UTEX arrangement relies heavily on the supplier providing work to an industry standard (AAR) or internal specification. The age and model of locomotive has direct effect on core availability. Newer technology is less likely to have core material available due to time in service and older technology can present a challenge in core acquisition as the population of the locomotive diminishes over time. The cost to the customer has to take into account the condition of the returned cores and parts & labor required to repair. This is commonly referred to as fallout. Different suppliers view this situation differently and different components are more subject to fallout than are some others.

UTEX Process Flow





Fleet Maintenance

This method of facilitating customer requirements is sometimes referred to as Core Component Management. The approach is an enhanced form of Repair & Return with immediate access to item. To utilize this approach, the customer needs to commit to maintaining their core pool onsite at the supplier. The supplier can then react quickly to purchase orders for reconditioned or requalified items from this inventory. The benefits of this arrangement are similar to those of a Repair & Return method. The level of repair can be specified to customer, supplier, or industry standards. As mentioned earlier, the customer knows the history of the requalified or reconditioned component. Cost is based on material and labor. In certain situations where appropriate, the customer/supplier may exchange parts from other core material in the pool in order to minimize the cost of replacement parts for heavy repairs. Another way the railroad benefits is the elimination of the need for some inventory management resources. Periodic inventory reports provided by the supplier are an important part of any Fleet Management program.

Conclusion

The unique requirements of individual customers and capabilities of suppliers need to be understood in order to determine best fit. Understanding the advantages and disadvantages of each method can facilitate a better customer/supplier experience.

Recommendation

Both sides need to clearly and concisely communicate requirements and capabilities so that the appropriate procurement method can be determined and executed. Having these discussions at the inception of the relationship on both sides will avoid problems later.

Report on the Committee on Mechanical Maintenance

TUESDAY, OCTOBER 5, 2021

10:15 am



Chair

John Hedrick

Principal Scientist

Southwest Research Institute, San Antonio, TX

Vice Chair

Eric Dillen

Advanced Engineering Leader

Wabtec Corporation-Frt Divn, Erie, PA

Committee Members

M. Abbott	Product Design Engineer	Hotstart	Spokane, WA
G. Avery	Supintendent Locomotive Fleet	Kansas City Southern Railway	Kansas City, MO
M. Ayette	Engineering Manager	Dayton Phoenix	Vandalia, OH
D. Bellemare	Executive Account Manager	Ekyrail	Chateaugay, Quebec
J. Bink		Kennedy Rail Consulting	
I. Bradbury	President	Peaker Services	Brighton, MI (Past President)
J. Brunson	Sales Manager	Link Up International	Roanoke, TX
T. Casper	Vice President-Operations	PowerRail, Inc.	Duryea, PA
M. Cleveland	Senior Mgr-Emerging Technology	BNSf Railway	Fort Worth, TX
W. Clevenger	Locomotive Operations Manager	Metro East Industries	Fairview Heights, IL
J. Cutright	Contractor	L&J Services	Roanoke, VA (Past President)
J. Dempsey	Manager Railroad Seating	Seats, Inc	Dayton, OH
T. Downey	Product Engineer	Dayton Phoenix	Ann Arbor, MI
A. Duncan	Dir-Diesel Engine Compliance Center	US-EPA	Norcross, Ga
D. fox	President & CEO	ACS Railroad Solutions	Plano, TX
F. Jalili	President	FFJ Independent Business Consultant	Omaha NE (Executive)
T. Kennedy	President	Kennedy Rail Consulting	Broomfield, CO
A. Meek	Manager-Rail Business Dev	Cummins, Inc	Montreal, Quebec
M. Macbeth	CMO-West	Genesee & Wyoming-Canada	San Antonio, TX
D. Osborne	Principal Engineer	Southwest Research Inst.	Chicago, IL
D. Parsons	Senior Manager-Engng.-Diesel	Amtrak	Anchorage, AK
R. Pochatko	Director-Locomotive & Equipment Opns	Alaska Railroad	
A. Pope	Manager-Technical Liaison	Bharat Forge-America	Russell, PA
P. Roach	Vice President-Sales	Interstate McBee	Cleveland, OH
D. Rutkowski	President	JAB Rail Svcs	Davenport, FL (Past President)
C. Shepherd	Chief Mechanical Officer	Arkansas & Missouri RR	Springdale, AR
B. Singleton	Owner	Transpar Corp	Niskayuna, NY
P. Smith	Manager	US-EPA	Ann Arbor, MI
T. Standish	Quality Manager	Progress Rail	LaGrange, IL (Executive)
K. Ulbick	Sales Manager	Peaker Services	Brighton, MI
G. Wilson	Superintendent of Cars	Iowa Interstate RR	Cedar Rapids, Ia
R. Wullschlegler	Chief Mechanical Officer	New York & Atlantic Rvy	Glendale, NY

PERSONAL HISTORY

John Hedrick

Principal Scientist
Southwest Research Institute
San Antonio, TX

John Hedrick has spent over 30 years at Southwest Research Institute (SwRI) conducting research, development and testing on medium speed and high horsepower engines. The focus has been on the effect of lube oil on fuel economy and emissions, facility engineering for a high horsepower large engines, assist in the development of a high-pressure, late cycle, natural-gas injected engine, and worked as a consultant to large-bore/medium-speed engine users in the industrial, marine, rail, and nuclear power plant settings to reduce emissions and determine causes of various engine failures.

Most recent focus has been targeted on performance and emissions related to medium speed engines used in locomotives, stationary power generators, and marine applications. He has also become a Test Inspector for European certification of railroad engines by the International Union of Railroads (UIC 623 & UIC 624 tests). Also awarded eleven US Patents that focus on engines and their supporting systems.

Married to his “Better $\frac{3}{4}$ ”, Peggy and they have two grown sons. Graduated from Texas A&M University in 1989 with a Bachelor’s Degree in Engineering Technology with a focus on Thermal and Fluid Systems.

**SPECIAL THANKS TO PAT ROACH AND INTERSTATE MCBEE
FOR HOSTING THE LMOA MECHANICAL COMMITTEE
SUMMER MEETING AT THEIR HEADQUARTERS IN
CLEVELAND, OHIO ON AUGUST 5, 2021.
THIS MEETING WAS ORIGINALLY SCHEDULED FOR
SUMMER OF 2020 BUT DUE TO COVID-19 TRAVEL
RESTRICTIONS, THE MEETING WAS DELAYED FOR A YEAR.
THEIR CAN DO ATTITUDE MADE THIS MEETING POSSIBLE
AND WAS GREATLY APPRECIATED.**

Crew Comfort for Locomotive Cabs

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Preface

In 1992, Congress passed legislation (PL 102-365), requiring the Federal Railroad Administration (FRA) to complete rule making activities relating to the improvement of safety and work condition in locomotive cabs. The FRA is charged with the task of assessing standards developed by the Association of American Railroads (AAR) on crash worthiness and working conditions that affect safety and productivity.

Noise, ventilation, seating, and cab cleanliness are examples of problem areas that affect crew comfort, safety, and productivity.

HVAC systems for locomotive cabs is a critical component to help keep the crew comfortable and alert. Railroads and OEMs are constantly looking for the best solution.

Multiple cab designs, available HVAC systems, seating systems, budgets, and lack of technical support make it difficult to find the best solution.

“Every-body” is different. Multiple seating configurations and interpretations of seat comfort can cause crew comfort complaints.

This paper discusses noise, climate control, seating solutions, and cab cleanliness.

Background


The locomotive cab has significantly evolved over the past 20 years. Smaller train crews, new technologies like Positive Train Control (PTC), options in seating designs, and climate control systems that will condition and clean the air, affects how train operators perform their jobs.

Evaluating how these new technologies, guidelines, and operating procedures require understanding the operator’s capabilities and limitations in safely performing his or her duties.

Incorporating these features into older locomotives through repower programs is another challenge for designers and engineers. Human factors guidelines can aid in this evaluation.



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Noise

The Code of Federal Regulations (CFR) limits noise to 85 dBA for 8 hours. Continuous level of 75 dBA or less, is desirable for crew comfort. A test was conducted in a new locomotive. Figure 1 shows the different areas of the cab where noise was recorded. Sound data was recorded in each of the four positions during the three tests. A sound meter was located 56” above the cab floor, at each location, during the test. Figure 2 shows decibel ranges inside the cab with the locomotive engine running at idle and the air conditioner operating in each of the 3 modes.

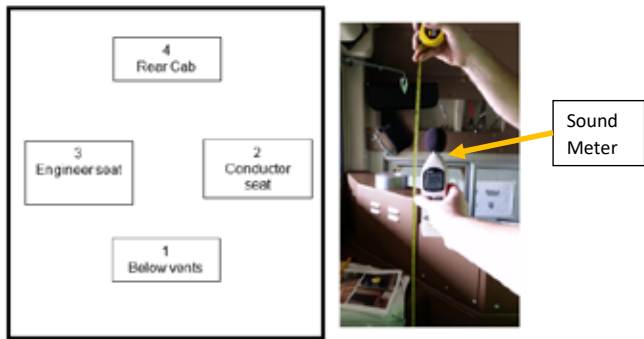


Figure #1 Areas of the cab where sound was recorded

Test 1 – HVAC in high cool mode	Test 2 – HVAC in low cool mode	Test 3 – HVAC off
Location 1 = 83 db	Location 1 = 80 db	Location 1 = 74 db
Location 2 = 80 db	Location 2 = 80 db	Location 2 = 78 db
Location 3 = 82 db	Location 3 = 80 db	Location 3 = 70 db
Location 4 = 83 db	Location 4 = 78 db	Location 4 =

Note: locomotive engine was shutting down during test 3 at location 3.

Figure #2 Decibel ranges inside the cab.

As shown in figure 2, the noise level was above the limit for crew comfort.

Different types of HVAC systems for different types of locomotive cabs

There are many different types of locomotive cabs and HVAC systems. Each have unique duct systems, performance ranges, and maintenance cycles. Newer US freight locomotives and repower cab designs are moving toward underfloor systems while export freight locomotives use rooftop systems. The most popular cab and HVAC combinations are shown in Figures 3, 4, and 5. Figure 3 shows the safety cab, underfloor, design with HVAC systems for EMD and GE cabs. Figure 4 shows Dash 8 / Dash 9 cab design with the Sidemount HVAC system. Figure 5 shows the standard cab design with rooftop HVAC systems.



underfloor HVAC
for EMD



underfloor HVAC
for GE locomotive

Figure #3 Safety Cab with Underfloor HVAC System



Sidemount HVAC
GE cab only

Figure #4 GE Dash 8, Dash 9 cab with Sidemount HVAC System



Rooftop HVAC system



Rooftop AC system

Figure #5 Standard cab with Rooftop HVAC System

HVAC Installation and Duct Design: OEM vs Custom

The HVAC air duct layout is critical to air movement, noise, and controlling the temperature inside the cab. The material used in the duct system can also affect how quickly the cab reaches the desired temperature inside the cab. Figure 6 shows the air duct system for an SD40-2 repower locomotive that was manufactured by a railroad. Figure 7 shows the air duct system for an SD40-2 repower locomotive that was manufactured by the original OEM.



Figure #6 SD40-2 repower by a railroad

Figure #7 SD40-2 repower by OEM

The air duct in figure #6 has more restrictive air flow to the evaporator in the HVAC. This design will cause less conditioning of the air and cause the blower to work harder.

Example of custom air duct design issues in a new cab.

The cab shown in figure 10 was designed by a railroad. During locomotive testing, the technicians noticed the cab was not cooling down and the HVAC system would shut down after 20 minutes in operation. Several issues were identified during the investigation: The air inlet duct was too small and restricted air flow into the cab, the louvers for the return air in the cab was too restrictive and caused the HVAC system to shut down due to low pressure, and the air duct design allowed more air flow to the toilet compartment which resulted in a warmer cab area.

Figure 8 shows the small return air filtration unit. OEM air filtration has an open area of 245 sq/in. The design shown in Figure 8 has only 25 sq/in. Only 550 CFM of air flow was measured with this design. To address the problem, the louvers were replaced with a screen to allow more air flow to the HVAC (Figure 9). The updated design created an open area of 315 sq/in and 971 CFM of air flow was measured. This prevented the HVAC from shutting down due to low pressure.

Figure 10 shows the air duct layout, and the arrows illustrate how each sharp turn in the air duct creates a pressure drop and reduces the amount of conditioned air into the crew compartment. This design channeled most of the conditioned air into the toilet compartment.

To create more airflow into the crew area and less into the toilet area, a more restrictive air vent was installed into the toilet compartment. Figure 11 shows the open-air vent that allowed more airflow into the toilet compartment. Figure 12 shows how the air flow to the toilet compartment was restricted which created more air flow to the crew area of the cab. This allowed the cab to quickly cool and regulate temperature inside the crew area of the cab.



Figure #8 Filter inlet (550 CFM)



Figure #9 Updated filter inlet (971 CFM)



Figure #10. The large to small arrows illustrate the air flow from large to small. Each time the air is forced to turn, the pressure drops resulting in less air velocity.



Figure #11. Open vent allowed more airflow into toilet area and



Figure #12. New more restrictive vent allowed more airflow into the crew

HVAC model comparison

During this study 10 tests were completed with multiple cab and HVAC system configurations. Multiple HVAC manufacturers were also represented in the study. Locomotive build / rebuild dates were from 1978 to 2015. Figure 13 shows the list of locomotives, HVAC type, and manufacturer that was evaluated for this study.

	Locomotive Info	HVAC Info
1	Road #4718. Dash 9, 44 CW	Prime Sidemount, PM5191-2, SN 0698-0189
2	Road #1666. SD 40-2	Coleman Mack Rooftop, model 9330F715, SN 14 08 02458
3	Road #2543. GP39-3 Rebuilt	Coleman Mack Modern Rooftop
4	Road #7390. ES 44 DC. Built '10	DPG 2807800-P22 underfloor, SN G0020 A10
5	Road #2552. SD70. NS loc.	DPG 2806700 Rooftop, SN 364 M14
6	Road #187. GP60	Vapor Rooftop
7	Road #187. GP60	Vapor Rooftop w/ added cab insulation
8	Road #106. GP60M-3 Rebuilt	DPG 22109402 underfloor, SN 1040-F98
9	Road #8511. SD70ACE. Built '14	Mitsubishi underfloor EU401-1
10	Road #3990. ET44C4. Built '15	DPG 2810700-P1 underfloor, SN G391 H15

Figure #13 List of Locomotives and HVACs evaluated for this study

Inspection sheet for each locomotive

An inspection sheet was used during each evaluation. The sheet includes model numbers and Interior cab conditions: missing or broken seals around windows and doors, holes in walls or ceiling. Also included was the HVAC system condition: clean or blocked coils, air flow restrictions and refrigerant level.

ASHRAE temperature guidelines state that during winter months, the temperatures should be between 68°F and 74°F. During summer months the temperature should be between 72°F and 80°F. Relative humidity (RH) should be 30% to 60%. RH above 60% can encourage the growth of mold and mildew. When RH is below 30%, occupants may experience eye irritation, stuffy nose, or aggravated allergies.

A comparison of the rooftop air conditioning models can be seen in figure 14. The two Coleman units took the longest time to cool down the cab. The combined Coleman units also have the lowest CFM of the other units. The Dayton-Phoenix unit cooled the cab down in less time and had a greater temperature drop than the other units. The Dayton-Phoenix unit is specifically designed for locomotive cabs where the other models were adapted to fit locomotive cabs.

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Manufacturer	Time to Cool	Temperature Drop from 100°F
Vapor	34 Minutes	11°F
2 Coleman units	48 Minutes	16°F
Dayton-Phoenix	25 Minutes	21°F

Figure #14 Rooftop AC Comparison

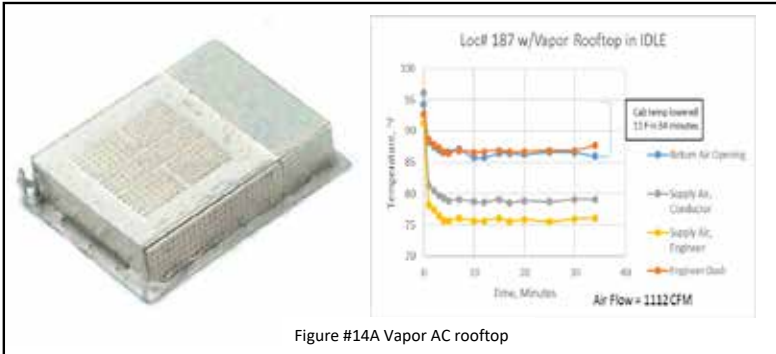


Figure #14A Vapor AC rooftop

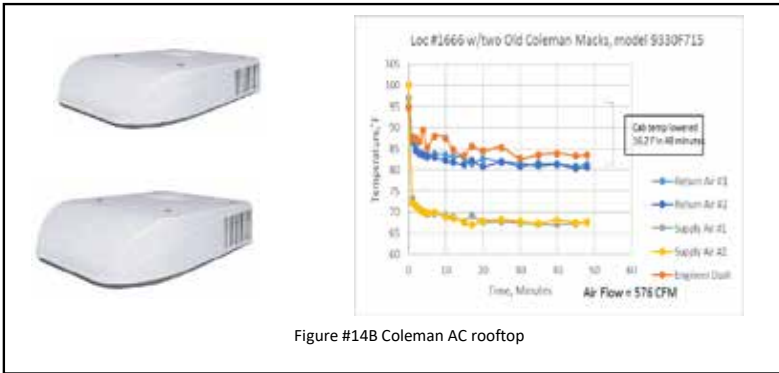


Figure #14B Coleman AC rooftop

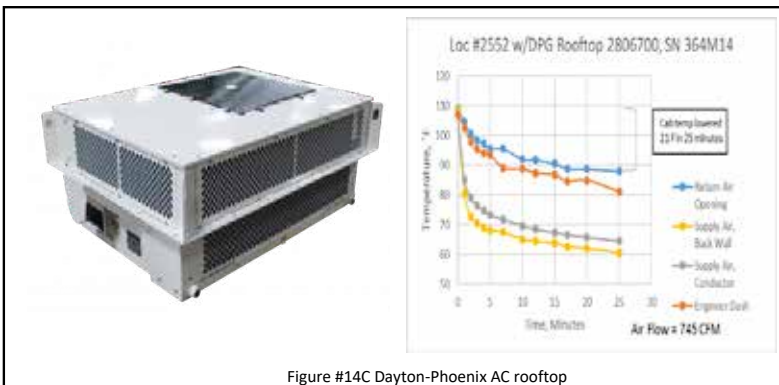


Figure #14C Dayton-Phoenix AC rooftop

Thermal Analysis – Cab Conditions

A thermal analysis was completed on all the cabs listed on the table in Figure 13.

Figures 15 through 18 are thermal images showing the range in temperature of different areas inside the cab. The outside air temperature during this study was 104°F. The air conditioner was on at the time of the thermal analysis.

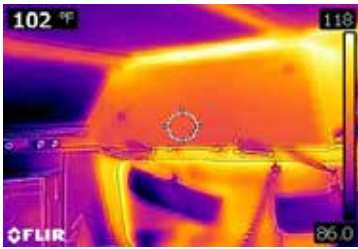


Figure #15 Temperature delta between insulated and non-insulated area = 32°F (86°F to 118°F)



Figure #16 Temperature delta between insulated and non-insulated area = 20°F (88°F to 108°F)

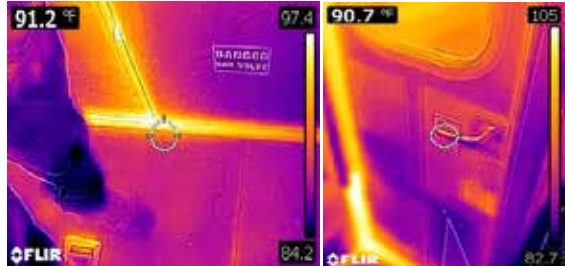


Figure #17 Door seals, window seals, cab corners.

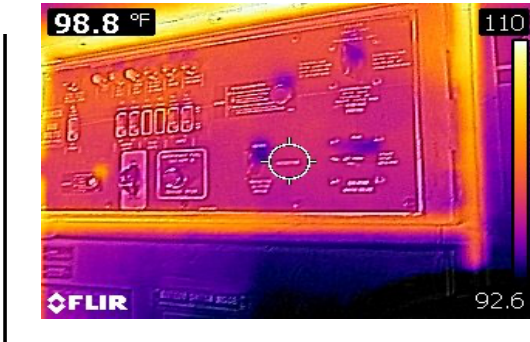


Figure 18

Electronic equipment, like shown in Figure 18, is another source of heat. Most locomotives today contain Positive Train Control (PTC) equipment on board. This was not installed on the locomotives during this study.

