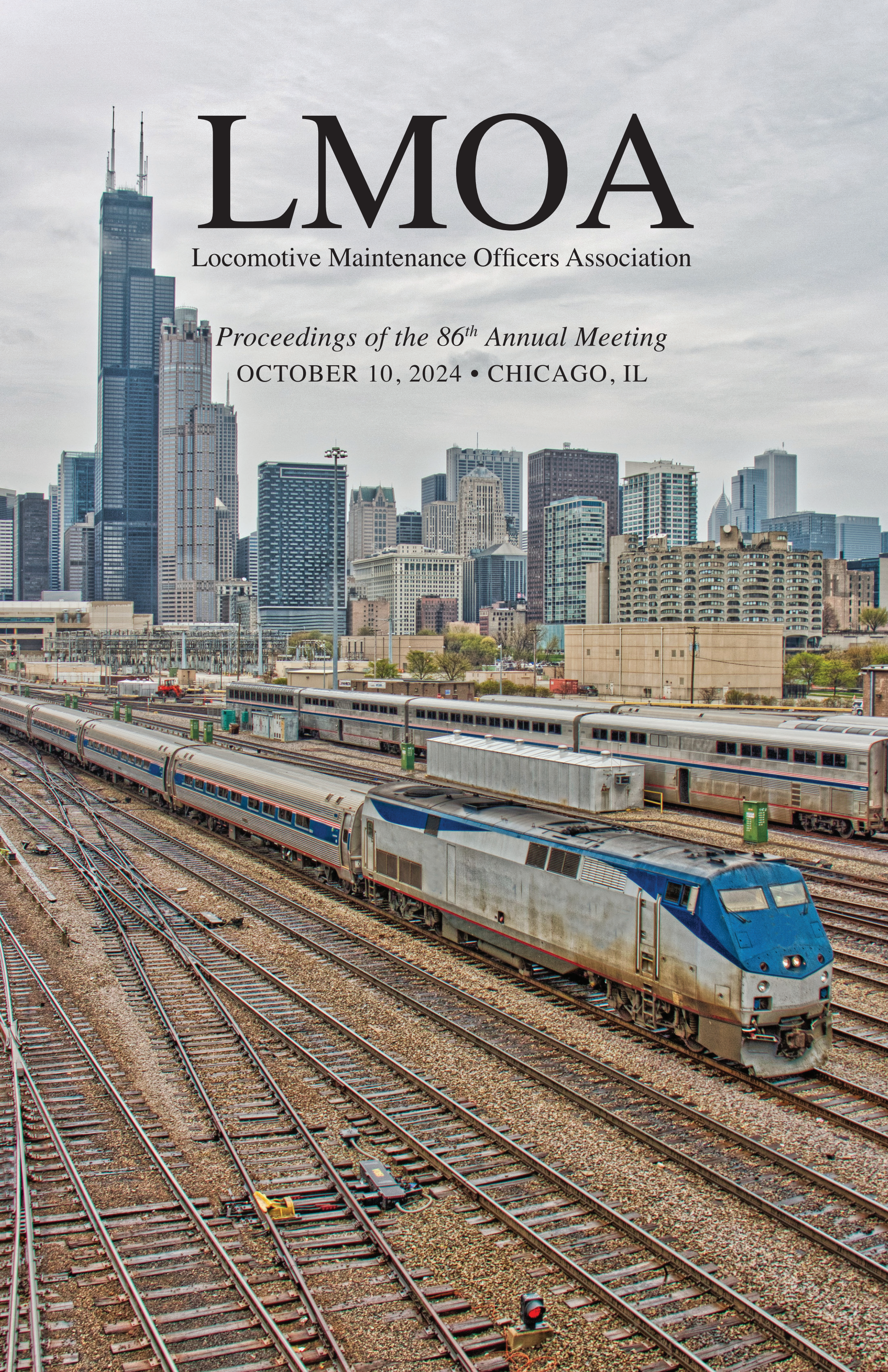
LMOA

Locomotive Maintenance Officers Association

Proceedings of the 86th Annual Meeting

OCTOBER 10, 2024 • CHICAGO, IL



2024 Advertisers Index

Locomotive Maintenance Officers Appreciate these 2024 Supporting Advertisers

ACS Railroad Solutions

Amglo

AMOT Controls

Amsted Rail

A. Stucki Company

ARMS-Automated Railroad Maintenance Systems

A.S.T. GmbH

Bach Simpson/Wabtec

Hotstart

NSH USA

Parker Hannifin

Peaker Services, Inc

PowerRail, Inc.