Cab Cleanliness – Affects crew comfort

Cab cleanliness affects crew comfort. Diesel fumes, VOCs, and dust may affect physical health while odors, stains on walls, and trash on floors may affect the mental health of the crew.

Covid-19 created a new cleaning process for everyone. The HVAC system in the locomotive, if properly maintained, will remove diesel fumes, VOCs, and dust out of the air inside the cab. The cab filters will pick up most of the large particulates. It is important to inspect and replace the air filters on a regular basis to continue to remove these contaminants. New advancements have made it possible to further clean the air, remove the smaller particulates, and deactivate viruses.

Merv 8 air filters are standard in new OEM freight locomotive cabs. Merv 8 air filters will clean some VOCs, diesel fumes, and dust in air but will not catch smaller particulates or micro-organisms like viruses.

UV-C light was introduced in 2020 in public transportation rail cars as shown in figure 19. The UV-C light inactivates micro-organisms on surfaces over time. Depending on the light spectrum it can take several minutes to kill micro-organisms. The UV-C light can damage human skin cells, so humans cannot be present during this cleaning process.

Bi-Polar ionization is being introduced in freight locomotive cabs. Bi-polar ionization de-activates micro-organisms and viruses. During this process, millions of positive and negative ions are released into the air as shown in figure 20. The ions attached to micro-organisms, de-activates the molecules and clumps

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them together as they get pulled into the HVAC filter. This process cleans the air, surfaces, and is safe for humans to be present during this process.

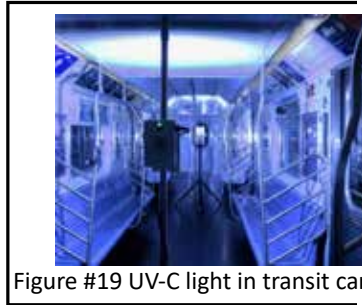


Figure #19 UV-C light in transit cars

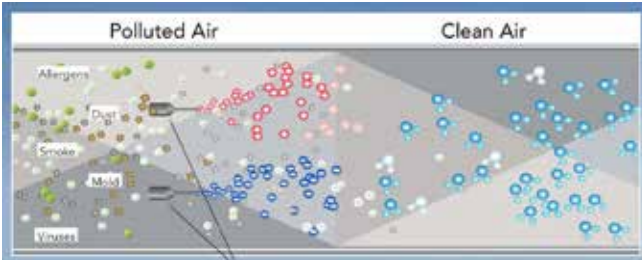


Figure #20 By-Polar ionization in freight loco cabs

Hepa filters will catch micro-organs but is not recommended for HVAC systems for freight locomotive cabs. The thick filter media restricts air flow and can shorten the life of the HVAC.

New published ASHRAE Post-Pandemic Building Guidelines states: A combination of filters and air cleaners that achieve MERV 13 or better, provide and maintain at least required minimum outdoor airflow rates for ventilation, and only use air cleaners for which evidence of effectiveness and safety is clear.

Locomotive Crew Seat Comfort

In 2016 AAR officially retired the last remaining Manual of Standards and Recommended Practices (MSRP) for locomotive cab seats. RP-5104 was the recommended practice, referencing proper selection and design of Locomotive Cab Seats. In 2016 RP-5104 was retired citing “Due to extensive evolution of seat design technology, recommended practice document RP-5104 is no longer relevant and the Locomotive Committee has elected not to revise RP-5104 to match these advances. In addition, railroad seat design and selection is often determined though Labor-Management negotiations. For these reasons, the Locomotive Committee voted to retire RP-5104 during their October 7-9, 2015 AAR meeting”. (AAR Letter C-12559).

Retired RP-5104 recommended seat sizes for crew comfort, fabric recommendations, cushion comfort, and adjustments for proper crew comfort and safety. Today seating companies work directly with Railroads to come up with a seating solution for each railroads need, however many times railroads do not understand what makes a seat comfortable, safe, and what wants vs. needs are.

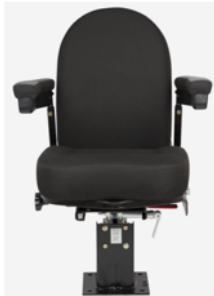
Different types of Seat systems for different types of locomotives

High-Back Seats



Suspension Base

Low-Back Seats



Floor Mount Pedestal

Narrow Seats



Tripod Pedestal

Wide Seats



Roller Bearing Tripod
Pedestal w/Footrest

A DESIGN TO “FIT EVERY-BODY”

There are many factors that contribute to seat comfort issues. The root cause of most complaints about a seat itself comes down to the seat not fitting the occupant. Locomotive crews have a very diverse population of crew members. In some cases there are crew members nearing the 400lbs. mark.

Traditionally, seats are designed to accommodate the 95th percentile male to the 5th percentile female. In the seating industry there are many different ways to interpret a 95th percentile and 5th percentile occupant.

Most people base the 95th percentile and 5th percentile size off of the 1988 Anthropometric Survey of US Army Personnel (ANSUR I). The original ANSUR I study from 1988 was really the only information available in a large scale format human size could be calculated from. The ANSUR I study included 145 measurements of the human body from 1,774 men and 2,208 women adult military personnel. In general terms the ANSUR 1 study shows the following height and weight data.

1988	95 th % Male	5 th % Female
Height	6ft 1”	5ft
Weight	216lbs	110 lbs.

In 2012 the ANSUR II testing was completed. Like the ANSUR 1 test the data gathered was from military personnel. The goal of this study was to determine the body size changes from the 1988 study. ANSUR 2 testing measured 136 total body measurements. Data was gathered from a total of 11,357 military personnel from 2010-2012, of those 7,435 were men and 3,922 were women.

2012	95 th % Male	5 th % Female
Height	6ft 1”	5ft
Weight	244 lbs.	113 lbs.

From 1988 to 2012 the ANSUR II study shows overall height for the 5th % female and the 95% male remain about the same. The weight of the 95% male has gone up over 12% to 244lbs. 5th % female has also gone up, but only 3%. These simple data points show seat designs based off of body size data from 1988 are not realistic today.

The ANSUR II study dives deep into over 136 total body size measurements. For basic seating comfort there are a total of six measurements that should be kept in mind when making a seat choice to conform to the locomotive crews.



Hip Breadth Sitting:

- The distance between the lateral points of the hips or thighs (whichever are broader).
- Relates to seating by setting the narrowest point of the occupant seating area, i.e., distance between items such as armrests should not be under 17". In most cases the width of the narrowest point of the seat should be even more than 18" to allow the occupant of the seat room to move around while seated.

Acromial Height Sitting:

- The vertical distance between a sitting surface and the right acromion landmark (highest point on your shoulder).
- For proper body support the shoulder area of the seat should be supported from 20.28" to 25.71" to cover both the 95% and 5% female.

Sitting Height:

- The vertical distance between a sitting surface and the top of the head
- Head and neck support is determined by the sitting height. For proper support of the 95th% male and 5% female there should be support from 31.61" to 37.6". Items like adjustable headrests can help provide support for both the male and female.

Popliteal Height

- The vertical distance from a footrest surface to the back of the knee
- This dimension is important when considering height adjustments of the seating system. To cover both the 95% male and 5% female the seat should adjust up and down 5".

Elbow Rest Height

- The vertical distance between a sitting surface and the olecranon (the bony prominence of the elbow)
- When choosing a seat with armrests they need to be adjustable to meet the height differences between the male and female. Per the data armrest should have a 4" adjustment range.

Buttock Popliteal Length

- The horizontal distance between a buttock plate placed at the most posterior point on either buttock and the back of the knee
- Adjustable cushions are a must to meet the differences between a 95th% male and 5% female. At least 4.25" of adjustment would be needed.

ALL DAY COMFORT

The locomotive crew spends hours in their seat every day. After choosing the correct seat to conform to the 95% male to the 5% female it is important to consider other factors for crew fatigue and all day comfort. These items include reducing pressure points, and finally selecting the right covering materials.

PRESSURE POINTS IN SEATING

Before selecting a seating product pressure points on a seat should be considered. Pressure points are common in the shoulder area, tailbone area, buttocks, and back of knees.

Pressure points are an overlooked item when selecting seating products. Many people want a seat with a long cushion for more leg support. Many times the cushions get so long they hit people in the back of the knee while seated. This may seem like it is not a big deal. This is a major pressure point concern. A pressure point in this area can cause restricted blood flow causing many health concerns including driver fatigue.

The most common way to check for pressure points in a seating product is to have a seating supplier or an independent lab do a complete pressure mapping study. Below is an example of a pressure mapping study done on a Railroad Seat Application. The ultimate goal is to have no or very limited pressure points that would lead to occupant discomfort. Generally, 0.0-1.36 PSI is acceptable.

I. Test Equipment

a. Laptop

A USB cable connects the DEWE43V with a laptop that stores the data onto its hard drive. The Lenovo ThinkPad E220s Windows 7 laptop runs proprietary XSensor software to setup, record, and analyze data.

b. XSensor Pressure Mapping System

An XSensor Pro pressure mapping system with a PX100 (24"x24") sensing pad was used to measure local pressures on the occupant. The system is able to deliver, through the use of the proprietary software, a recorded profile and colored printout of pressures throughout the sensing pad. The pad has a resolution of 1/2" and measurement range of 0.19psi to 3.93psi which is deemed appropriate for seat measurements.

c. Seats Incorporated Standard Freight Rail Seat

One, Seats Incorporated, Rail seat was tested in this study. The seat upper is similar to the standard seat. The seat was mounted on a base that allowed the top of the cushion to be 19" from the floor.

II. Test

The seat was temperature conditioned through storage in an office environment. The sensor pad was placed on the seat and the occupant sat on the pad. The measuring surface was then conditioned for 5 minutes to allow the cushion foam to settle with the occupant in place. After the conditioning process, data was recorded with the use of the pressure mapping system on the cushion.

The pressure mapping pad was then moved to the backrest and was loosely secured to the backrest to hold it in place, but not to introduce any false data. The backrest was adjusted to approximately 10° relined from vertical and the occupant sat in the seat again. Due to the low amount of force that is placed on the backrest compared to the cushion, conditioning is not necessary and measurement samples were taken right away.

A larger occupant was selected to perform the testing on. Some additional information regarding the occupant can be found in Appendix B.

III. Analysis Method

Seats Incorporated uses a very visual method of determining comfort for occupants based on pressure mapping. Some of the easily identified items that contribute to comfort are overall uniform pressure distribution, a lack localized pressure points, and overall areas of high pressures. A localized high pressure area would indicate that the occupant is not properly supported. It is common that elevated pressures exist at the ischial tuberosities (a rounded bone that extends from the **ischium** — the curved bone that makes up the bottom of your pelvis. It's located just below the **ischial** spine, which is a pointed bone that extends up the backside of your pelvis), which is less sensitive to increased pressures, however high pressures would indicate eventual discomfort and muscle fatigue. Pressures over 1.16psi have been shown to contribute to arterial constriction which will affect the nerves and cause numbness and general discomfort. This discomfort can generally be seen when the occupant is frequently shifting or changing seating positions.

For both the cushion and backrest, the pressure map was reviewed for any areas of localized high pressure as well as uniform pressure. No score was given to either of the measured areas, however, a conclusion can be drawn with the visual information.

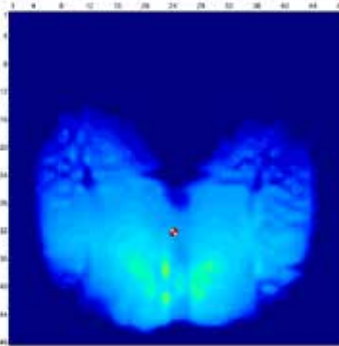
For the cushion, a visual scale of 0-2.00psi was used while a scale of 0-0.75psi was used for the backrest. This same scale and color representations were successfully used in analyzing previous seat cushions for other applications.

IV. Results

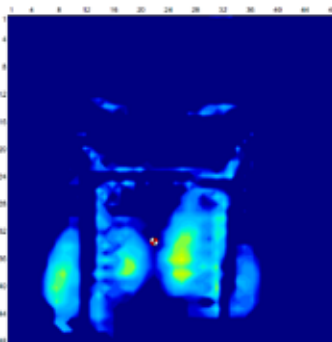
Detailed results can be found in Appendix A.

Cushion

As can be seen from *Picture 1* below, the average pressure is fairly well distributed with some of the higher pressures occurring at the ischial tuberosities. When looking at the pressure map, it can be seen that the bolsters support the occupant well sideward without creating discomfort. The front of the cushion is not producing high pressures, which indicates that the cushion rake or angle is properly set. The average pressure over the contacted area on the cushion is 0.65psi with a peak pressure of only 1.28psi. While 0.4% of the area is higher than the 1.16psi threshold where arterial constriction starts to develop, this value and total area is still low enough and located at the ischial tuberosities such that occasional movements in the seat will prevent numbness. Overall, this cushion performed very well and it is shown that the design properly supports the occupant.



Picture 1 – Cushion Pressure Map



Picture 2 – Backrest Pressure Map

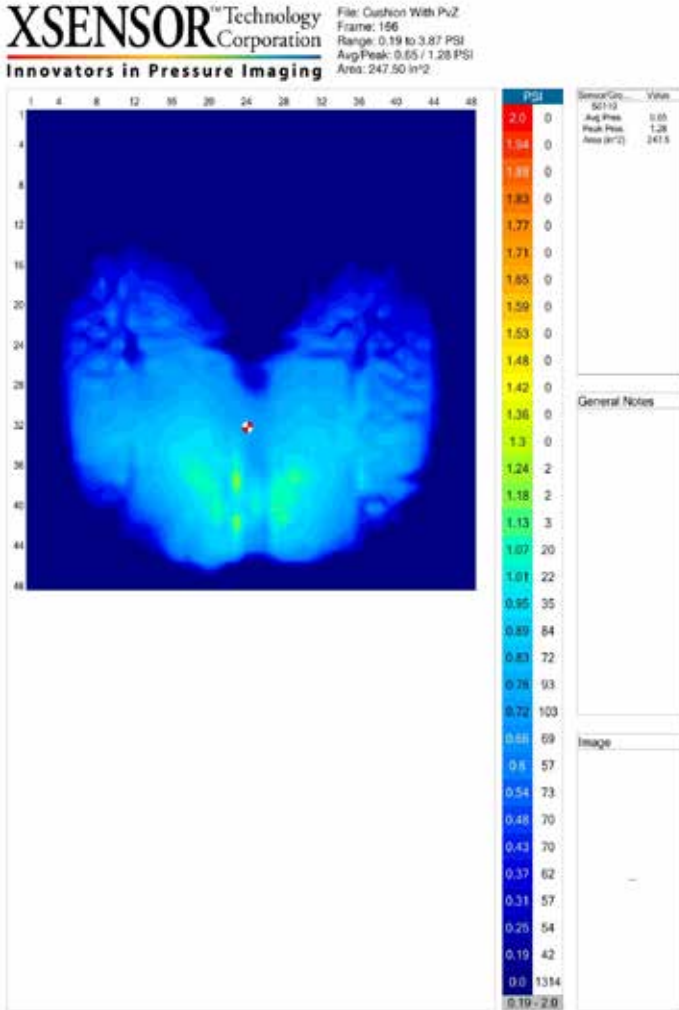
The backrest (*Picture 2*) was evaluated at a lower scale than the cushion due to the little amount of force that is actually applied to the backrest resulting in lower pressures. Once again, it appears that the backrest is comfortable to the occupant as it can be seen that pressures are fairly uniform and that the occupant is properly supported at the lumbar, bolster and shoulder area. Some of the higher pressures occur at the lumbar which is an area that is critical to proper posture and back problems. Further adjustments are possible at the lumbar area; however, increased lumbar pressure was not investigated in this study. It does appear that the occupant was sitting slightly off-center in the seat; however, this is not a concern in this study and also gives some indication of the pressure maps of smaller and larger occupants. No discomfort was noted by the occupant. The average pressure over the contacted area was 0.33psi with a peak pressure of only 0.56psi.

IV. Conclusion

After conducting a study to determine comfort of the freight railroad seats, it was determined that both the seat cushion and backrest have a good pressure distribution and no areas of high localized pressures. The seat supports the occupant well throughout the seating surfaces and no discomfort was noted. The design of this seat is deemed appropriate and will be comfortable for use in situations where the seat will be occupied for an extended period of time such as in the freight rail industry. There are no recommended changes suggested to this series of seats at this time.

Appendix A – Pressure Mapping Data

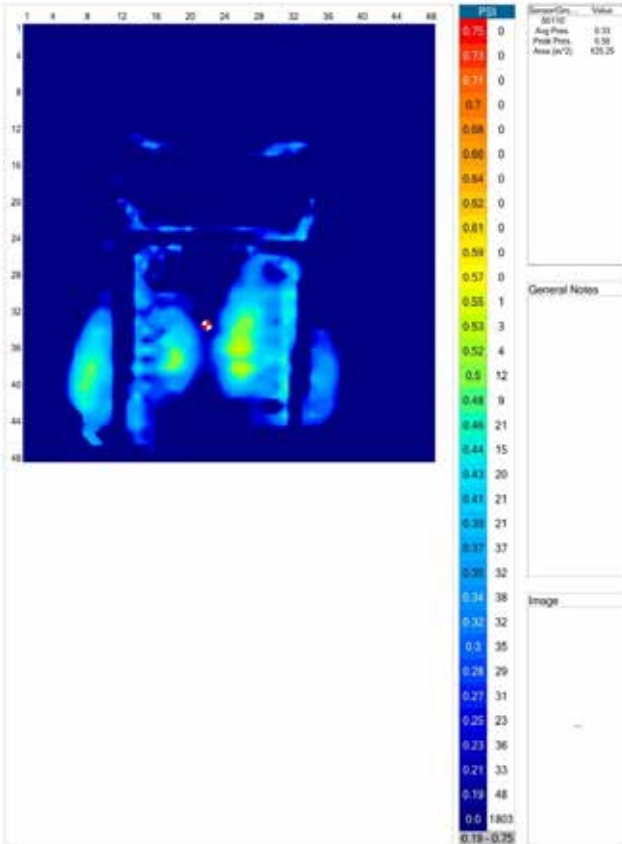
Cushion Pressure Map



Backrest Pressure Map

XSENSOR™ Technology Corporation
 Innovators in Pressure Imaging

File: Back With PvZ
 Frame: 120
 Range: 0.19 to 3.87 PSI
 Avg/Peak: 0.33 / 0.56 PSI
 Area: 120.25 in²



COVERING MATERIAL SELECTION

In general terms there are three different types of covering materials. Cloth, Vinyl, and Leathers. These three categories have thousands of choices under them. Different brands, colors, thicknesses, and wear characteristics.

Most seat suppliers can source almost anything a locomotive crew would want when it comes to cab seat covering material. There are cloths that have breathability feature to increase comfort and other cloths that do not. Seating companies can add perforation to vinyl's and leathers to make a non-breathable material breathe.

The covering material technologies continue to evolve. Do not assume you cannot use items such as vinyl "because they are too hot" or refuse to look at other options because you are happy with how long your seats are lasting. There are newer technologies in seating that can increase comfort, clean-ability, and last longer than what you are using today.

Conclusion

Crew comfort is critical to keeping the crew aware, safe, and productive.

Noise, climate control, seating, and cab cleanliness must be a top priority for crew comfort.

- Contact your HVAC system and seating provider for expert engineering services and advice when developing plans for your next repower program

Acknowledgments / References

Human Factors Guidelines for Locomotive Cabs, US DOT

CFR Title 49 Parts 229 (2019) Locomotive Cab Noise

ASHRAE Epidemic Task Force, Core Recommendations for Reducing Airborne Infectious Aerosol Exposure. 2021

Seats Incorporated, United States Safety & Survivability, and Baultar Websites.

1988 Anthropometric Survey of Personnel.

2012 Anthropometric Survey of Personnel.

Seats Incorporated Pressure Mapping Study.

AAR Letter C-12559



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BNSF & Wabtec Battery Electric Locomotive Demonstration Summary

Prepared by:

Michael Cleveland, BNSF Railway

Abstract

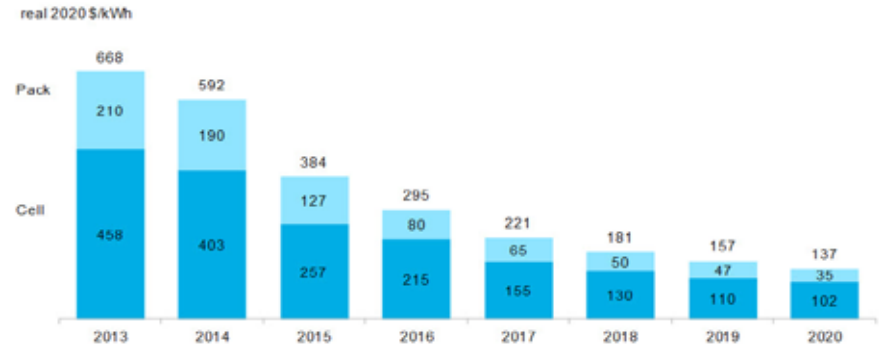
BNSF Railway and Wabtec partnered in the development and demonstration of a battery electric locomotive (BEL) in a hybrid consist approach. This 100% battery powered locomotive uses regenerative braking and wayside charging to reduce the emissions and fuel consumption of the locomotive consist. By integrating with Wabtec's Trip Optimizer energy management system, the BEL was able to save an average of 12% of the locomotive consist fuel burn during 18 round trips between Stockton and Barstow, CA. The demonstration showed that a BEL in a consist with other diesels can operate safely, charge the batteries through regenerative braking and wayside charging, offset diesel fuel use using that stored energy, and use unique control algorithms to optimize the use of the BEL in the consist. This first of its kind demonstration lays the foundation for future work which will expand the energy storage of the BEL, improve charging safety and speed, and improve locomotive consist efficiencies.

Introduction

Locomotive technology has progressed via evolutionary development since the introduction of diesel electric locomotives in the 1930s. Some evolutions, like the introduction of alternating current traction, have radically transformed the rail industry for the better. Locomotives are now more powerful, more reliable, and higher performing than ever before. The North American freight standard locomotives of today represent a level of engineering achievement that would have been considered unthinkable even a few decades ago. This evolution grows out of the persistent striving for continuous improvement by railroads, locomotive manufacturers, and component suppliers. Further improvements are certainly possible and needed, however the global imperatives associated with constituent and greenhouse emissions reductions call for new approaches to be considered. This project represents a major step forward in the development and refinement of lower emitting locomotives for freight service. This paper is a follow up to the 2019 LMOA paper "BNSF & GE Pilot Hybrid Locomotive Consist using a Battery Electric Locomotive".

While BELs are certainly not a new idea, Michael Iden’s 2014 ASME paper does an excellent job of describing the efforts of BELs through 2014, the subsequent advancements of lithium ion batteries present a new opportunity for the rail industry.¹

Figure 1: Volume-weighted average pack and cell price split



Source: BloombergNEF

Figure 1 Volume weighted average pack and cell price split²

As shown in figure 1, the cost of lithium ion batteries has fallen dramatically over the past decade and this decline is expected to continue as the automotive industry increasingly advances their battery electric vehicle lineups. The rail industry can take advantage of this by integrating this technology in BELs to be used in conjunction with diesel-electric locomotives to form “hybrid consists” or, BELs alone, for limited zero emissions train operations.

With this goal in mind, BNSF and Wabtec (formerly GE Transportation) partnered in the development and testing of a 100% BEL to be used in a consist with other diesels to form a hybrid consist. Through a grant from the California Air Resources Board (CARB), and in partnership with the San Joaquin Valley Air Pollution Control District (SJV), BNSF and Wabtec developed, deployed, and tested the first BEL used in mainline high horsepower freight service. This paper details the approach, equipment, testing, and results from this effort.

Motivation & Approach

As the global issues focus on emissions and fuel consumption reduction continue to intensify, the reduction of diesel fuel use presents a mutual benefit to all parties involved. BELs have higher system efficiencies that result in less energy use and can have lower operating costs with reduced environmental impact. Typically, locomotive improvements have made marginal gains of around 1.0% improvement in fuel use. A step change in technologies is needed to produce further significant reductions in fuel use.

The application of BELs to form hybrid consists could be that step change improvement. In this model, the BEL uses dynamic braking as regenerative charging and wayside charging to store energy in a battery system and then offsets diesel fuel used for tractive effort. The capture of dynamic braking in a battery system, also known as regenerative braking, is the core enabler of hybrid consists' fuel reductions.

In this demonstration, the BEL worked in conjunction with two "mate" locomotives (BNSF 3940 & 3965) which were kept adjacent to the BEL for the duration of the demo, see figure 2. These units were equipped with special communication hardware and software to form the hybrid consist. The hybrid consist operated in two major modes; tractive effort and dynamic braking. While these operating modes are common functions to all locomotives, the hybrid consist used special algorithms to optimize the use of the BEL. In tractive effort, the BEL did not provide any tractive effort until a throttle notch command over notch 2 was requested. The BEL and the lead locomotive would work together to ensure that one locomotive's worth of tractive effort was supplied. Tractive effort needs for the test hybrid consist above notch 2 were provided by the BEL if it had enough power output or energy storage available. If the BEL was unable to provide the tractive effort needs, the mate locomotives would increase their throttle notch to meet the tractive need. Additional locomotives in the train simply follow the trainline. In this way the BEL energy was used first to offset diesel fuel use as it was available. This contrasts with conventional locomotive consists where all locomotives simply follow the trainline throttle notch command.



Figure 2 Image of BEL Hybrid Consist

Conversely, the other mode, in dynamic braking the test hybrid consist used a similar but reversed algorithm to that of tractive effort. The lead locomotive and BEL would supply up to two locomotives worth of braking effort. The BEL would provide dynamic brake effort first in the test consist, before the two mate locomotives. Once the BEL was fully charged or additional braking effort was required the mate locomotives would supply any needed braking effort. This

allowed the BEL to be recharged through regenerative braking first.

The test consist used this algorithm with the route planning and energy management software, Trip Optimizer (TO), to optimize the tractive effort of the BEL. TO is an energy management software system that accounts for the locomotives, train make up (cars and trailing tons), and route ahead to plan an optimized throttle notch schedule for the train. It effectively acts like a smart cruise control system for the train and in this demo was the software foundation for the hybrid consist.

Equipment Description

The BEL was operated from Barstow, California to Stockton, California for just over three months of demonstration. The battery electric locomotive is a six axle - four powered – 4400 horsepower (HP) road locomotive very similar to an ES44C4 common to the BNSF fleet, specifics provided in table 1. It was purposely built as a development platform for this demonstration. The locomotive, GECX 3000, is a development asset owned by Wabtec that has been used for a variety of innovation equipment applications, and prior to this demonstration, it was a natural gas demonstration unit used with both BNSF's and Florida East Coast Railway's LNG programs. The GECX 3000 was completely reconfigured for use as a battery electric locomotive. The entire frame was cleared, and new battery compartment added. The battery system consists of 18,000 cells grouped into modules of thirty-six. Twenty-five modules are grouped in a string and controlled by a battery string controller. Five strings power each axle for a total of twenty strings. This battery system occupies the entire rear portion of the locomotive and has a central walkway to allow transit between locomotives.

Table 1 GECX 3000 Specifications

Energy Source	Lithium-ion batteries
No. of Axles	6 (4 powered)
Weight	430,000 lbs
Emissions	Reduces train's emissions by 10%
Duration @ Rated Output	30 to 40 minutes
Rated Output	4400 horsepower
Charging	Wayside charging and regenerative braking
Energy Capacity	2,400 kW-hours
Thermal Management	Air cooled
Maximum Speed	75 mph

The BEL was rated as a zero-horsepower locomotive as the battery size and TO algorithm was insufficient to ensure that the BEL could be available for power in the highest tractive effort locations. It was however, rated as having full dynamic brake axles as that is a critical link in the safe operation of mountain grade operations and to optimize regenerative braking charging of the battery. Figure 3 shows the systems added and removed describes the changes made to this locomotive.



Figure 3 System Changes made to the BEL demo locomotive

The wayside charging system for the BEL demonstration was a custom designed power supply for the GECX 3000. The system used 480V three phase AC at a peak power of 400kW to charge the BEL in 6-8 hours. The system has ground fault and short circuit protections and given that this is a prototype system electrical lineman's gear (gloves, jacket, and boots) were required by operators. The connection to the BEL was custom built by Amphenol and contains four power cables (three AC phases plus ground) and communication pins. Due to the connector's large size a charging crane from LinkUP was used to support and guide the connector and cables, see figures 4, 5, & 6. The procedure for connection to the locomotive involves parking the locomotive, ensuring it is setup to receive charging, protecting the area from entry, connecting the cable, and finally energizing the system. Given that safe operation of this high-power equipment is critical, only specially trained members of the test crew were allowed to connect the charger.



Figure 4 BEL of Charging Station in Stockton, CA



Figure 5 Image of BEL While Charging at the BNSF Stockton Mormon Yard

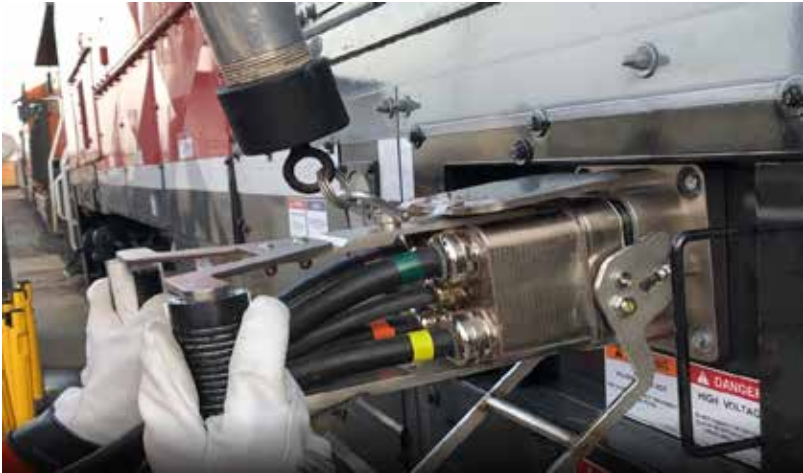


Figure 6 Image of Charging Port and Charger Connector on BEL Locomotive

Test Description

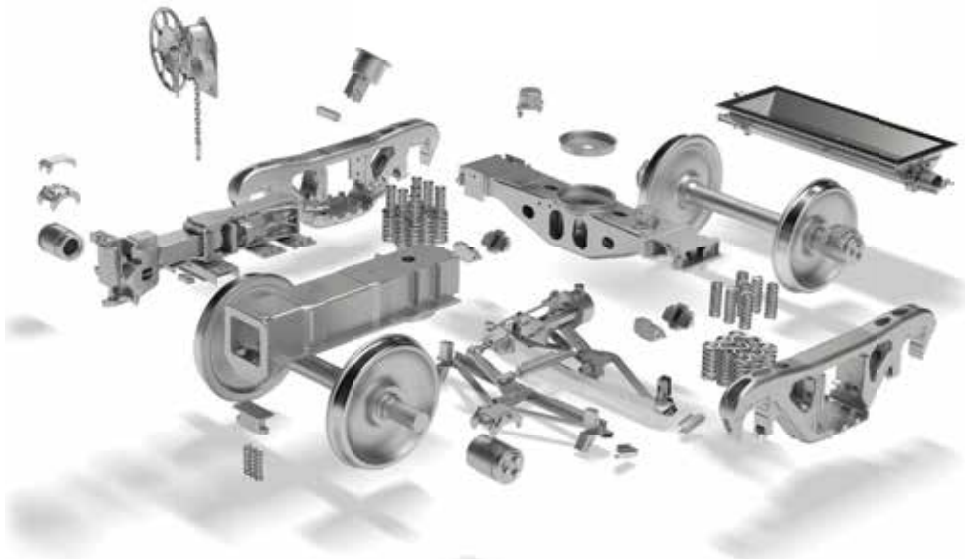
BNSF runs a daily mixed manifest train from Barstow to Stockton and from Stockton to Barstow which were used for this testing. The BEL consist was assigned to this train and any additional power needed for horsepower per trailing ton requirements was added to the rear of the head end consist or to the distributed power (DP) position. These mixed manifest trains can vary significantly in tonnage from 2,500 tons to 10,600 tons but were typically 7,000 tons. The round trip from Barstow to Stockton and back was about 750 miles.

Starting on January 4th, the test consist operated in regular service between Barstow & Stockton in two-week cycles consisting of three round trips planned each cycle for three months. While regular train operations and delays limited these cycles occasionally, the test consist never caused a delay from BEL operations. Barstow was used as the “base” of operations as the large locomotive and yard facilities facilitated servicing the equipment. Typically, a round trip from Barstow to Stockton and back to Barstow would take just over three days but in some extremely delayed situations, it took up to 7 days.

Data collection for this project was completed by Southwest Research Institute (SwRI). The locomotives were all individually data logged using a system developed by SwRI for locomotive data logging. This system was based on a self-contained data logging system that can be adapted to a variety of applications to automatically log and report data to a back-office server. Close coordination between Wabtec and SwRI was required so that the appropriate data could be collected from the vehicle control system.

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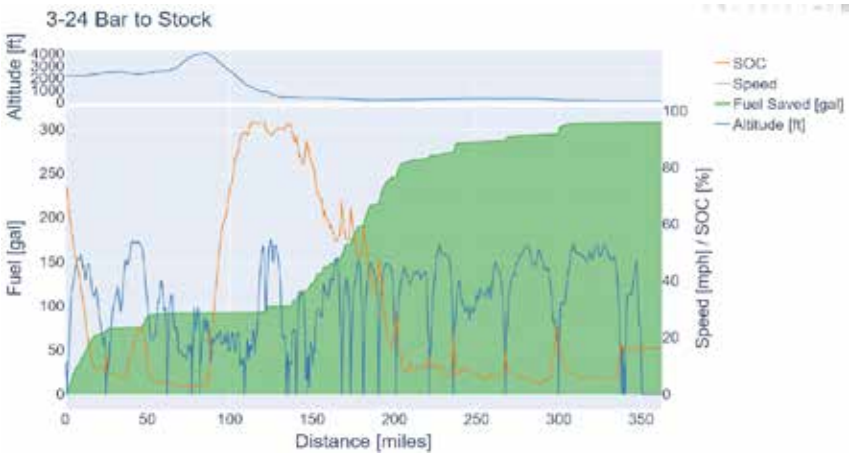


Figure 7 Characteristic Plot Showing Altitude, SOC, Speed, and Estimated Fuel Reduction for a run Traveling from Bartow, CA to Stockton, CA

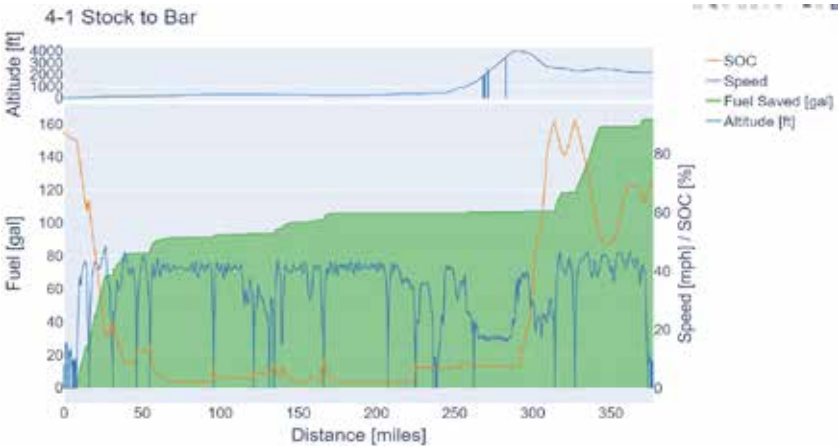


Figure 8 Characteristic Plot Showing Altitude, SOC, Speed, and Estimated Fuel Reduction for a run Traveling from Stockton, CA to Bartow, CA

The SwRI data logging system proved hugely beneficial for the operation and evaluation of this project. Having real time reliable data on the position, speed, and function of the equipment allowed the team to quickly address issues as they arose. Additionally, having a mutually agreed upon system of evaluating the data eliminated quite a bit of confusion. The data collection system, dashboard, and the insights they provided laid the foundation for the results of the program and the ability to validate success.

Findings

Most importantly no safety issues, injuries, or “close calls” were encountered as a part of this testing. It cannot be overstated that this is the single most important result of this testing. Having everyone return home safely is the first goal for all railroading, including new technologies. It is a testament to the hard work and dedication of everyone involved that this demo was completed safely.

The first run of the BEL & test consist in revenue train service was on December 14th. For this run a team of Wabtec engineers and BNSF battery team members rode the train from Barstow to Stockton, CA. During this run the hybrid consist performed as intended with all major functions behaving exactly as described above. Once in Stockton the test consist was moved to the wayside charger and the team was able to connect the locomotive and fully charge the locomotive before the consist returned to Barstow on the next outbound train. On the return trip to Barstow, the consist performed as intended again.

Over the course of the demonstration testing, 18 round trips were completed between December 12th, 2020 and April 2nd, 2021. The test consist traveled for approximately 13,300 miles during this time. It offset 8,600 gallons of diesel fuel for an average of 12% fuel abatement across the test consist. The variation of the fuel avoidance was significant ranging from 4% to 19%. Barstow to Stockton runs had better fuel reductions than the return trips as the large downhill section provided regenerative braking energy to the battery that contributed greatly to the BEL's efficiency. The other major driver of variation between runs was train tonnage. Intuitively this seems logical, as heavier trains would use more fuel, however these trains also have more opportunity for regenerative braking thus more fuel reduced on either downhill stretches or other braking events. Interestingly, this implies that the runs with some of the highest gallons abated did directly correlate with the percentage fuel reduced.

Additionally, it was found that braking events associated with the train stopping in a siding to allow for traffic to pass was a significant source of regenerative braking. Each event contributed about 200kWh worth of energy to the batteries. While an expected result, it is surprising in magnitude and frequency. This effect can clearly be seen in the characteristic small peak increases in state of charge (SOC) in the state of charge vs distance plot. Characteristic plots of the state of charge, speed, fuel avoidance, and topography are shown for both Barstow to Stockton and the return Stockton to Barstow trips in figures 7 and 8.

As with any new technology project there were issues encountered. Most notably the wayside charger presented several obstacles in development and mitigations had to be implemented to ensure that the charging system was safe to the operators in all conditions. For example:

- The ground fault monitoring system limits needed to be carefully tuned to limit the possibility of personal injury. Even after tuning, the detection limits were above those typically regarded as safe for personal protection and the following two mitigations were implemented.
- A robust set of instructions on the operation of the charging station were developed and only specifically trained operators could use charge the locomotive.
- Special personal protective equipment and isolation measures were used so that in the event of a failure no employee was exposed to high voltage conditions.

Since this demonstration's goal was to prove the concept and determine areas of further development, several other items were noted from operational testing. While never intended as a fully revenue service locomotive, these items will be addressed in future generations of this technology.

1. The relatively low 2.4 MWh energy storage on the BEL meant that it was not capable of fully replacing a locomotive and instead was always an additional unit to the consist. Regenerative braking filled the battery and would have been able to provide more storage with a larger battery. Future versions will need greater energy storage to be a full diesel locomotive replacement.
2. High auxiliary loads (air compressor, fans, blowers, etc.) caused significant battery draw during idle events. While software changes implemented mid-way through the program lessened this effect, future BELs will need to be designed to minimize the auxiliary loads.
3. Eight battery modules and three battery string controllers were replaced during this demonstration. These components were identified by the battery management system as failed. A postmortem analysis does not give a clear indication of failed components, indicating that the detection system or limits require additional refinement in the next version.
4. The local Federal Railroad Administration (FRA) inspector inspected the BEL and found two exceptions. The BEL has a middle emergency egress ladder. These steps & handrails were not painted a contrasting color. Additionally, the front end "F" stencil was not present. The Barstow locomotive team addressed these issues immediately. No other FRA exceptions were identified during the program. Overall, coordination and communication with both the local and national FRA teams was excellent and the battery team would like to thank them for the guidance and feedback throughout the program.

5. The BEL charge time was 6-8 hours, ideally the charge power would be increased such that future BELs can charge within 4 hours or less.