Rail Products Intl

Railhead Corporation

Snyder Equipment

TPSC-Transportation Products Sales Company

Transportation Equipment Supply Company

ZTR, LLC

2024 TOC and Index

2023 LMOA MVP RECIPIENTS

The Executive Board of LMOA wishes to congratulate the following individuals who were selected as the Most Valuable Person of their respective committees for 2023:

NAME	COMMITTEE	COMPANY
Ian Bradbury	Mechanical Maintenance	Peaker Services, Inc
Chad Gibson	Mechanical Maintenance	Genesee & Wyoming
Chris Miller	Fuel, Lubricants and Environmental	Wabtec Corporation
Oleg Goureev	Electrical Maintenance	ABB-Canada
Josh Figurski	Facilities, Material and Support	Wheeling & Lake Erie Railway

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

LMOA EXECUTIVE COMMITTEE

LMOA JOINT TECHNICAL COMMITTEE MEETING
TOPEKA, KANSAS, USA – MAY 7, 8 and 9, 2024

The Executive Committee of LMOA would like to express their sincere appreciation to BNSF Railway – Technical Research and Development Laboratory for hosting the event and providing financial and logistical support along with additional sponsors:

Randy Garver – Innospec Fuel Specialties
https://innospec.com

Dwight Beebe – Temple Engineering
http://www.temple-eng.com

LMOA also wishes to thank the multiple tour guides throughout the BNSF Facility, including:
BNSF Railway Shop Tours – Alex Beasley, Bryan Price, Josh Varner and Teams
TR&D Train Dynamics Presentation – Matt Duncan and Nathan Williams
TR&D Maintenance of Way Lab Tour– Will Clements and Zach Dombrow
TR&D Metallurgy Lab Tour – Huseyin Guzel and Caitlin Harpell
TR&D Physical Lab Tour – Darrell Krueger, Adam Rhodes, Caleb Rogers and Corey Wills
TR&D Chemistry Lab Tour – Rachel Flott and Alex Gutierrez
Special Thanks to Henry Schafer – BNSF Shop Superintendent, Aaron Ratledge - AVP Training & Op Practices, Alicia Lollar and Jessica Wieder for their help and support in planning, coordination and implementation.

The LMOA executive board would like to express their sincere gratitude to our 1st Vice President, Corey Ruch, BNSF Railway for his efforts in coordinating the joint technical committee meeting. Thank you Corey!

PAST PRESIDENTS

1939 & 1949	F.B. DOWLEY (Deceased) Shop Supt., C. & O. Ry.
1941	J.C. MILLER (Deceased) MM, N.Y.C. & St. L.R.R.
1942-1946, Inc.	J.E. GOODWINN (Deceased) Exec. Vice President, C. & N.W. Ry.
1947	S.O. RENTSCHILLER (Deceased) Chief Mechanical Officer, Bessemer and Lake Erie R.R.
1948	C.D. ALLEN (Deceased) Asst. C.M.O. - Locomotive, C. & O. Ry. & B. & O. R.R.
1949	J. W. HAWTHORNE (Deceased) Vice-Pres.- Equipment, Seabord Coast Line R.R.
1950	G.E. BENNET (Deceased) Vice-Pres.- Gen, Purchasing Agent, C. & E. I. Ry.
1951	P.H. VERD (Deceased) Vice-Pres.- Personnel, E. J. & E. Ry.
1952	H.H. MAGILL (Deceased) Master Mechanic, C. & N. W. Ry.
1953	S.M. HOUSTON (Deceased) Gen. Supt. Mech. Dept. Southern Pacific Co.
1954 & 1955	F.D. SINEATH, Retired Chief of Motive Power, Seabord Coast Line R.R.
1956	T.T. BLICKLE (Deceased) General Manager-Mechanical, A.T. & S.F. Ry.
1957	J.T. DAILEY (Deceased) Asst. to Pres.-Mech., Alton & Southern R.R.
1958	F.E. MOLLOR (Deceased) Supt. Motive Power, Southen Pacific Co.
1958	F.R. DENNY (Deceased) Mechanical Supt., New Orleans Union Passenger Terminal
1959	E.V. MYERS (Deceased) Supt. Mechanical Dept., St. Louis-Southwestern Ry.
1960	W.E. LEHR (Deceased) Chief Mechanical Officer, Pennsylvania R.R.
1961	O.L. HOPE (Deceased) Asst. Chief Mechanical Officer, Missouri Pacific R.R.
1962	R.E. HARRISON (Deceased) Manager-Maintenance Planning & Control, Southern Pacific Co.
1963	C.A. LOVE (Deceased) Chief Mechanical Officer, Louisville & Nashville R.R.
1964	H.N. CHASTAIN (Deceased) General Manager-Mechanical, A.T. & S.F. Ry.
1965	J.J. EKIN, JR. (Deceased) Supt. Marine & Pier Maintenance, B. & O. R.R.
1966	F.A. UPTON II (Deceased) Asst. Vice-President-Mechanical, C.M. St. P. & P. R.R.
1967	G.M. Beischer, Retired Chief Mechanical Officer, National Railroad Passenger Corp. Washington, D.C. 20024
1968	G.F. BACHMAN (Deceased) Chief Mechanical Officer, Elgin Joliet & Eastern Ry.
1968	T.W. BELLHOUSE (Deceased) Supt. Mechanical Dept., S. P. Co., - St. L. S.W. Ry.
1970	G.R. WEAVER (Deceased) Director Equipment Engineering, Penn Central Co.
1971	G.W. NEIMEYER (Deceased) Mechanical Superintendent, Texas & Pacific Railway
1972	K.Y. PRUCHNICKI (Deceased) General Supervisor Locomotive Maintenance, Southern Pacific Transportation Company
1973	W.F. DADD (Deceased) Chief Mechanical Officer, Chessie System
1974	C.P. STENDAHL, Retired General Manager, M.P.-Electrical, Burlinton Northern Railroad
1975	L.H. BOOTH (Deceased) Retired Assistant C.M.O.-Locomotive, Chessie System
1976	J.D. SCHROEDER, Retired Assistant C.M.O.-Locomotive, Burlinton Northern Railroad, 244 Carrie Drive, Grass Valley, CA 95942
1977	T.A. TENNYSON (Deceased) Asst, Manager Engineering-Technical, Southern Pacific Transportation Co.
1978	E.E. DENT (Deceased) Superintendent Motive Power, Missouri Pacific Railroad
1979	E.T. HARLEY, (Deceased) Senior Vice President Equipment, Trailer Train Company, 289 Belmont Road, King of Prussia, PA 19406
1980	J.H.LONG (Deceased) Manager-Locomotive Department, Chessie Systems
1981	R.G.CLEVENGER, Retired, General Electrical Foreman, Atchison, Topeka & Santa Fe Rwy
1982	N.A. BUSKEY (Deceased), Asst. General manager-Locomotive, Chessie Systems
1983	F.D. BRUNER (Deceased), Asst. Chief Mechanical Officer, R&D, Union Pacific RR