Despite the limitations of a demonstration BEL, the ability to safely operate and prove core functionality on the very first revenue service demonstration run, is encouraging. This effort demonstrated that BELs in hybrid consists are a viable concept that deserves further development. The significant amount of development, planning, and coordination lead to the success of the demonstration project. Moreover, the avoidance of fuel consumption averaging 12% (max 19.2% & min 6.2%) is consistent with the energy modeling predictions for this service. Overall, this demonstration was a fantastic success, and the battery team is very appreciative of the opportunity to technically advance the industry.

Future Work

BNSF & Wabtec found that the demonstration, by meeting all key objectives, proved that the hybrid consist concept is a technically viable approach for emissions and fuel reductions for high horsepower linehaul/regional locomotives. After the demonstration between Barstow and Stockton, the GECX 3000 was returned to Wabtec in Erie, Pennsylvania where it will continue to be used as a development platform for the next generation of locomotive battery systems. Any additional road testing requires more development work which is best addressed in Erie.

Going forward, BEL development will focus on addressing the limitations of this demonstration and building a locomotive that is a drop-in replacement for a diesel locomotive. The single largest advancement needed for this is the increase in energy storage. It is expected that an increase to 20 MWh in energy storage could allow for the replacement of a diesel locomotive (in a hybrid consist application) in regional service. It is important to note, that the hybrid consist approach is best suited for areas where grades maximize regenerative braking. Longer distance operations without significant grades are less desirable due to the less prominent regenerative braking. As such, initial deployments of BELs will focus on regions, like the LA basin, where the terrain & traffic density are advantageous. Once the technology is well proven, hybrid consists with greater than one BEL or all BEL consists may be viable. This requires the further increase in energy density (~10MWh for regional operations) and a significant level of confidence in both the BEL and the charging technology.

To address interoperability concerns and standardization across suppliers, the AAR Locomotive Committee has formed the Locomotive Charging Interface Standard (LCIS) Task Force. This group aims to develop a standard for the charging of future BELs and hybrid locomotives. This will be an important next step as early standards development could accelerate confidence and adoption around BELs and hybrid locomotives.

The BELs in yard or road switching service is worth considering. This demonstration also showed that the BEL could perform switching in “yard mode”. It is reasonable to conclude that a BEL for yard or local switching is possible. This service in a railyard makes the charging solution more compelling as a single charging facility could serve several locomotives. However, the low capital and fuel consumption of current switcher locomotives makes the conversion from the current diesel switcher difficult given the higher capital cost. Regardless, switchers present an encouraging opportunity for the development of zero emissions locomotives particularly in environmentally sensitive areas.

Conclusions

The operation of the Wabtec BEL between Stockton and Barstow showed that a hybrid consist can be a safe and effective approach for the reduction of emissions and fuel abatement. While there is much work to be done to address issues such as charging, auxiliary loads, and energy storage, this first demonstration is a very promising step in the future of locomotive technology. Future efforts will focus on expanding BEL capability, standardizing charging, and ensuring that this technology is viable in regular service operations.

Acknowledgements

I would like to thank everyone who contributed to and supported this project. It has been a massive effort across many organizations, and I can’t thank everyone enough who put in the long hours, time away from home, and deep thought to make this a success. Everyone who worked this project rightfully feels that this is *their* locomotive; we are just incredibly proud to share it with the industry.

References

1. Iden, Michael E. “Battery Storage of Propulsion-Energy for Locomotives.” *ASME 2014 Joint Rail Conference*, 2014, doi:10.1115/jrc2014-3805.
2. Bloomberg NEF “Battery Pack Prices Cited Below \$100/kWh for the First Time in 2020, While Market Average Sits at \$137/kWh” <https://about.bnef.com/blog/battery-pack-prices-cited-below-100-kwh-for-the-first-time-in-2020-while-market-average-sits-at-137-kwh/#:~:text=By%202023%2C%20average%20prices%20will,%24100%2FkWh%20have%20been%20reported.>



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NEW LOCOMOTIVE & NEW TECHNOLOGY “DISAPPOINTMENT SYNDROME” What is it? What causes it? How do you avoid it? (If not avoided it can be difficult to cure.)

Prepared by:
Michael Iden, P.E.
Tier 5 Locomotive LLC

Locomotive Maintenance Officers Association (2021 conference)

We will start this paper with a quotation from within the U.S. locomotive industry, made seventy-two (72) years ago, that provides a foundation for what we are discussing: “new” locomotive designs and especially locomotive technologies:

“The road of discovery, in whatever field, can always be recognized by the “bleached bones” of those who failed to make the grade, for it takes not only courage, but extraordinary endurance to sustain the voyager.” - A comment by Lisle F. Small, Director of Research, Lima-Hamilton Company, Society of Automotive Engineers (SAE) technical paper 490082, June 1949.

Lima-Hamilton was the smallest diesel-electric locomotive manufacturer in 1949; it had also been the smallest (lowest volume) U.S. steam locomotive builder, although it was sometime described as being the “Swiss watchmaker” of American steam locomotives because of its technical leadership in steam propulsion. In attempting to survive, it quickly transitioned from steam-to-diesel technology, merging with the Hamilton Engine Company and assembling and selling a small number of diesel-electric switching locomotives. Mr. Small’s mission at Lima-Hamilton was to develop a “free piston gasifier” that could produce high-temperature gas energy for a gas turbine powerplant for locomotives, allowing Lima-Hamilton to technically-and-commercially eclipse diesel-pioneer GM Electro-Motive Division as well as the American and Baldwin locomotive companies.



Mr. Small had previously served in the U.S. Navy, and after World War II had risen to the rank of Commodore in the Bureau of Ships shipbuilding division in charge of machinery planning and procurement. Even with full corporate commitment, however, technical and commercial success was not in Lima-Hamilton's future. The free-piston gasifier experiment was never successful, and the company ended all diesel-electric locomotive production 2 years later, on September 11, 1951. The point of this opening commentary is that "courage and extraordinary endurance" are not always sufficient in undertaking technological change.

PURPOSE OF THIS PAPER

The purpose of this paper is to describe a problem that has long existed in and has been a burden for the railroad and locomotive industries (but has often been overlooked and under-reported) and may be increasing in frequency and impact (on operations, maintenance and finances) as locomotives become increasingly more "complicated" with increasing amounts of new technology. We will also discuss a means of avoiding this problem before new locomotives and/or new technologies enter commercial production.

Given the extensive discussion about new "zero-carbon" propulsion technologies such as hydrogen fuel cells and large-scale propulsion batteries, we can safely state that "tomorrow's" locomotives will likely be much more technology-intensive than even the latest EPA Tier 4 diesel-electric locomotives. It is the author's opinion that the problem discussed here is increasingly apparent not only with freight line-haul and switching locomotives but also new passenger-and-commuter locomotives. Therefore, this topic should be of joint and inseparable interest to locomotive manufacturers, locomotive customers (in the freight, passenger and commuter markets), to people in the financial industry, government regulators and even private taxpayers.

TARGET AUDIENCE: WHO SHOULD READ (AND HEED) THIS PAPER?

In the author's opinion, any person having "managerial", "technical" or "financial" responsibilities in the design, experimental construction, engineering, validation, manufacturing, servicing, operation, maintenance or financing of "new design locomotives" (especially those incorporating "new technologies") should become familiar with the content of this paper.

The target audience is, therefore, quite large, and includes people in these organizations:

- Locomotive builders (established, large-and-small, plus "new entrants" to the industry)
- Railroad personnel (especially in mechanical/maintenance roles, but also in transportation, supply/acquisition, environmental and finance positions)

- “Railroad” includes commuter rail operations overseen by government agencies
- Locomotive parts and systems suppliers for locomotive builders
- Government agencies such as federal (EPA), state or regional “air quality” organizations, especially those that offer and provide “financial grants” for “cleaner locomotives”
- Finance industry (including locomotive appraisers, leasing companies, banks, etc)

DO NOT FORGET (OR OVERLOOK) NEW INFRASTRUCTURE NEEDED FOR NEW LOCOMOTIVES!

While this paper focuses on “new” locomotives and “advanced” onboard technologies, it is important that we remember that future locomotives (such as hydrogen fuel cell locomotives with supplemental propulsion batteries, and all-battery electric locomotives) will require new infrastructure to support their operation, enable maintenance and “refuel” them as their onboard energy supply is “used”. There is also the possibility that hydrogen fuel cell locomotives for line-haul (long-distance) operation may require “fuel tenders” to carry liquefied or compressed hydrogen. Such tenders can be variations of tenders designed for refrigerated (liquefied) or compressed methane. However, hydrogen has unique chemical and molecular properties that make such mobile transportation-and-use more complex and involving greater engineering effort.

Bottom line: do not ignore or forget new infrastructure that will be required to support new-technology locomotives! Ironically, the strong “link” between new technologies and “supporting infrastructure” is one of the areas often overlooked or misunderstood by “managers”. We will discuss this later under the “strategic” topic. A paper examining battery-electric locomotives and infrastructure needs was published by the American Society of Mechanical Engineers at the 2021 Joint Rail Conference. Readers of this paper may obtain a copy at www.asme.org:

Proceedings of the ASME 2021 Joint Rail Conference
JRC2021
April 20-21, 2021, Virtual, Online

JRC2021-1030

**BATTERY ELECTRIC LOCOMOTIVES & BATTERY TENDERS:
OPERATIONAL & INFRASTRUCTURE CHALLENGES TO WIDESPREAD ADOPTION**

Michael E. Iden, P.E.
Tier 5 Locomotive LLC
Kildeer, IL

“DISAPPOINTMENT SYNDROME”

Merriam-Webster Dictionary defines “syndrome” as follows:

“1: a group of signs and symptoms that occur together and characterize a particular abnormality or condition. 2: a set of concurrent things (such as emotions or actions) that usually form an identifiable pattern.”

The author is framing this discussion in part along the lines of discussing a medical condition having identifiable signs and patterns of behavior; there are re similarities:

1. Disappointment with the operational and/or maintenance aspects of a new locomotive design (or of a new technology incorporated into a locomotive design) is not a new occurrence nor is it particularly rare. It has inflicted the railroad and locomotive industries for decades. Some instances are well known (or have been publicized). Other instances are less well known or never revealed and understood. Like some medical issues, this problem seemingly “comes and goes” (often like a virus). ***An improved approach is needed for the development, design and commercialization of all “new” locomotives and especially for “new locomotive technologies.”***
2. Once a new locomotive model (or newly introduced locomotive technology) exhibits undesired operational or maintenance conditions, trends or limitations ... the locomotive owner and the locomotive manufacturer are often “stuck” with limited ways of correcting or eliminating the problem(s). Often the locomotive owner must endure sometimes endless modifications to keep changing locomotive components or locomotive configurations in an attempt to improve the locomotive’s performance, improve reliability, reduce road failures and reduce maintenance expenses. And, in some cases, railroads have resorted to the ultimate means of overcoming gross performance issues with a series of new locomotives: premature scrapping (dismantling) of an entire series of locomotives, often far short of an expected 25-year life. ***Once a new locomotive goes into commercial production, it is too late to measure and correct inherent design weaknesses and incipient component failures without major operating and financial penalties.***
3. As happens in the medical world, the author believes there are some basic preventive actions that locomotive owners and locomotive manufacturers should take in the earliest stage of “creating” a new locomotive design or in seeking to incorporate a new technology into a locomotive design. Like basic medical practices to prevent illnesses, these actions can be thought of as being akin to “washing one’s hands” to prevent the transmission of bacteria or viruses. ***The bottom line: new locomotives and especially new locomotive***

technologies must be designed and then tested (validated) for maintainability and reliability in a “pre-production phase” to ensure that the “production-ready” commercial product will meet all customer expectations.

ATTACKING THIS PROBLEM: TACTICALLY VERSUS STRATEGICALLY

We will frame this discussion around two concepts, one “tactical” (for the overall process of visualizing, designing, validating and manufacturing a new locomotive design, or incorporating a heretofore never used technology) and the other “strategic” (recognizing some key misconceptions about managing technological change, and adopting the corresponding realities to improve the probability of project success).

The tactical concept being proposed is known as “Reliability Growth Testing (RGT)” and is, in a few words, *the thorough validation of any new locomotive design (or a new locomotive technology) under “real railroad conditions” but only after a statistically significant fleet of “pre-production” locomotives have been assembled and provided to railroad users for validation.* “Pre-production” means that components, systems and locomotive configurations are essentially “ready for mass production” or “commercialization”. Railroads don’t acquire new locomotives for the sake of simply acquiring new locomotives, and it isn’t their core business to be a locomotive proving ground.

Assembling one (or a small number) of experimental, largely “hand built” (i.e., not production-ready and certainly not assembled on a production line) test locomotive(s) is a quick way of “getting an idea onto rails”. However, such locomotives prove nothing other than “the concept can function”. There is little to no realistic validation of the design, components, systems or performance. Test locomotives usually contain experimental non-production components with no track record of endurance, performance or maintainability. A locomotive of this type is ... an experiment.

Concept > one-or-a-few test loco(s) > is only an experiment

A fleet of “RGT” locomotives, on the other hand, must represent the locomotive builder’s best faith attempt at putting into service (for evaluation and observation by railroad personnel under actual railroad conditions) locomotives that are “just short” of being ready for broad-scale commercial production.

Concept > test loco(s) > pre-production locos. with RGT > commercial production

What does “pre-production” mean? MIL-STD-280 defined “*preproduction*” as being “... *an item suitable for complete evaluation of form, fit and performance. It is final in all respects, employs standard parts ... and is completely representative of final equipment.*” (I have added the underlining for emphasis.)

RGT is proposed and intended to serve as the “bridge” between the two extremes (test locomotive(s) versus commercially manufactured locomotives).

The strategic concept we will discuss is to understand and accept the frequent existence of nine (9) misconceptions that “managers” often have about how to make changes in technology (and recognizing and always following nine corresponding “realities”). The author believes that many people in the railroad and locomotive industries will realize the existence of many of the misconceptions in previous encounters with “disappointing” locomotives and locomotive technologies.

First, let us look at some “textbook examples” of “locomotive disappointment syndrome” with new locomotives that have had less than desirable “product launches”, and highlighting some of the reasons for their checkered histories.

EXAMPLE 1: ENGLISH ELECTRIC “DELTAIC” LOCOMOTIVE (1960s)

We’ll start our journey with a discussion about a new locomotive (and new-to-railroads diesel engine) in the United Kingdom. In 1955 the English Electric Company designed, built and put in service on the UK’s nationalized rail network an experimental (prototype) high-speed diesel-electric passenger locomotive. The locomotive was powered by a pair of Napier “Deltic” diesel engines originally designed for wartime British attack boats; each 2-stroke-cycle engine was of the “opposed-piston” design and had three (3) crankshafts arranged in a triangular-shape welded crankcase (hence the name “Deltic engine” which also became the “locomotive’s name”). The engines had the highest power-to-weight ratio of any diesel engine ever built, and the locomotive manufacturer felt that the ease of replacing engines would be a major “sales point” with railroad customers. (English Electric even had corporate visions of selling “Deltic” locomotives to Canadian railroads, as a competitive product against GM-EMD “E units”. In reality, only 3 EMD E8A units were ever sold to only one Canadian railroad!)

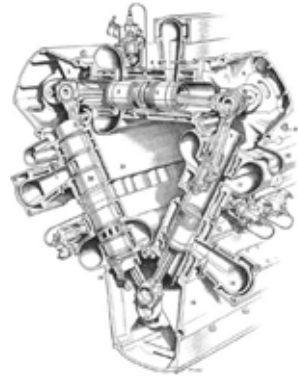
For six years the prototype “Deltic” locomotive operated on British Rail hauling passenger trains hauling relatively small-and-lightweight trains on trip schedules that never emphasized high-speed operation. Maintenance was

performed by English Electric engineers and technicians, and defective engines were usually removed-and-replaced (and corrected in the Napier engine factory) instead of such work being done in the railroad shops by railroad maintainers. The unique out-of-carbody maintenance of the engines can be described as being “repair by replacement”.

Shown below is the prototype Deltic locomotive now preserved at the National Railway Museum in Shildon, UK, and a 3-dimensional drawing of the Deltic engine’s unique 3-crankshaft opposed-piston configuration:



<https://worldwiderails.com/national-railway-museum/>



<https://www.dieselarmy.com/engine-tech/engine/significant-engines-in-history-how-the-napier-deltic-diesel-works/>

In 1960-1961 British Rail acquired 22 “production” Deltic locomotives, ordered to replace 55 older steam locomotives (a seemingly “great” operational-and-financial incentive, as each Deltic would be replacing 2.5 steam locomotives.) However, customer British Rail also changed the passenger train operations between London and Edinburgh, Scotland, to which the production Deltic locomotives would be assigned. Each production Deltic would now be expected to handle more passenger cars (heavier trains demanding more average power) on accelerated trip schedules (faster train speeds, again demanding more power) and with shorter turnaround times at London and Edinburgh (leaving less time for inspection and maintenance). And all inspection, repairs and maintenance would be performed by British Rail personnel in BR locomotive shops.

The 22 “commercial production” Deltic locomotives immediately experienced operating and maintenance problems, for several reasons:

1. Engine failures were now being “found and fixed” by railroad maintainers (not engineers from the engine manufacturer engineers). Many seemingly minor prototype engine issues with the single prototype locomotive were never resolved before starting production of the 22 locomotives and their engines. The locomotive and engine manufacturers and the ultimate railroad customer were “disconnected” in terms of what was considered acceptable for failures and maintainability. ***Engine validation, in particular, was never done under “real world” railroad conditions using “real world” railroad personnel. Failures and maintenance workload of the production locomotives exceeded the railroad’s expectations because the prototype locomotive and the production locomotives were subjected to radically different operating demands and maintenance practices.***
2. The 22 production locomotives were put into significantly more severe train service than the prototype locomotive had ever experienced. The production locomotives started experiencing failures that had never been seen. ***Locomotive validation before commercial production did not reflect “real world conditions.”***

Over several years the 22 production Deltic locomotives and their engines were repeatedly modified and eventually became a hallmark fleet for British Rail, but the corrective process took significant manpower, reduced locomotive availability and spent money to improve reliability, maintainability and satisfaction for train operations.

EXAMPLE 2: 6000 HP AC LOCOMOTIVES (1990s)

History tends to repeat itself, especially if history is not studied with an eye to avoiding mistakes of the past.

In the early 1990s a major U.S. freight railroad made commercial requests for new AC-traction diesel-electric locomotives each powered by a single 6000 (traction rating) HP diesel engine. The intent was to achieve a 2-for-3 replacement of older 3800-4000 HP DC-traction locomotives on high-priority higher-speed intermodal trains. Two major locomotive builders responded, each with a new-design diesel engine to achieve the 6000 HP single-engine rating. Both locomotive builders were also concurrently involved in many other “new locomotive development” projects for other customers in the freight, passenger and commuter markets.

One builder adopted (and modified for North American locomotive applications) a European-design new locomotive engine while the other developed a new engine based on a prior experimental design. Both builders performed considerable load testing of their several pre-production diesel engines in test cells and on stationary “test platforms” but little actual “real world” operating

time was accumulated before starting commercial locomotive production and deliveries. Only a small number of “field test” locomotives were assembled by both builders (with only limited revenue train operation on the intended railroad before “commercial” production began).

Once production deliveries began, various failure modes became apparent, particularly in the new diesel engines. Turbocharger mounts were insufficient; crankshaft bearing issues appeared. One builder’s locomotive also was subject to complaints from operating crews about “ride quality”. The two builders had taken two different paths regarding underframe (locomotive platform) and operator cab design-and-interaction. One builder chose an “isolated cab” on elastomeric cab mounts; the other builder had the cab welded to the platform. The “isolated cab” locomotive was later determined, following extensive instrumentation and testing in the railroad, to occasionally have “pitching” cab motions (fore-and-aft around a lateral axis) with a frequency of about 4.5-to-5 hertz (in the range of resonance for the lower human abdomen) while operating on certain types of track. (The cabs, and “crew complaints” differed widely between operations on wood crosstie and concrete crosstie track, as well as older “worn” welded rail and newer welded rail.)

Both builders did limited amounts of “track testing” before production; one builder, in fact, did extensive track testing at a commercial testing facility, accumulating mileage and engine running hours.

One locomotive model experienced sporadic truck hunting after delivery to the customer railroad, eventually mitigated by reducing lateral clearance between the inside of the truck casting and the outside surface of the axle journal box castings. The “solution”, however, involved replacing twelve (12) “wear pads” on each locomotive (2 per traction motor/axle) with slightly thicker pads. Doing that modification, however, required partially lowering each traction motor/wheelset combination (on a locomotive shop drop table) to gain access to the existing wear pads (as they could only be replaced when the traction motor/wheelset combo was not in position). This modification alone forced several hundred units onto drop tables to replace relatively simple components. (The wear pad had been designed as a “life of the motor/wheel combo part;” engineers should have considered the need for premature replacement.)

One builder’s fleet was subsequently repowered with lower-horsepower engines; the other builder’s fleet was prematurely retired after less than 10 years of service. The photo below shows two units being dismantled in a scrap yard after only a decade of life:



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Lessons learned from the “6000 horsepower era.”

1. Testing and validation of a small number of experimental diesel engines (particularly in stationary test cells) is no substitute for extensive “field operation” of pre-production test engines onboard locomotives. **The builders chose an “accelerated” design-build-deliver schedule, likely to satisfy the customer railroad’s demands.**
2. Operating and maintenance conditions (and “performance excursions or deviations”) when “tested” under a manufacturer’s control can be exceptionally different from conditions on a “real railroad”. Only after getting “production” locomotives in quantity on the customer railroad did the manufacturers discover previously unknown failures. **Again, “real world” means operating on railroad tracks, hauling railroad trains, operated by railroad personnel and maintained by railroad personnel in railroad shops.**
3. Validation testing at a dedicated “test facility”, such as accumulating mileage operated, will never result in identifying many common faults, defects or operating problems that do appear on “real railroads”. **Test tracks don’t always replicate all track design, maintenance or other conditions found on individual railroads.**

EXAMPLE 3: MULTI-ENGINE “GENSET” ULTRA-LOW EMISSIONS SWITCHERS (MID-2000s)

Many people know of (and may be highly opinionated about) the history of multi-engine “Genset” switchers, first introduced by a western railroad in 2005 (even though people with the opinions may not have had any first-hand or factual evidence or data to support their opinions).

The Genset “era” began with the commissioning in September 2004 by the one railroad, with a smaller locomotive manufacturer, for the assembly of a prototype 2-engine 1400 HP Genset switcher. The technical request was for a switching locomotive that could meet, and preferably be better than, the U.S.

Environmental Protection Agency (EPA) Tier 2 locomotive emissions Standard that went into effect January 1, 2005. The Genset switchers in fact were “cleaner” in some emissions than required by EPA Tier 2. Once delivered in late-2005 the prototype locomotive was put in rail yard switching service.

However, within six months of receiving the single prototype Genset locomotive, the railroad placed commercial orders with the same manufacturer and a competitor for two orders of “production” Genset locomotives (each with three engines, total rating 2000-2100 HP per unit) for almost 200 units, to be delivered starting in one year. “Real world” operations-and-maintenance of the single prototype (test) Genset accumulated only about one year-plus of experience and had little relevance to the second manufacturer’s design.

An additional factor in the Genset experience is that the smaller (3 per locomotive) truck-derivative diesel engines were “high-speed small-bore” (1800 RPM versus medium-speed large-bore 900-1050 RPM for typical locomotive engines). Such engines required (and require) different maintenance practices, maintainer skills and tooling than is common in maintaining, for example, an EMD 16-645E engine in a much older GP38-2 locomotive. One Genset builder used a domestic U.S. truck-derivative engine; the other builder opted for a European engine. (In retrospect, the railroad should have required both Genset builders to use a common engine product to simplify training and tooling in the railroad’s shops.)

Lessons learned from the Genset experience:

1. A small number of “test or prototype” locomotives (in the Genset example ... one prototype unit) is totally insufficient to validate commercially produced locomotives. **Again, a “test” locomotive only proves an experimental concept, not long term performance and certainly not maintainability or reliability of “production” locomotives.**
2. Significant “real world” operating time, mileage and accumulation of horsepower-hours is needed to identify and allow correction of component or system failures, design weaknesses, maintenance difficulties, etc. **One locomotive, being a “hand built experiment,” will never validate the design nor allow incipient component failures, etc to surface and be corrected.**
3. Test, test again, test more, redesign, validate and then “sell/buy”.
4. Avoid testing a few, “selling or buying many” and then modifying locomotives forever.

EXAMPLE 4: A BRIEF COMPENDIUM OF RECENT COMMUTER LOCO. & TRANSIT ISSUES

Here are several quotes from news media headlines and public documents from the past decade describing “disappointment” with new commuter locomotives (and even passenger cars):

- “[transit agency] new rail cars heading for a retooling” (a 2014 media headline): *“A new fleet of [agency] commuter rail cars, delivered 2-1/2 years late by the ... manufacturer, is now so plagued by mechanical, engineering, and software problems that it has to be shipped to a facility ... to be fitted with new parts.”*
- “[transit agency] Works on Locomotive Woes” (a 2016 media headline): *“While it is not where [fleet reliability] needs to be, and we will get it better, and we will get anything fixed that is owed us under warranty ...”*
- “[transit agency] stops delivery of new trains amid reliability problems with ‘Fleet of the Future’” (a 2021 media headline): *“[the agency’s] \$2.6 billion effort to swap out its decades-old fleet of trains with gleaming new cars has hit another snag ... temporary halt of deliveries ... has already accepted 300 of a planned 775 new cars ... routinely suffer a problem with software until the operator reboots the system ... wheels can develop flat spots during stops [in wet weather] ...”*
- “Tier 4 Locomotive Update and Delivery Status” (2021 transportation agency board minutes): Discussion documented progress with a new locomotive fleet ordered in 2012 and deliveries now being completed 2-years late.

“... reducing the engine cooling fan noise during the warmer summer months ... locomotives have experienced some continuing failure trends such as fluid leaks, sensor failures, and electrical grounding. These issues appear to be primarily the result of production quality. A design issue has been noted with the clamps at the turbo exhaust elbow ... (manufacturer) is working with engine (manufacturer) to address this engine issue ... An associated over-temperature detection software also needs further refinement, as false positive readings have caused unnecessary protective shutdowns ... issued a software revision to correct the problem.”

This fleet of new-design locomotives was originally validated by operating 1-2 units at a commercial test center. The delivery contract required operating 500 miles after arrival at the customer, without failure, for commercial acceptance; that was later raised to 2500 miles. Later units were operated after arrival by the agency in non-revenue (i.e., not moving passengers) “push-pull service” with other locomotives to provide “mobile load testing” as a means of “shaking down” reliability before entering regular operation.

As shown by these examples, improper validation of new locomotives and new locomotive technologies has existed in the locomotive and railroad industries for many decades.

A TACTICAL SOLUTION & COMMITMENT: RELIABILITY GROWTH TESTING (RGT)

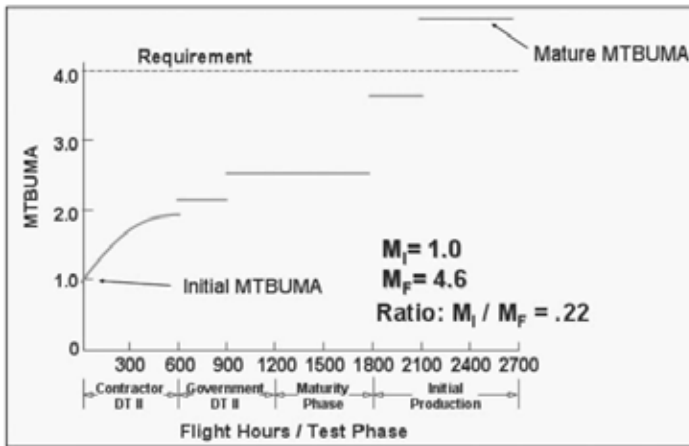
RGT is “... *the process of operating-and-maintaining a new product in pre-production phase with incremental identification and correction of component failures*” (quotation from E. E. Lewis, “Introduction to Reliability Engineering,” John Wiley & Sons, New York, 1987, page 161).

RGT was initially developed in the mid-1960s by an engineer, J. T. Duane, at General Electric’s Erie, Pennsylvania, plant. Duane was not however involved in GE’s locomotive product but with military applications of GE motors, etc. Duane’s discovery was:

- Component failure rates follow predictable patterns.
- Initial designs are often inadequate to meet reliability goals.
- Component redesigns iteratively improve reliability (leading to a “design-build-test-break-redesign-retest-validate” process).
- As time passes, progressive component improvements will generate successively smaller improvements in reliability, pointing to “product maturity”.

Duane first practiced what became known as RGT on components for various military products. Then Duane and his work became known to the U.S. Department of Defense (DOD) which was spending huge amounts of federal monies in support of the Vietnam War, including acquisition of newly designed aircraft and ground equipment.

In 1972 the U.S. Army Materiel Systems Analysis Activity (AMSAA) developed a statistical model for RGT to improve the reliability of military hardware as technological complexities increased. The AMSAA model was first used by the Department of Defense to investigate and improve the reliability of “Blackhawk” helicopters for the U.S. Army. When early pre-production Black Hawk helicopters were delivered, their “mean time between unscheduled maintenance actions (MTBUMA)” was only 1 hour (i.e., 60 minutes of flight time ... followed by corrective maintenance). Following a “test-fix-test-fix-test-produce” cycle, DOD and the manufacturer were able to improve the helicopter’s reliability so that MTBUMA increased from 1 hour, to 2.2, then to 2.6 and at the conclusion of 2100+ hours of flight time it reached 4.6 hours, exceeding the military’s goal of 4.0 hours MTBUMA. The illustration below is from: Larry Crow, PhD, August 21, 2008, “Reliability: A Look at Four Decades of Reform Within the Department of Defense,” ITEA Journal of Test and Evaluation, pages 244-246.



Interestingly, a recent business magazine article:

<https://www.forbes.com/sites/lorenthompson/2016/05/05/black-hawk-poised-to-be-u-s-armys-workhorse-helicopter-through-mid-century/?sh=1a4839c96532>

referred to the military's Black Hawk helicopter as being an "Aging Over-achiever: Black Hawk Poised To Be U.S. Army's Workhorse Helicopter Through Mid-Century." The DOD and Army (and the U.S. Navy and Marines) had been planning on phasing out and replacing the "aging" Black Hawk helicopter fleet with a new high technology "vertical lift system" integrating the functionality of three different military helicopters, but a lack of funding delayed the replacement. And now the Black Hawk's decades old record of high reliability and manageable maintainability is being highlighted. (Similarly, the U.S. Air Force "B-52" heavy strategic bomber, first flown in 1952, is now projected as remaining in active U.S. military operations through mid-century ... 2050.)

Not everything "new and more advanced" is, in reality, necessarily "better".

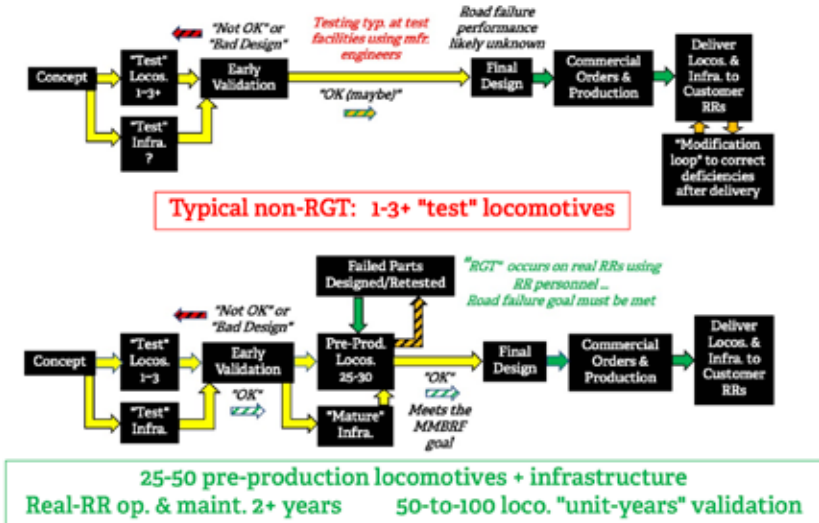
Recent or past applications of RGT in the U.S. military have improved the Abrams M-1 battle tank, Navy cruise missiles and the F-16 fighter jet.

VISUAL COMPARISON OF NEW LOCOMOTIVE VALIDATIONS: “NON-RGT” V “RGT”

The two illustrations (below) show, in general terms, the task elements and sequences typically associated with “non-RGT validation” of new locomotives and/or new locomotive technologies (the top drawing) as compared to “RGT validation” (the bottom drawing) as described and recommended in this paper.

This paper assumes the “new locomotive/new technology” being introduced has a significant amount of “new engineering, material and technology content”. Therefore, it considers having an RGT fleet of 25-to-50 locomotives (plus auxiliary equipment such as fuel tenders, if needed, and related infrastructure).

The significant differences between classic “non-RGT” and “RGT” validation are (1) the presence of pre-production locomotives, (2) in a fleet of statistically sufficient size, (3) operated and maintained by railroad personnel with manufacturer participation, (4) for a period of time sufficient to cause the identification and correction (redesign and revalidation) of components and systems most likely to fail or perform poorly, (5) followed by post-RGT commercialization of the new locomotive and/or new locomotive technology.



Both non-RGT and RGT validation have “end points” that can be considered “the voyager’s destination” (please refer to the quotation at the beginning of this paper). While non-RGT validation will always ultimately get you to some “destination” it may not be where you (the locomotive manufacturer and/or the

railroad customer) want to arrive at. And once you get to that “unplanned destination” it may be difficult, expensive or even impossible to “leave.”

Non-RGT validation will always “get you somewhere” (in terms of placing new locomotives and/or technologies in commercial service); the risk is that of ending up at a “bad destination.”

RGT validation, by contrast, clearly puts additional “trip burdens” on both the locomotive manufacturer and the railroad customer(s). Additional “program development” time is required to assemble and put into the field a fleet of “RGT validation locomotives. That also adds a financial burden (likely to the manufacturer) of building the pre-production RGT units (unless a railroad customer is willing to share the expense).

The greatest extension to “program development” time is the time required to execute the RGT “field testing” which includes finding, removing, analyzing, redesigning, installing and additional field testing of parts and systems showing significant risk of failure. (Again, think of RGT as being a “test-break-fix-test-finalize design” process.)

MARKET & SOCIETAL PRESSURES TO “MOVE QUICKLY” WITH NEW LOCOS. & TECHNOLOGIES

The reader may ask “*Why would any locomotive manufacturer (either an “established” manufacturer or a small “new market entrant”)* not use RGT to validate a new design before going into commercial production?”

There are several reasons why many new “products/services/technologies” are often “rushed into the market” and end up being less than they were hoped to be:

1. We live in a society where we are “flooded” with a multitude of software apps for personal devices such as “smart phones” and computers. (If the “app” doesn’t work properly, sit tight and a revised app “fixing” the problems will soon be available for you to download. And likely followed by yet another “fix.”)
2. The media provides a constant deluge of “information” about new technologies, devices, etc. (Ironically, most “computer developments” in general appear to be for personal entertainment purposes. The “computer age” has not, for example, brought about many of the “benefits and savings” (including a “paperless work space”) once promised during the early stage of personal computing. Have you “run out of digital storage space” lately?)
3. Engineering as the practice of applying scientific knowledge has shifted from the “slide rule” to the “simulation”. America put multiple citizens on the moon (and brought all of them safely back home to Earth) based almost entirely on calculations made using pencils, paper and slide rules. One advantage of “slide rule calculations” is that an engineer has to master “orders

of magnitude” (i.e., placement of the decimal point). Is the “answer” 10.97 or 109.70? Does the “answer” intuitively “seem correct”? Computer simulations are great tools for contemporary engineers. However, unless care is exercised in modeling and interpreting simulation results, the old adage “GIGO” (garbage in, garbage out) can come back to haunt an engineer.

4. Society in general (citizens, people, residents, workers, managers) has been conditioned to “*make it work, make it quick, nothing is impossible, do it*”. An electric car manufacturer now has one of its EV autos, launched into space in 2018, racing along at more than 24,000 miles per hour! Yet here on Earth we will need a massive investment over the next decade (at minimum) in new carbon-free electricity generation/transmission/distribution to facilitate a broad conversion from personal automobiles consuming petroleum fuel to zero-emissions vehicles.
5. Particularly in situations where governmental bodies (such as local governments and agencies such as those involved in “air quality”) have public funds available for “new technology improvements” (such as ... reducing or eliminating locomotive emissions), such government activities can place great pressure on “speed of development and implementation”. Rephrasing an old saying ... “speed kills” ... can be reworded to “speed adds risk to technological change”. (We will discuss this in our discussion about “strategic thinking” for technological change.)
6. Society in general tends to forget (or it ignores or refuses to study and learn) history. Particularly technological history. And as industries react and respond to market and financial pressures, they sometimes shed large amounts of “institutional memory” as experienced people leave the organization (or are left by the organization).

WHO PERFORMS “RGT”?

Ideally, the locomotive manufacturer should establish and perform an on-going RGT process when introducing a new locomotive model (or a locomotive with a significant infusion of new technology). But at least one railroad must also be involved, preferably a railroad that will be operating and maintaining the “RGT fleet” during measurement of reliability, identification of incipient failures, redesigning components to eliminate the failures, installing and field testing the “redesigned” components and finally ... agreeing that the pre-production locomotive design has reached “reliability maturity” and is “ready for commercial production.

There are several RGT software models available for developing, managing and evaluating an RGT program. We will not select or recommend any in this paper.

WHAT IS AN “RGT FLEET”? WHO “OWNS” IT? WHAT HAPPENS TO IT OVER TIME?

Given the complexity of locomotives (... and they can only become even more complex as we move toward “decarbonization” ...), the author feels that the following criteria would apply in general to performing Reliability Growth Testing for a newly-designed locomotive model or a locomotive model having significantly new technology included.

A typical RGT fleet for a new “high-horsepower line-haul” locomotive model would likely consist of 20-to-35 locomotive units. Again, these must be “pre-production” locomotives assembled using components, parts and systems that are “production ready”. These are not “hand built” test or experimental locomotives. Every locomotive in the RGT fleet must be operated in actual railroad service and maintained by railroad personnel (with manufacturer technical assistance) for at least two (2) years. Two years of operation is generally adequate to result in most component failures to appear, be analyzed, corrected through redesign, reinstalled and then operation continued. It is important that adequate service time be experienced so that “weak or poorly designed” components can be allowed to fail, be replaced, redesigned and then reinstalled.

A 20-to-35 locomotive unit RGT fleet, operating for 2 years, will accumulate 40-to-70 “locomotive unit-years” of actual railroad operation and maintenance. Assuming a typical line-haul locomotive will operate in train service an average of 5,493 hours per year (based on 8,760 hours in a year, 95% availability for train service and 66% actual utilization of available time), and accumulate 100,000 miles per unit per year ... such an RGT fleet will produce the following performance parameters over 2 years:

- 219,720 to 384,510 locomotive-hours of operation
- 4 million to 7 million locomotive unit-miles of operation

Assuming a conservative average of 300 engine megawatt-hours of work per month, the RGT fleet will produce:

- 144,000 to 252,000 megawatt-hours of engine work

It is the author’s opinion that the locomotive manufacturer must be responsible for manufacturing the RGT fleet. It is likely that the manufacturer would be the “owner”, but assuming the RGT program is successful and commercial production ultimately starts ... the RGT fleet can be reconditioned at the end of the RGT program and commercially sold to customers.

On the surface, this approach and the equipment (and financial) demands described herein may seem extreme to some readers. However, locomotive manufacturers have already engaged in this type of “RGT fleet” validation in the



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past. The problem is that such RGT fleet validation has not always been done consistently!

Here are some examples of past new locomotive and new locomotive technology validations (i.e., RGT fleets) that have happened here on North America:

- A major locomotive manufacturer assembled and tested (in actual railroad service) a fleet of more than 12 “test locomotives” each containing a new generation diesel engine.
- A major locomotive manufacturer assembled and tested (in actual railroad service) a fleet of 15 AC-traction and 35 DC-traction line-haul locomotives, each powered by a new diesel engine design (2003-2005).
- A major locomotive manufacturer assembled and tested (in actual railroad service) a fleet of 25 line-haul locomotives, each powered by yet another new diesel engine design (2013-2015).

The RGT “yard stick” or measure recommended in this paper for validating a new locomotive design or new locomotive technology is “mean miles between road failures (MMBRF)”. The accumulated mileage of the RGT locomotives must be tracked over time, and all “road failures” also tracked. Road failures must be jointly agreed to by the manufacturer and the railroad(s). For line-haul locomotives an MMBRF “target” (at the conclusion of RGT validation) of 55,000 MMBRF (about 2 road failures per year) seems to be realistic and achievable.

If the MMBRF target or goal cannot be reached in the planned length of time for the RGT program, that is a clear signal that the locomotive design (or the technology) “may never function properly” and that will clearly call for some major decisions by the manufacturer and the railroad customer(s). In general, a new locomotive design (and/or installed technology) should show regular and consistent improvement “upwards toward the RGT target.”

RGT VALIDATION CAN BE EXPENSIVE & TIME CONSUMING. (WHY “WASTE” THE MONEY?)

The two “*real questions*” to ask are:

“As a locomotive manufacturer (and as a potential locomotive customer), can I afford to NOT perform Reliability Growth Testing, and risk wasting money to produce a locomotive (or introduce a locomotive technology) that does not perform, that ultimately causes loss of customer support (and likely loss of future sales) and will force my customers to waste their monies modifying locomotives to make them less unacceptable?”

And

“As a locomotive customer, can I afford to invest in a new locomotive and/or new locomotive technology that has significant risk of performing poorly?”

A STRATEGIC SOLUTION & COMMITMENT: AVOIDING MISCONCEPTIONS ABOUT TECHNOLOGICAL CHANGE

Anyone responsible for managing technological change should be cautious in proceeding and particularly in avoiding nine (9) misconceptions that often cloud decision making and can create chaos in technological projects. The former Staff Executive for Corporate Technology Planning at General Electric in the 1980s, Lowell F. Steele, published a book “Managing Technology” (1989, McGraw-Hill), as a follow-up to an article in the Harvard Business Review magazine. Steele believed there are nine (9) “misconceptions regarding technology” that often cause technology projects to go “off the track.” Steele also postulated nine (9) “realities of successful technological change” to keep projects “on track” and destined toward a successful product launch, etc:

"Managers Misconceptions About Technology"

1. **Invention** (creating something new)
2. **Innovation** (initial applications)
3. **Diffusion & commercialization** (“making the choice, and spending \$s to acquire bankable assets”)

Misconceptions regarding technology:

1. Always go for “best possible”
2. Technology is picked rationally
3. Change always occurs as planned
4. Success follows initial application
5. Technology has intrinsic value
6. Radical change will always succeed
7. Success is guaranteed by investment
8. Enhancements guarantee progress
9. New technologies can be grafted onto existing businesses and operations



Realities of successful tech. change:

1. Use only what is “good enough”
2. Past practice limits future change
3. Plan for things to go wrong (“Murphy’s law”)
4. Future unknowns are risky
5. Customer (user, not seller) determines value
6. New is not necessarily better
7. Infrastructure is often the weakest link
8. Standards, constraints, routines are critical
9. A new technology and supporting existing business systems must be jointly produced and installed

From: Lowell Steele in his 1989 book, Managing Technology, McGraw-Hill, pages 52-67
(follow-up to Harvard Business Review Nov-Dec1983, “Managers Misconceptions About Technology”)

Lowell Steele was the Staff Executive for Corporate Technology Planning at General Electric

Readers of this paper are urged to review and follow Mr. Steele’s advice. And when doing that, think back to situations and personal experiences with introducing new locomotive models and/or new locomotive technologies.

If you have been in this industry for considerable time, you most certainly have had situations that now, in retrospect, you can identify where a “misconception” contributed to “disappointment”.

A CLOSING THOUGHT

For both experienced readers and for readers who are new to the locomotive and railroad industries ... it is hoped that this discussion about a **tactical approach** to validating new locomotives and technologies (**Reliability Growth Testing**) and a **strategic understanding of “technological realities”** (**Lowell Steele’s recommendations**) will help you to avoid “locomotive (and technology) disappointment syndrome”!

“Those who never change their minds, never change anything.”

- Winston Churchill

**FUEL, LUBRICANTS AND ENVIRONMENTAL COMMITTEE
(formerly known as Fuel and Lubricants Committee)**

2020

1. Locomotive Engine Fuel Economy Testing
2. Locomotive Engine Coolant-Best Practices
3. Performance Review of OEM Specifications for Traction Motor Support Bearings

2019

1. The Effects of a Hydrogenation-Derived Renewable Diesel (HDRD) Fuel Surrogate on Fuel Consumption and Emissions from a GE Tier 2 Locomotive
2. Used Oil Analysis – Is It Reliable? (2018 Railroad Used Oil Test Laboratory Evaluations)
3. Review of AAR M-963-84 All-Year Journal Box Lubricating Oil Specification
4. Engine Oils for Improved Fuel Economy and Oil Consumption to Railroad Services

2018

1. Diesel Fuel Heating Value Correction for Locomotive Fuel Consumption Calculations
2. SCR for Locomotive NOx Reduction
3. X-Ray CT Scanning of Diesel Locomotive Fuel Injectors

2017

1. One Size Fits All? Clarifying Standards for Locomotive Fueling Infrastructure –Storage Tank Overfill Protection
2. Statistical Evaluation of Lube Oil Analysis as a Potential Predictive Maintenance Tool
3. Failures Resulting from Misunderstanding Used Oil Data, Locomotives, and the Trouble with Trending
4. High Pressure Common Rail Engines in Locomotive Service: Symptoms, Causes and Cures for HPCR Deposits
5. Diesel Fuel Cleanliness- Application of the ISO 4406 Particulate Contamination Codes

2016

1. Defining LMOA Generation 7 Engine Oil Performance Category
2. Natural Gas for Rail Applications: LNG Fuel Quality Considerations
3. Effects of Fuel Composition on In-Service Engine Oil Properties

2015

1. Railroad's Fuel Options, Research and Literature Review
2. Transmix-Derived Fuel for Locomotives

2014

1. Fuel Filtration Considerations in the Changing Landscape of Engines and Fuels in Railroad Applications
2. Diesel Fuel Troubleshooting Guide
3. Locomotive Biodiesel Updates
4. Cold Soak Filter Plugging Test

2013

1. Railroad's Changing Fuel Supply: Diesel No. 2 (high-sulfur, low-sulfur, and ultra-low sulfur), Biodiesel, Fischer-Tropsch, and Blends
2. Locomotive Fuel & Lubricant Oil Filters 101
3. Generation 6 Locomotive Engine Oil Properties

2012

1. Diesel Engine Health Prediction with Integrated Lube Oil Analysis
2. Locomotive Durability Test Protocol for Alternate Fuels and Biodiesel

2011

1. Diesel Exhaust Fluid Properties & Technical Information
2. Locomotive Biodiesel Fuel Update

2010

1. The Clean Water Act and How it Affects Railroad Operations

2009

1. New Generation Oil Additive Technology for Engines Operating on Low & Ultra-Low Sulfur Diesel Fuel
2. The Clean Water Act and How It Affects Railroad Operations
3. Locomotive Testing of an Automatic Self-Cleaning Lube Oil Filter & Centrifuges

2008

1. Prevention of Fuel and Fuel Filter Headaches
2. Locomotive Idle and Start-Up Exhaust Emissions Testing
3. Operational Effects of Low Sulfur Diesel Fuel in Locomotives

2007

1. Automatic Self-Cleaning Lube Oil Filters and Centrifuges
2. Diesel Fuel 2007 and Beyond -What will be in Your Tanks?

2006

1. Fuel Additives-A Possible Method to Reduce Fuel Consumption in Railroad Diesel Locomotives

2005

1. Engine Oil 202 - Refined Base Oils and their Importance in Lubrication
2. Biodiesel - A Potential Fuel Source for Locomotives

2004

1. Discussion of the LMOA Fuels, Lubricants and Environmental Committee Pentane Insolubles Procedures Revision 4
2. Engine Oil 101 - Viscosity and Additives
3. Used Oil Analytical Result: What do they Mean, How to Interpret the Results and How do you Respond?

2003

1. Laboratory Results May Put Your Locomotive at Risk
2. Top of Rail Friction Modification Studies on the BNSF

2002

1. Improved Generation 5 Lubricant Provides Potential for Extended Lube Oil Filter Life
2. Corrosion Protection of Locomotive Cooling Systems

2001

1. On-Board Oil Management System
2. Evaluation of Locomotive Engine Oil Analytical Laboratories
3. Fuel Additives - Friend or Foe

2000

1. Biodegradability and its Relevance to Railroad Lubricants and Fluids
2. Engine Lubricating Oil Evaluation Field Test Procedure
3. Detecting Abnormal Wear of AC Traction Motor, Pinion End, Armature Bearings Through Lubricant Wear Debris Analysis
4. Further Development in Top-of-Rail Lubrication Testing

1999

1. Lube Oil Analysis-Achieving Quality Results
2. Effects of Engine Lubricants on Oil Filtration
3. Recycling and Re-refining of Used Lubricated Oils

1998

1. Safety and Chemical Cleaners
2. Development of a Low Emissions, Dual Fuel Locomotive
3. Fuel Oil Stability Update
4. Ten Questions on EPA's Locomotive Exhaust & Emission Regulations

1997

1. Ferrography-Used Oil Analysis Program
2. 2000 - A New Millennium for Locomotive Maintenance: EPA Exhaust Emissions Regulatory Impacts
3. Standardized Test Procedures - Current Developments
4. Industry Updates and New Developments

1996

1. Standardized Test Procedures-The Annual Subcommittee Update
2. Diesel Fuel Standards and their Applications to Railroad Fuel Quality Issues
3. A Look at Generation 5 Oil Performance and Future Oil Needs
4. LNG as a Railroad Fuel

1995

1. MSDS'S - What do they tell us?
2. Applying Satellite Communications Technology to On-Line Oil Analysis of Crankcase Diesel Engine Lubricants
3. Standardized Test Procedures - Past, Present & Future Developments
4. Locomotive Exhaust Emissions Regulations

1994

1. TBN-A Review of Currently Accepted Methods.
2. GE Multigrade Lubricating Oil Testing and Specification.
3. The Economic Impact of Low Sulfur Diesel Requirements.

1993

1. Used Oil Analysis of Multigrade Oils and Condemning Limits.
2. Insoluble Determination with the Advent of Multigrade Diesel Engine Oils
3. Bioremediation

1992

1. Environmental Issues Relating to Multigrade Railway Issues
2. Readily Biodegradable and Low Toxicity Railroad Track Lubricants
3. Support Bearing Oils
4. Recycling and Re-refining Locomotive Oils

1991

1. Infrared Spectroscopy as an Analytical Tool
2. Diesel Exhaust: Health Effects Research and Regulations
3. Traction Motor Gear Case Seals and Lube Containment (Oil Lubricant)
4. Partnership in Development

1990

1. The Responsibility of Railroads and Facility Managers in the Handling and Disposal of Hazardous Materials
2. Update on Diesel Fuel Regulations
3. Diesel Exhaust and Worker Exposure
4. Field Experiences with Multigrade Railroad Locomotive Oils.
5. Conrail Wheel/Rail Lubrication Update

1989

1. Field Test Data Follow-Up and Description of "Generation 5" Locomotive Crankcase Oil
2. Diesel Emissions: Regulations and Fuel Quality
3. Petroleum Storage Tank Regulations - Guest Speaker - George Kitchen, International Lube & Fuel Consultants

1988

1. Used Oil Analysis and Condemning Limits
2. Review of A.A.R. Procedure RP - 503, "Locomotive Diesel Fuel Additive Evaluation Procedure"
3. Update on Improved Oils - Multigrade
4. Wheel Flange Lubrication Update - Lubricants Being Used
5. Survey of Disposable Practices or Locomotive Engine Lube Oil and Lube Oil Filters
6. Speaker on Overview of Environmental Requirements for The Use of Petroleum Products in The Railroad Industry - Peter Conlon - AAR

1987

1. Common Fuel Additives and their Effectiveness
2. History of LMOA Lubricating Oil Classification System
3. Performance Requirements Needed by the Railroads for a New Generation Lube Oil
4. How do we Provide the Performance Needed for a New Generation Oil

1986

1. Extended Performance Lubricants
Through Better Chemistry
2. Fuels and Lubricants Handling Hygiene
3. Fuels Availability and Price Outlook
4. Selection of Lubricants for Wheel
Flange and Rail Lubricators

1985

1. Disposal of Lube Oil Drainings
2. Non-ASTM No. 2 - D Fuel
3. Oxidation Analysis
4. Wheel Flange and Rail Lubrication

1984

1. Locomotive Filters
2. Traction Motor Gear Lube Field Test

1983

1. Field Test Update of Multigrade Oils
2. Update of Alternate Fuel Testing
3. A Review of Locomotive Fuels

1982

1. Energy Conserving Lube Oils
2. Alternative Fuels Update
3. Availability of Medium and High
Viscosity Index Railroad Oils
4. Journal Box Oil and Aniline Point.
5. Traction Motor Gear Lubricant Update
6. Traction Motor Gear Case Seals

1981

1. Effects of Using Alternate Fuels on
Existing Diesel Engines
2. Update on Cold Weather Procedures for
Fuels
3. New Techniques in Lube Oil Analysis
4. Traction Motor Gear Lubrication.
5. Multi-Viscosity Oils as an Energy
Conservation

NEW TECHNOLOGIES COMMITTEE
(formerly known as the New Developments Committee)

2016

1. ECP Beyond Train-Handling – How ECP System Development Can Enhance Other Locomotive Technologies
2. New Developments in Diesel-Electric Passenger Locomotives
3. Diesel Emissions Control Technologies – A Post-Tier 4 Review

2015

1. Second life for DC locomotives
2. Natural Gas – Dual Fuel Locomotives Developments and Field Demonstrations
3. Hidden Costs of Locomotive Modernization

2014

1. End of the Line for the MU Jumper Multiple Locomotive Unit Control: A Discussion of Past, Present and Future
2. Natural Gas Economics and Fueling for Locomotives
3. What are my Natural Gas Engine Choices?

2013

1. Locomotive Data and Acquisition Reporting Systems (LDARS) and Crash Memory Module (CMM)
2. Natural Gas Locomotives
3. Remote Monitoring of Locomotive Systems
4. Extending Battery Life

2012

1. Tractive Effort and Adhesion: A Review of Yesterday, a Look at Today, Concerns for Tomorrow
2. A New Tier 0+ Solution EFI for EMD 645 Engines
3. Locomotive Repower with a High-Speed Engine and a Reduction Gearbox
4. The A3 Problem Solving Process in Action – a Case Study

2011

1. Positive Train Control
2. EPA Tier 4 Locomotive Development Status Update

2010

1. Tier 4 Diesel Emission Reduction Strategies
2. Testing of the BNSF Fuel-Cell Switch Locomotive: Part 2

2009

1. Ethanol Electric Hybrid Locomotives
2. Testing of the BNSF Fuel Cell Switch Locomotive: Part 1

2008

1. Maintenance Experience with Gen Set Switcher Locomotives to Date
2. Maintenance of the BNSF Fuelcell-Hybrid Switch Locomotive

2007

1. Fuel cell Hybrid Switcher Locomotive: Engineering Design
2. Locomotive Digital Video Recorder
3. CN Distributed Braking Car

2006

1. Variable Hybridity Fuel cell-Battery Road Switcher
2. GE Transportation-Hybrid Freight Locomotive
3. Dynamic Brake Status Reporting

2005

1. PL42AC Locomotive-Overview
2. Fuel Cell Locomotives
3. Locomotive Electric Hand-brake Systems

2004

1. GE Evolution Locomotive – An Overview
2. EMD SD70Ace Locomotive-Reliability for 2005 and Beyond
3. Get Them into Condition: Condition Based Traction Motor Reliability
4. Making the Switch - An Update on the EMD GP20D/GP15D Switcher Locomotive
5. “Fuel Proof Tank Repairs” - A Best Practice for your Locomotives

2003

1. New MPXPRESS Commuter Locomotive Models MP 36PH-3S & MP36PH-3C
2. The Green Goat Hybrid Locomotive
3. Observation on Auto Engine Start/Stop

2002

1. On Board Rider - A Remote Locomotive Condition Monitoring System
2. Cool Your Jets: A Low Cost, High Performance Rooftop Air Conditioner

2001

1. Performance and Economic Aspects of Various Environmentally Friendly Coatings for Rolling Rail Equipment
2. Non-destructive Testing: Crack Detection Technology - EMFaCIS

2000

1. FIRE: EMD Turns up the Heat on Railroad Electronics Integration
2. Put the Chill on Air Conditioning Costs
3. Do Not Get “Steamed” Over Fuel Tank Repairs
4. Industry Responses to Emission Regulations
5. Improved Adhesion Through the Use of Individual Axle Inverters

1999

1. Locomotive Filtration-Where are We Going?
2. EMD Markets a New Line of Switchers

1998

1. Expert Systems
2. EMD SD90MAC 6000 HP Locomotive - Where Are We Today? GE AC6000CW Locomotive - Where Are We Today?

1997

1. An Overview of the Electro-pneumatic Train Brake
2. Locomotive 6724, Where Are You? GPS, Mobile Telemetry and GIS Technologies in a Railroad Environment
3. Runout Measurement Using Non-Contact Sensor Technology
4. Common Rail Fuel Injection

1996

1. Activities Toward New Safety Standards for Passenger Equipment
2. SP-3 Thin Sensor Technology for Variable Force Measurement
3. Top-Of-Rail Lubrication
4. Traction Motor Vibration and its Effects

1995

1. Belt pack Locomotive Control System
2. The MK1200G Switching Locomotive
3. Advanced Traction Motor Testing

1994

1. Electronic Fuel Injection Systems.
2. Status of Distributed Power in Freight Trains.
3. Advances in Distributed Power-Iron Highway.

1993

1. New Technology to Solve Old Problems
2. Developments in Off-Shore Technology
3. Updates on AC Traction Developments

1992

1. Talking to the "Smart" Locomotive
2. Cab Noise Abatement
3. Electronic Management of Locomotive Drawings

4. Update on High Productivity Integral trains
5. AC Traction - A New Development

1991

1. Locomotive Cab Integration and Accessory Management
2. Improvements in Locomotive Adhesion Performance
3. The Role of Duty cycles in Locomotive Fuel Consumption.
4. What's New in Gadgets and Black Boxes: What do our Locomotives Really Need?
5. Failure Analysis

1990

1. Motor Driven Air Compressors for Diesel-Electric Locomotives
2. Locomotive Cab (HVAC) Heating, Ventilation and Air Conditioning Systems
3. Effect of Technology on Standardization of Cab Control Equipment
4. Locomotive Durability, Reliability and Availability Understanding Your Abilities

1989

1. A Rational Approach to Testing Locomotive Components
2. New Developments in Locomotive Cab Design

1988

1. Amtrak F69 PH AC Passenger Locomotives
2. New Component Developments Retrofittable to Older Model Locomotives
3. Locomotive Applications of Caterpillar Engines
4. Wheel slip Control for Individual Axles

1987

1. Electronic Fuel Injection Systems
2. Update on Electronic Governors
3. Recent Advances in Steerable Locomotive Trucks - the EMD. 4 Axle, 4 Motor HT-BB Articulated Truck
4. Converting an F40 Locomotive to AC. Traction

1986

1. Future Train Control Systems
2. Bringing Future Train Control Systems Back to Earth
3. Low Maintenance Locomotive Batteries
4. Electronic Engine Control Systems

1985

1. The Sprague Clutch for EMD Turbocharged Engines
2. AC Traction Locomotives Update
3. Natural Gas Locomotive Update
4. Ceramic Coated Engine Components
5. Locomotive Cab Developments

1984

1. GE Dash 8 Locomotives
2. EMD 50A Series Locomotives
3. Natural Gas Locomotives
4. Appraisal of the AC Traction Locomotive

1983

1. Microprocessors for Locomotive Control and Self Diagnosis.
2. Locomotive Fuel Tank Gauges
3. Locomotive Aerodynamics
4. Bombardier HR 616 Locomotive
5. Missouri Pacific - Phase III Locomotive Heavy Repair Facility, N. Little Rock, Arkansas

ELECTRICAL MAINTENANCE COMMITTEE
(formerly known as the Diesel Electrical Maintenance Committee)

2020

1. AESS & Battery Health Task Force Study
2. Compressor Control Reliability Improvement for GE Locomotives
3. Distributed Power Consists Setup
4. The Evolution of Traction Motors

2019

1. Lost In Transition: The Collaborative Effort to Develop a Solution for Generator Transition Circuit Failures
2. What Can the Load Regulator Tell Me?
3. Getting off to a Good Start

2018

1. Slip Rings & Collectors - What Keeps Your Wheels Turning?
2. Still Stuck in the Middle With You: PTC and Short Line Railroads
3. Condition Based Maintenance VIA Rail Canada
4. Troubleshooting a One-Way Serial Link on an EMD SD70M Using EM2000
5. Battery Temperature Performance Study with Strategies to Optimize Charging and AESS Settings

2017

1. We Didn't Start the Fire: Best Practices for Inverter Cooling Management
2. Troubleshooting the Excitation Circuit on an EMD SD40-2
3. AESS (AUTOMATIC ENGINE START STOP)
4. A Study of Locomotive Battery Charging and Performance

2016

1. Stuck in the Middle With You: PTC and Short Line Railroads
2. Troubleshooting Multiplexer Faults on EMD Locomotives Using EM2000
3. Battery Technology Within the Diesel Starting Industry
4. Supercapacitor Safety

2015

1. Modular Hardware & Software
2. Idle Reduction on GE Locomotives
3. The Ghost in the Machine: EMI on Your Locomotive

2014

1. FRA Requirements for Headlights, Ditch Lights & Other Lighting
2. Investigating Distributed Power Failures
3. Product Validation and Certification
4. Sensors and Transducers Installation Tips

2013

1. Locomotive Diagnostics
2. Positive Train Control (PTC) - Onboard Segment: An Update and Recommendations
3. Locomotive Battery Storage and Maintenance A Recommended Best Practice

2012

1. Extending Locomotive Maintenance to 184-day Intervals - Part II
2. Design for Reliability: Locomotive Lifecycle Approach

2011

1. Efficiency and Maintenance Aspects of the New Amtrak Electric Locomotive ACS 64
2. Modernizing an Aging Heavy Haul Locomotive Fleet
3. Three Stage Battery Charging for EMD Locomotives

2010

1. Infrared Thermography in Locomotive Electrical Maintenance
2. Electrical Connectors: Standards & Field Service Challenges
3. Locomotive Batteries and Long Term Storage
4. Long Term Storage Electrical Rotating Equipment
5. Long Term Storage Electrical Equipment

2009

1. EMD Slip Rings-Brushes & Wear
2. Using Test Instrumentation Safely on Gen-Set and AC Locomotives
3. Extending Locomotive Maintenance
4. 710 ECO Power

2008

1. Challenges with Retrofitting New Systems to Old Locomotives
2. Locomotive Maintenance Conventional vs Genset
3. Using Test Instrumentation Safely
4. Electric Motor Preventative Maintenance

2007

1. Finding Open and Short Circuits on AC Traction Motors
2. Locomotive Cab Signal Failures and Troubleshooting
3. Maintaining Main Generators - Some Safer Methods
4. Locomotive Software Management

2006

1. Application of 2000 HP Hybrid Yard and Road Switcher Locomotives
2. Portable Troubleshooting Data Logger
3. Adapting a Freight Locomotive into a Passenger Locomotive

2005

1. Wireless Communication Technology Overview
2. Maintenance Benefits of the Green Goat - Part A Hybrid Switcher Update – Green Goat - Part B

2004

1. Electrical Maintenance Benefits of the SD70ACe
2. Remote Monitoring & Diagnostics: Development and Integration with Maintenance Strategies
3. Carbon Brushes Revisited – an Update for 2004

2003

1. Diesel Driven Heating System
2. Trainline - ES TIBS as Applied to CN/IC Locomotives
3. Head End Power (HEP) Safety Issues
4. Fuel Savings Using Locomotive Consist Management

2002

1. Commutator Profiling
2. Basics of an Operations Center
3. Diagnostics for Older Locomotives
4. Traction Motor Protection Panel
5. "Locomotive Auxiliary Power Units" - Lessons Learned

2001

1. Diagnostic and Predictive Maintenance
2. Locomotive Replacement Control System
3. Automatic Shutdown Startup Controls - Fuel Savings through Technology
4. Locomotive Alternative Air Conditioners

2000

1. Custom Electronics and their Applications
2. Locomotive Wire Update
3. Integrated Air Brake & Distributed Power Under EMD Fire System
4. Carbon Brushes - A Fresh Look
5. RM&D - What It Is, What It Does
6. An Alternate Adhesion System

1999

1. Transition Panels for Older Locomotives
2. R.S. A.C. Crash Worthy Event Recorder Update
3. Traction Motor Suspension Bearing Temperature Monitoring System
4. EMD SD90MAC 6000 HP Locomotive-An Update
5. IGBT-What's New for GE AC6000 Locomotives

1998

1. Locomotive Troubleshooting Assistant
2. Locomotive Electronic Brake Maintenance

3. SD70MAC Capacitor Discharge Procedure
4. Power Savings for Electrical Locomotives
5. Auto Stop/Start and Layover Systems

1997

1. Review of Battery Maintenance and Available Options
2. Battery Charger/Booster
3. Locomotive System Integration
4. Electronic Governors

1996

1. EMD SD80MAC High Voltage Safety
2. GE AC Locomotive Electrical Safety Features
3. Electromagnetic Interference (EMI on AC Locomotives)
4. QTRAC 1000 Adhesion Control System
5. Locomotive Health Monitoring- The Key to Improved Maintenance

1995

1. Canadian National Battery Water Usage
2. Remote Diagnostics-Radio Download
3. Programmed Preventive Maintenance
4. Commutation Monitoring in Locomotive DC Traction Motors
5. The EMD Diesel Engine Control (EMDEC) System

1994

1. Safety First - Video on Electrical Safety
2. Locomotive Health Monitoring Systems
3. Event Recorder Update SD60 Dynamic Brake Improvements

1993

1. Automatic Engine Shutdown and Restart System
2. Layover Systems/Standby Power Systems
3. CN North America – Electronic Temperature Control
4. Speed Sensing Devices Adhesion Alternative
5. Electronic Brake 6. Modern Tooling Update

1992

1. Nickel-Cadmium Batteries as an Alternative
2. Overview of Locomotive Microprocessor Based Controls
3. Locomotive Air Conditioning
4. Testing Traction Alternator Fields on EMD Locomotives
5. Flange Lubricators

1991

1. Locomotive Rebuilding Something Old- Something New. Standardization of Electrical Equipment
2. Locomotive Batteries: a. Storage Handling Procedures; b. Recommended Maintenance Procedures; c. Recommended Repair Procedures
3. Amtrak's AC Traction Locomotives
4. Modern Tooling for Electricians Recorders
5. Why Can't We Have One Central Computer?
6. EPA and Regulation Driven Cleaning

1990

1. Modern Tooling of Electrical Troubleshooting
2. Maintaining Solid State Event Recorders

3. Why Can't We Have One Central Computer?
4. EPA and Regulation Driven Cleaning

1989

1. Modern Tooling for the Troubleshooting Electrician: a) test meters available (single function); b) test meters available (multiple functional); c) analysis and diagnostic tools
2. Sound Electrical Repairs and Practices for: a) traction motors; b) grids and fans; c) wire and cable solderless termination
3. Guidelines for Preparing Electricians for the 1990s

1988

1. Utilizing Magnetic Recorders for Maintenance
2. Solid State Locomotive Recorder
3. Improved Utilization of GE DASH 8 Data Recording Systems
4. Locomotive Health Data and Its Uses to The Railroad
5. Improved Data Acquisition from EMD's 60 Series Display Computer

1987

1. Proper Maintenance of Electrical Fuel Savings Options
2. Preliminary Report on AAR Traction Motor Study

1986

1. Cleaning, Handling & Storage of Electrical Equipment: A. Solid State Components; B. Rotating Equipment
2. Qualification of Locomotive Power Plants through Self load

1985

1. Locomotive Microprocessor Technology in Retrospect
2. Dynamic Brake Protective devices and Troubleshooting EMD-2 and GE-7 Locomotives
3. Indicators and Recorders for Locomotive Retrofit Application - Fuel, Speed, Power and Selected Events

1984

1. Electronic Technology to Improve Performance
2. GE Dash 8 Diagnostic Display
3. "Probe" Locomotive Diagnostic Equipment
4. CATS-Computer Aided Troubleshooting
5. Fuel Conservation Through Electrical Modifications-GE and EMD
6. Performance of Locomotives After Storage

1983

1. Ground Relay Trouble Shooting
2. Specification for remanufactured D87 Traction Motor Frames (Using D-77 Armature Coils)
3. Locomotive Storage (Electrical)
4. Water Cooling and Refrigerating Methods for Locomotive Cab Application

1982

1. Tests on Traction Motors
2. Transition Troubleshooting
3. Onboard Diagnostic Systems
4. Starting Systems

1981

1. Evaluation of Improved Test Methods
2. Teflon Bands
3. New Generation Locomotives
4. Electrical Troubleshooting
5. Batteries and Charging Systems
6. Troubleshooting EMD AC Auxiliary Generator System
7. Selection of Locomotives for Major Locomotive Overhauls

SHOP SAFETY, PROCESSES AND EQUIPMENT COMMITTEE
(formerly known as the Shop Equipment and Processes Committee and also
the Shop Equipment Committee)

2016

N/A

2015

1. Video Borescope for Locomotive Maintenance Officers
2. Mechanical Department-Three Main Safety Focus Areas

2014

N/A

2013

1. Bolt Torquing / Tensioning Manual Torque Wrenches and Adapters
2. Mechanical Seven Safety Absolutes-BNSF Railway
3. PROPER TRAIN WASHING – More Than Just Brushes and Nozzles

2012

1. Application of Machine Vision Technology in Train Inspection
2. Smart Technologies for Locomotive 92-Day Inspections-Automate or Semi-Automate Wheel Measurement Gauges

2011

- * 1. New Tooling Development-Level Loading, Extended Reach “C” Frame Lifting Device and Manipulator - Under the Hook Load Limiter Alarm
2. Automatic Wheel Inspection Systems

2010

1. New Tooling Development-Level Loading, Extended Reach “C” Frame Lifting Device and Manipulator - Under the Hook Load Limiter Alarm
2. Ultrasonic Inspection of Railway Wheels
3. Introducing a Portable yet Affordable Solution for Truing your Locomotive Wheels “Without the need to remove the wheels”
4. Automatic Wheel Inspection Systems

2009

1. Going Green in the Maintenance Facility
2. Shop Equipment for Truck Removal, Maintenance and Repair

2008

1. Vehicle Progression Systems

2007

1. Evolution and Improvements in Locomotive Rerailing Cranes

2006

1. Wheel Gauge Technology 2
2. Train Washing
3. Environmental Railroad Containment Products

2005

1. Mobiturn Wheel Truing Services

**This topic appeared in both the 2010 and 2011 LMOA Proceedings Publication*

2004

1. Under the Hook Lifting Devices
2. Sanding in the Railroad Industry- Part III - A Gentle Answer for an Abrasive Situation

2003

1. Locomotive Shop Support Systems and Equipment
2. Hand Tools - An Ergonomic Update
3. Locomotive Lifting Systems

2002

1. Note: Paper on lifting systems was presented by Ron Begier of Portec at the 2002 convention; however it did not appear in publication - will appear in the 2003 proceedings publication.

2001

1. Sanding in Railroad Industries - Part II - How to Specify Reliable and Safe Sanding Systems

2000

1. The Tandem Wheel Truing Machine at Amtrak's Ivy Shop
2. Shop Talk 2000: Fall Protection Technology
3. Sanding in the Railroad Industry

1999

1. Increasing Diesel Shop Capacity
2. Conrail-Cold Asphalt Processing of Environmental Waste Sand and Sludge
3. Dry Ice Cleaning of GE Intake Ports
4. AAR-LFIS No Spill Fueling System

1998

1. Smoke Opacity Testing-Emission Detection Equipment and its Use
2. HydraulicTensioning Tools and its Use

3. High Speed Portable Align Boring Series
4. Locomotive Mobile Servicing

1997

1. Wheel Truing as Preventive Maintenance
2. Conrail-Selkirk Diesel Terminal Wastewater Treatment Facility Recent Environmental Improvements

1996

1. Locomotive Painting Drop Table Tooling for New EMD and GE Locomotives

1995

1. Pre-Maintenance Inspection
2. Railroad Turntable Modification
3. Mobile Locomotive Service Vehicle

1994

1. Electronic Fuel/Unit Injection Tooling.
2. Locomotive Roller Support Bearing Tooling.
3. Fall Protection and Man Lifts.
4. Locomotive Washing Systems.

1993

1. Dynamic Balancing for GE Dash 8 Model Locomotives
2. Air Compressor Automated Station
3. Ergonomics in the Work Place
4. Hydraulic Traction Motor Shimming Table

1992

1. Automated Test and Production Equipment
2. Safety Corrective Action Team
3. Automated Locomotive Wheel Shop

4. Cleaning and Surface Preparation
 - 1, with Sodium Bicarbonate Based Abrasive Blasting
5. Trainline Continuity Tester
6. BN - Railroad Power Assembly Shop of the 1990's

1991

1. Economic Separation of Emulsified Oil from Waste Water Using Ultra Filtration Membranes
2. EMD Cylinder Head Valve Seat Machining
3. Automated Barring Over Machine for EMD Diesel Engines
4. New Equipment for Testing EMD Engine Protectors
5. Compressed Air for Railroad Facilities Issues and Solutions to Achieve Clean, Dry, Oil Free Air

1990

1. EMD Valve Bridge Machine
2. GE Traction Motor Roller Suspension Bearing Replacement Equipment and Procedure.
3. Locomotive Component Replacement Forklift Attachment.
4. Locomotive Sanding, Fueling and Drop Tables
5. Hazardous Waste Disposal

1989

1. Automated Locomotive Wheel Shop
2. Laser Guided Material Handling Vehicles
3. Bulk Rail Lubrication Storage & Fill Systems
4. Pilot Plate Straightening Equipment

1988

1. Fuel Management Control Systems
2. Locomotive Mounted Rail Lubrication Fill Systems.
3. Comparison of Shop Air Compressors
4. Locomotive Toilet Servicing Equipment
5. Innovations in Blue Flag and Derail Protection

1987

1. Modern Servicing Facility for Improved Reliability and Availability
2. New Developments in GE Tools
3. Implementation of a Quality Process
4. A Quality Traction Motor Shop
5. Wheel Truing Machine Technology

1986

1. Robotics Update 1986 – Now What?
2. CNC Machine Tools
3. A New GE Power Assembly Area
4. Locomotive Wash System -1986

1985

1. Computer-Assisted Preventative Maintenance
2. New Tools for Material Handling and Overview of Balancing Technology
3. Effect of Governmental Regulations on Locomotive Finishing

1984

1. Shop Tools: A. New Tools; B. Shop-Made Tools
2. Traction Motor Shop Equipment Update
3. Hazardous Waste Handling and Disposal

1983

1. Locomotive Maintenance Using a Production Line Process
2. Shop Tools to Increase Productivity and Improve Quality
3. Dynamic On-Line Performance of Locomotives Without On-Board Telemetering
4. Management in Action
5. New GE Training Center
6. Welding Qualifications

1982

1. Tools
2. Rebuild line for EMD Turbochargers
3. Air Brake Equipment Line
4. Industrial Robots
5. Automated Machines
6. Safety Related Items and Equipment

1981

1. Training Aids
2. Testing Devices Inspired by New FRA Laws
3. Tools and Training for Productivity
4. Changes to Shop Facilities Required by Newly Adopted EPA & OSHA Regulations
5. Tour through Conrail Altoona Shop
6. Supply/Service Facilities
7. GE Assembly Shop

DIESEL MATERIAL CONTROL COMMITTEE

2016

N/A

2015

1. "CORES" Long term assets... What is their value?
2. Innovations in Material Storage/ Management
3. Bar Coding: A 2015 Update and Beyond

2014

1. Examining Lifecycle Costs Part One - Defining the Inputs

2013

2. Recycling of Materials
3. Material Solutions for Implementing PTC

2012

1. Tracking Cores
2. Bar Coding: An Update on Tier Emission Compliance

2011

1. Small/Heavy Component Ergonomics Locomotive Starters
2. Storage, Handling, and Recycling of Locomotive Batteries

2010

1. Green Initiatives
2. Bar Coding, Material Tagging and Identification for Recycle and HAZMAT Controls
3. CN & Sustainable Procurement

2009

1. CSX Supplier Quality "Supplier Rating System"

2008

1. Lean Manufacturing as it Applies to Material Handling

2007

1. Insourcing vs. Outsourcing "The Altoona Story"

2006

1. PDAs for Inventory Control
2. Inventory Management System

2005

1. Centralized Materials Management
2. Centralized Component Core Management-Centralized Warehouse- Locomotive Components - Part A: BNSF Rwy. Centralized Component Core Management-Rotable Warehouse - Part B: Norfolk Southern Corp.

2004

1. Milk Run: Norfolk Southern's Dedicated Locomotive Parts Shipping System

2003

1. Just in Time Delivery - The Juniata - Shop Material Control Program
2. The Continuous Improvement Approach

2002

1. “Mentored Champion Process” - CSX Supply and Service Management

2001

1. RAILMARKETPLACE.COM The Industry’s Market Exchange

2000

1. GE Global exchange Services
2. My.SAP.Com

1999

1. Composite Floors and Doors for Locomotives
2. Packaging Standards

1998

1. Tighter is Not Better
2. Are Vending Machines the New Wave for Safety Items?

1997

1. Raising Our Standards for Safety
2. The Rail Industry’s Electronic Parts Catalog Exchange Standard (EPCES) - A Better Way

1996

1. Technology Transfer-The Hot Process of the 90’s-Condition Based Maintenance
2. Warehouse Automation

1995

1. Warranty and Reliability Management
2. Railroad Industry Group (RIG) Exchange Standard for Parts Catalog Information

1994

1. Material Consignment
2. The Next Step in Electronic Information Management Interactive Technical Manuals.
3. Electronic Catalog Alternatives.

1993

1. Technology Transfer
2. Electronic Cataloging from a Material Perspective
3. Computerized Reordering from the Mechanical Employee’s Point of View
4. Electronic Catalogues: OEM/Supplier Point of View

1992

1. Warranty Overview and Issues
2. Recycling-1992
3. Bar Coding
4. Material Packaging

1991

1. The World of Recycling
2. Problems with Solution
3. Problems with Opportunities

1990

1. Waste Minimization.
2. Hazardous Materials End Cost
3. The Role of the Suppliers

1989

1. Packaging and Containerization for Today’s Railroad.
2. Innovations in Material Distribution Resulting from Shop Consolidations.
3. Outsourcing! Does Anyone Really Understand the Difference Between UTEX and Repair and Return and the Effect on the Budget?

4. "Stuff" Happens! - A Skit About the Necessity of Feedback from Suppliers - Suppliers to the end User

1988

1. Communication - The Vital Link in Materials Acquisition
2. Quality Assurance Through Communications and Feed-back
3. Paperless Requisitions
4. A Practical Application of Bar Coding in the Railroad Industry

1987

1. Suppliers Selection for Component Failure Analysis
2. Vendor Performance or Service Level
3. Bar Codes
4. Bar Coding - Railroads
5. Material Handling Innovations by the Airline Industry

1986

1. The In-House Electronic Requisition System
2. Electronic Data Interchange.
3. RAILING and Electronic Purchasing
4. Quality Evaluation Sourcing Decisions of Material

1985

1. Evaluating Locomotive Maintenance Projects
2. Reconditioning Material: In-House vs. Vendor
3. Identification and Disposition of Surplus Material
4. Cost of Carrying Surplus
5. Evolution and Future Directions of Material Handling Equipment in Railroad Use

1984

1. The New Language of Bar Codes
2. Forecasting Material Requirements
3. a. Fuel Security - Are You Getting What You Pay For? b. Fuel Oil Is Expensive
4. Pros and Cons of Material Purchasing Contracts (Single Source - Just In Time Inventory)

1983

1. Improved Locomotive Productivity Through Computerized Data
2. Inbound Material Inspection
3. Minimize Maintenance Cost Through Material Management Systems
4. New Ideas in Material Storage Containers

1982

1. Use of kits in locomotive maintenance
2. Cost effective methods of shipping material from vendors
3. Union Pacific's Component Inventory Maintenance System (CIMS)
4. Advantages of using shipping containers

1981

1. Disposal of Unserviceable Component Parts: What is the Most Profitable Method?
2. Innovations in Stores Material Handling, Via Computer Technology
3. Locomotive Held for Material: An Update for the 80's
4. The Best Approach to Procuring Material; New, UTEX, Repair and Return or Shop Repair

MECHANICAL MAINTENANCE COMMITTEE
(formerly known as Diesel Mechanical Maintenance Committee)

2020

1. AAR RP-589 Locomotive Compressor Load
2. Introduction to Variation

2019

1. Locomotive Storage and Return to Service – Update Best Practices
2. Problem Solving Basics
3. Locomotive Emissions Labeling
4. DEF Systems for Locomotives
5. BNSF & GE Pilot Hybrid Locomotive Consist Using a Battery Electric Locomotive

2018

1. New Procedure to Check GE-FDL Cam Timing
2. A Review of Compressed Air Systems
3. Basic Maintenance Practices for High-Pressure Common Rail Fuel Systems
4. Locomotive Shore Connection Heating Systems Update

2017

1. Locomotive Emission Kits
2. DC To AC Locomotive Conversion
3. Water Treatment of Cooling Systems
4. Overview of Locomotive Starter Abutment & Fail-to-Start Issues

2016

1. Locomotive Horsepower
2. Best Practices Locomotive Fuel Spill Prevention
3. LOCOMOTIVE METRICS: Reliability/Availability; Is there a need for a Standard Definition?

4. SD59MX EGR Performance Reports
5. GE Dual Fuel Locomotive Development

2015

1. Measuring the Value of Installing Solid Lube Sticks on Locomotives
2. NS CNG Locomotive Test Program
3. Utilizing Modern Electronics to Assist with Mechanical Maintenance Planning
4. Shore Connection Heating Systems for Locomotives Electric Heating Systems with New Implementation Techniques
5. Locomotive Exhaust Emission Regulations: Is Tier 5 Next?

2014

1. Avoiding Logic Traps in Problem Solving
2. AFM Calibration Absolutes for All Air Brake Systems
3. Locomotive Hand Brake Maintenance, Best Practices
4. Locomotive Cab Securement
5. The Drooping Brake Head – A Perennial Problem

2013

1. Pacific Harbor Line Tier 3+ and Tier 4 Re-Powered Locomotive Emissions After-treatment Experience
2. Locomotive Repower: Why Repower and What to Consider
3. 21st Century Locomotive Truck and Bogie Related Improvements

2012

1. Failure Modes and Effects Analysis
2. Main Generators - AR Type Traction Alternators - Best Practices – II Removal, Installation and Alignment
3. Finding an EPA Certified Emissions Kit for Locomotive Engine Overhaul
4. Locomotive Idle Minimization
5. Manual Torque Wrench Basics

2011

1. Locomotive Storage and Return to Service Best Practices
2. Design for Reliability
3. Main Generators - AR Type Traction Alternators - Best Practices -Identification and Maintenance

2010

1. EMD Turbocharger Change Out Best Practices
2. Effect of Intake Air Filter Restriction on Fuel Consumption and Emissions
3. Locomotive Diesel Exhaust Aftertreatment Demonstrations; Size, Location and Issues

2009

1. Variability and the Toyota Production System
2. The Thorough Bred Maintenance System
3. Air Compressors – Best Practices – Back Shop Maintenance Part II
4. Alignment Control Coupler Requirements

2008

1. Ultra-Low Sulfur Diesel Fuel:Impact on Locomotive Maintenance
2. Exhaust Aftertreatment Technologies: Definitions and Maintenance
3. EPA Emission Requirements for Locomotives
4. Air Compressors-Best Practices- Identification and Maintenance, Part I

2007

1. Training a New Work Force
2. Locomotive Horn Testing
3. Diagnostic Techniques for Predictive/ Preventative Maintenance-Exploitation of New Technology
4. Locomotive Particulate Matter Emissions Reduction through Application of Exhaust Aftertreatment Systems

2006

1. Lost Opportunities of Rebuilding Trucks
2. GP/SD38-2S Locomotive-A New Class of Power
3. Heavy Diesel Engine Field Repair
4. Benefits of Mobile Maintenance

2005

1. Crankcase Overpressure Today - Concentrating on EMD and GE Locomotives
2. Cold Weather Locomotive Operations
3. Importance of Cooling System Health, EPA Compliance Impact
4. Overhaul Extension

2004

1. GE Evolution Series-Maintenance and Reliability
2. EMD 70ACe and SD70DC-Tier 2 Locomotive Models-Mechanical Maintenance Enhancements
3. Best Practices Series-For Regional and Shortline Railroads-Managing Locomotive Wheel Wear
4. Maintenance Savings - Mother/ Daughter Units

2003

1. Training 60/30 Impact Now Beyond
2. Condition Based Maintenance, Practical Approaches and Techniques

2002

1. Detrimental Effects of Locomotive Engine Idling
2. Emissions Standard Compliance for the GE Dash 8 Locomotives
3. Tier 0 Emissions Compliance for the GE Dash 8 Locomotive
4. Locomotive Inspection Training - A Preview of CFR 229/238
5. Computerized Record Keeping to Improve Performance and Reduce Maintenance Expense for Shortline and Regional Railroads

2001

1. Troubleshooting Electronic Fuel Injection on GE Locomotives
2. Troubleshooting Electronic Fuel Injection-EMDEC ElectroMotive Division Two-Stroke Engine
3. How to Maintain ALCO Locomotives in the 21st Century
4. Catastrophic Engine Failures: Shortlines & Regionals (Best Practices)
5. Are We Ready for Reliability- Centered Maintenance?

2000

1. 2000 Emissions Review - GE Perspective
2. 2000 Emissions Review – EMD Perspective
3. EMD Diesel Engine Crankshaft Main Bearings Edge-Load Condition (Description, Detection and Resolution)
4. 2000 - LMOA Best Practice Series: Locomotive Truck Overhaul Procedures

1999

1. Vibration Analysis
2. EMD Power Assemblies Change Out Practices for Regional and Shortline Railroads
3. Improved Access to GE7FDL Engine Intake Manifold for Cylinder Inlet Port Cleaning
4. What's Ahead in Plastics for Locomotive Applications
5. Cast Iron, Composition Brake Shoe Arrangements vs. Type-J Relay

1998

1. LMOA Best Practices Series: GM Engine Crankcase Pressure Troubleshooting
2. Union Pacific's New EMD Diesel Engine Rebuild Line At Downing B. Jenks Locomotive Facility-No. Little Rock, Arkansas
3. GE Turbo Rebuild Procedures
4. Mechanical Impact of Locomotive Emissions Regulations
5. Locomotive Engine Bearing Developments

1997

1. LMOA Best Practices - GE Water Leaks
2. Locomotive Update - MK 1200G LNG Powered Switcher
3. Proper Use of Gaskets and Seals

1996

1. Air Brake Trouble Shooting-Where We Are Now
2. Best Practices - Internal Water Leaks on EMD Locomotives
3. Best Practices - Oil Out Stack

1995

1. General Electric New 7HDL 6000 HP Diesel Engine
2. LMOA Best Practices Series – Low Oil Pressure Trouble-shooting Procedures for EMD Turbocharged Locomotives
3. How Can a Regional or Shortline Justify a Wheel Truing Machine?
4. EMD SD60M Natural Gas Locomotive Development

1994

1. Electronic Fuel Injection.
2. ICAV - The Physical Affects on Instantaneous Crank Shaft Angular Velocity Technology
3. Maintenance Practices Comparison Between Regionals and Class I Railroads
4. Amtrak Document Management.

1993

1. EMD's Three-Axle Radial Steering Truck
2. The Natural Gas Locomotive at BNRR
3. Locomotive Waste Oil Retention
4. Fragmented Maintenance

1992

1. Mechanical Quality Progress Developing on Major Railroads.
2. Coal Fuelled Diesel Locomotive Development.
3. 18:1 Upgrade for the 645E Engine
4. Automatic Stop and Start Control System
5. Acquiring Locomotives for Regionals and Shortlines

1991

1. Recommended Practices for upgrading 567 to 645 Design.
2. Conversion of SD40 Locomotives to SD 40-2 on CSX
3. Update: Diesel Engine Emission Controls
4. Stationary and Dynamic Test Procedure for Locomotive Fuel Efficiency Measurement
5. Personnel training on New Technology.

1990

1. Caterpillar Power in Remanufactured Locomotives.
2. The EMD 710G3A Engine
3. Improving Performance of Traction Motor Friction Suspension Bearings.
4. Fluid Leaks on GE 7FDL Engine.
5. Rebuild of the EMD F3B Fuel Injector.

1989

1. Wheel Axle Gear Wear/Impact on Traction Motor Life
2. 710 Engine - Operational and Overhaul Update
3. GE Power Assembly Improvements on Welded Head-to-Liner
4. Assembly Rework Procedures.
5. EMD Engine Oil Leaks. Secondary Air Filtration - Barrier vs. Impingement

1988

1. Low-idle Operating Costs vs. Fuel Savings.
2. Rebuilding GE's EB Liner
3. The Extended Maintenance Truck
4. Flange Lubricator Update
5. Permaspray II - Cylinder Liner

1987

1. EMD Water Pump Rebuilding
2. On Board Flange Lubricator
3. Gear Case, Bull Gear and Pinion Gear Longevity in the 1980's - Gear Cases - Canadian National Experience.
4. Maintenance of Locomotive Fueling Systems for a Spill Free Operation

1986

1. Rebuild of Valve Bridge Assemblies
2. Update of New Locomotive Service Problems, EMD and GE Effecting Quality Performance
3. Chromium Plating and Its Uses
4. Development of a New Diesel Engine for Heavy-Duty Locomotive Service

1985

1. Procedures for Storing Serviceable Locomotives for Quality Performance
2. New Locomotive Service Problems, EMD and GE
3. 92 Day Service Requirements: EMD, GE and Bombardier

1984

1. Mechanical Aspects of New Locomotive Designs
2. Maintenance of Locomotive Components

1983

1. Leaks: Cooling Water, Lube Oil, Fuel Oil and Air
2. Torquing Recommendations.
3. Update on Fuel Efficient Locomotives
4. Radiator Screens
5. Alternate Starter Systems

1982

1. Fuel Conservation - Effects on Maintenance
2. Fuel Conservation - What It Costs.
3. Diesel Fuel Receipt and Disbursement
4. Turbochargers

1981

1. Running Gear
2. Filtration
3. FRA Rules
4. Follow-up on Previous Topics

LOCOMOTIVE SOFTWARE AND SYSTEMS
(formed in 2017)

2020

1. COVID-19 and Shortline Railroads

2019

1. IoT – Big Data and Real Time Processing
2. Implementing Predictive Maintenance for Locomotives Using Big Data
3. Analytics through Repairs Integration
4. Locomotive Data Publication Standard S-XXXX.V1.0

2018

1. Best Practices for Locomotive Software Updates
2. Locomotives of The Future as a Mobile Data Center
3. Locomotive Remote-Control Systems

2017

1. Connected Locomotives
2. Sensors and Instrumentations on Locomotives-A Railroad Case Study

FACILITIES, MATERIAL AND SUPPORT COMMITTEE
(formed in 2017)

2020

1. A Comparison of UTEX, Repair and Return, and Fleet Maintenance Process Flows
2. Bar Coding in Railroad Emission Consideration

2019

1. Wheel Truing Technology Development and Innovation
2. Reducing Locomotives Held for Material
3. New Coating Technology for Graffiti Prevention

2018

1. The Proper Paint Shop-Current Trend and Best Practices
2. PTC at the Belt Railway of Chicago
3. Designing the Bricks and Mortar for Locomotive Maintenance



STOP your locomotive AESS being in the hummingbird mode starting the engine excessively for main reservoir pressure built ups

START saving fuel with monitoring the handbrake applied status by **ABrake Sense** to inhibit unneeded AESS engine starts for main pressure build ups



ABrake Sense measures the correct parking brake applied force directly at the brake cylinder lever

It complies to AAR AESS spec. S-5502: When the applied status of the handbrake is known, low main reservoir pressure is no longer a required engine start-up parameter for all units on trail operation and isolated lead units



Clevis with load pin

ABrake Sense retrofit handbrake sensor



Constitution and By-Laws Locomotive Maintenance Officers Association

Revised October 3, 2016

Article I – Title:

The name of this Association shall be the Locomotive Maintenance Officers Association (LMOA).

Article II – Purpose of the Association

The purpose of the Association, a non-profit organization, shall be:

- to improve the interests of its members through education,
- to supply locomotive maintenance and technical information to Association members and their employers,
- to exchange knowledge and information with members of the Association,
- to make constructive recommendations on locomotive maintenance procedures through the technical committee reports for the benefit of the railroad industry.

Article III – Membership

Section 1 – Railroad Membership shall be composed of persons currently or formerly employed by a railroad company and interested in locomotive maintenance. Membership may be subject to approval by the General Executive Committee.

Section 2 – Associate Membership shall be composed of

persons currently or formerly employed by a manufacturer of equipment or devices used in connection with the maintenance and repair of motive power. Membership may be subject to approval by the General Executive Committee. Associate members shall have equal rights with railroad members in discussing all questions properly brought before the association at the Annual Meeting, serving on Association committees and shall have the privilege of voting and holding elective office.

Section 3 – Life membership shall be conferred on all Past Presidents. Life membership may also be conferred on others for meritorious service to the Association, subject to approval by the General Executive Committee.

Section 4 – Membership dues for individual railroad and associate membership shall be set by the General Executive Committee and shall be payable on or before September 30th of each year. The membership year will begin on October 1 and end September 30. Members' whose dues are not paid on or before the opening date of the annual convention are subject to being prohibited from attending the annual meeting, shall not be eligible to vote and may not be entitled to receive a copy of the published Pre-Convention

Report or the Annual Proceedings of the annual meeting. Failure to pay membership dues within a reasonable amount of time will result in loss of membership. Life members will not be required to pay dues, and will be entitled to receive a copy of the Pre-Convention Report and Annual Proceedings.

Article IV – Officers

Section 1 – Elective Officers of the Association shall be President, First Vice President, Second Vice President and Third Vice President. Each officer will hold office for one year or until a successor is elected. In the event an officer leaves active service, he may continue to serve until the end of his term, and, if he chooses, continue to serve as an elective officer and be allowed to elevate through the ranks as naturally occurs, to include the office of President.

Section 2 – There shall be one Regional Executive officer assigned to oversee each technical committee. Regional Executives shall be appointed from the membership by the General Executive Committee for an indefinite term, with preference given to those having served as a Technical Committee Chairperson. A Regional Executive who leaves active service may continue to serve as such, and shall be eligible for nomination and election to higher office.

Section 3 – There shall be a General Executive Committee composed of the President, Vice Presidents, Regional Executives, Technical Committee Chairpersons, and all Past Presidents remaining active in the Association.

Section 4 – There shall be a Secretary-Treasurer appointed by and holding office at the pleasure of the General Executive Committee, who will contract for his or her services with appropriate compensation.

Section 5 – All elective officers and Regional Executives must be LMOA members in good standing. (See Article III, Section 4.)

Article V – Officer, Nomination, and Election of

Section 1 – Elective officers shall be chosen from the active membership. A Nominating Committee, composed of the current elective officers and the active Past Presidents, shall submit a slate of candidates for each elective office at the annual convention.

Section 2 – Election of Officers shall be determined by a voice vote, or if challenged, it shall require a show of hands.

Section 3 – Vacancies in any elective office may be filled by presidential appointment, subject to approval by the General Executive Committee.

Section 4 – The immediate Past President shall serve as Chairman of the Nominating Committee. In his absence, this duty shall fall to the current President.

Article VI – Officers- Duties of

Section 1 – The President shall exercise general direction over all affairs of the Association and approve expenditures subject to availability of funds.

Section 2 – The First Vice President shall, in the absence of the President, assume the duties thereof. He shall additionally be responsible for arranging a mid-year joint meeting of the Association, preferably to be held in the early part of May.

Section 3 – The Second Vice President shall be responsible for selecting advertising. He will coordinate with the Secretary-Treasurer and contact advertisers required to underwrite the cost of the Annual Proceedings.

Section 4 – The Third Vice President will be responsible for maintaining a strong membership in the Association. He will ensure that membership applications are properly prepared and distributed, monitoring membership levels and reporting same at appropriate times to the General Executive Committee.

Section 5 – The Vice Presidents shall perform such other duties as are assigned them by the President.

Section 6 – The Secretary-Treasurer shall:

- A. Keep all the records of the Association.
- B. Be responsible for the finances and accounting thereof under the direction of the General Executive Committee.
- C. Perform the duties of Secretary of the Nominating Committee and

General Executive Committee, without vote.

- D. Furnish surety bond in the amount of \$50,000 on behalf of his/her assistants directly handling Association funds. Association will bear the expense of such bond.
- E. Arrange the schedule for presentation of technical reports at the annual convention and coordinate same with the other associations to minimize conflict.
- F. Serve as liaison for the LMOA with other associations
- G. Arrange for publications of the LMOA Annual Proceedings.

Section 7 – The Regional Executive officers shall:

- A. Participate in the General Executive Committee meetings.
- B. Monitor material to be presented by the technical committees to ensure reports are accurate and pertinent to the goals of the Association.
- C. Attend and represent LMOA at meetings of their assigned technical committees.
- D. Promote Association activities and monitor membership levels within their assigned areas of responsibility.
- E. Promote and solicit support for LMOA by helping to obtain advertisers.
- F. Train new Committee Chairpersons on LMOA procedures and bylaws. Mentor and support Chairpersons.

Section 8 – Duties of General Executive Committee:

- A. Assist and advise the President in long-range Association planning.
- B. Contract for the services

- and compensation of a Secretary-Treasurer.
- C. Serve as the Auditing and Finance Committee.
 - D. Determine the number and name of the Technical Committees.
 - E. Exercise general supervision over all Association activities.
 - F. Monitor technical reports for material considered unworthy for publication or inaccurate.
 - G. Approve the tentative schedule and list of topics to be presented at the annual convention and published in the Annual Proceedings.
 - H. Exercise authority to disapprove, for just cause, any new committee member or other item submitted for its approval. Such member or item will stand approved as submitted if the General Executive Committee declines to act.
 - I. Handle all matters of Association business not specifically herein assigned.
 - J. Handle all public relations decisions within LMOA and coordinated associations with confidentiality.

Article VII – Technical Committees

The technical committees will consist of:

Section 1 – A chairperson appointed by the President and approved by the General Executive Committee.

Section 2 – A vice chairperson selected by the chairperson and approved by the President.

Section 3 – Committee members, selected as follows:

A. Representatives of operating railroads and regional transit authorities submitted by their Senior Mechanical and Materials Officers and approved by the President of LMOA.

B. Representatives of locomotive builders designing and manufacturing locomotives in North America submitted by their perspective company and approved by the Committee Chairperson.

C. The Fuel, Lube and Environmental Committee will include members from major oil additive companies or their subsidiaries submitted by their perspective company and approved by the Committee Chairperson.

D. As needed, the Committee Chairperson may invite other non-railroad personnel to participate in committee activities on either a limited time or permanent basis

E. The Chairperson will submit the name of perspective new committee members to the Executive Committee which reserves the right to approve or disapprove membership.

F. Companies are allowed a primary and alternate member on committees at the Chairperson’s discretion.

Section 4 – All individuals who are on technical committees must be LMOA members in good standing. (See Article III, Section 4.)

Section 5 – Each technical committee shall prepare one or more technical reports for presentation at the annual meeting and publication in the Annual Proceedings. Oral presentations should include the use of slides, videos,

or other media as appropriate to the subject.

Section 6 – Subjects for technical papers will be selected and approved by the General Executive Committee.

Article VIII – Proceedings

Section 1 – The Locomotive Maintenance Officers Association encourages the free interchange of ideas and discussion by all attendees for mutual benefits to the railroad industry. It is understood that the expression of opinion, or statements by attendees in the meeting, and the recording of reports containing the same, shall not be construed as representations or statements ratified by the Association.

Section 2 – Those present at any meeting called on not less than thirty days advance written notice shall constitute a quorum.

Article IX – Rules of Order

The proceedings and business transactions of this Association shall be governed by Robert’s Rules of Order, except as otherwise herein provided.

Article X – Amendments

The Constitution and By-Laws may be amended by a two-thirds vote of the active members present at the Annual Meeting.