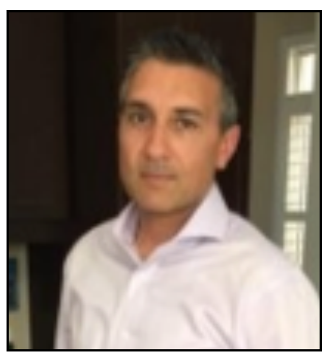
1984	R.R.HOLMES (Deceased), Director Chemical Labs & Environment, 600 Brookestone Meadows Place, Omaha, NE 68022
1985	D.M.WALKER, Retired, Asst. Shop Manager, Norfolk Southern Corp, 793 Windsor St, Atlanta, GA 30315
1986	D.H.PROPP, Retired, Burlington Northern RR, 10501 W. 153rd St, Overland Park, KS 66221
1987	D.L.WARD (Deceased), Coordinated-Quality Safety & Tech Trng, Burlington Northern RR
1988	D.G. GOEHRING (Deceased), Supt. Locomotive Maintenance, National RR Passenger Corp, 1408 Monroe, Lewisburg, PA 17837
1989	W.A.BROWN, Retired, I&M Rail Link, 9047 NE 109th St. Kansas City, MO 64157
1990	P.F.HOERATH (Deceased) Sr. Mech. Engr. Shop, Conrail 1534 Frankstown Rd, Hollidaysburg, PA 16648
1991	D.D.HUDGENS, Retired, Sr Mgr R&D, Union Pacific, 16711 Pine St., Omaha, NE 68130
1992	K.A.KELLER (Deceased), Supt. Locomotive Maint, Reading RR, 241 E. Chestnut, Cleona, PA 17042
1993	W.R.DOYLE, Retired Commuter Rail Transportation Superintendent, Sound Transit, Seattle, WA 98104
1994	M.A.COLES, Retired, Sr. Mgr-Loco. Engineering & Quality, Union Pacific RR, Omaha, NE 68179
1995	C.A.MILLER, Retired Mgr-Loco. Engineering & Quality, Union Pacific RR, 17745 Doras Circle, Omaha, NE 68130
1996	G.J.BRUNO, Retired, Supt.-Mechanical, Amtrak 14142 S.E. 154th Pl, Renton, WA
1997	D.M.WETMORE, Retired-Genl Supt.-Fuel Opns, NJT Rail Opns, 2005 Acadia Greens Drive, Sun City Center, FL 33573
1998	H.H.PENNELL, Retired-Ellcon National, 1016 Williamsburg, Lanne, Keller, TX 76248
1999	JAKE VASQUEZ, Retired, Asst. Supt.-Terminal Services, Amtrak, 25531 NE 138th St., Salt Springs, FL 32134
2000	RON LODOWSKI, Retired Production Mgr, CSX Transportation, Selkirk, NY 12158
2001	LOU CALA, Retired, Duncansville, PA 16635
2002	BOB RUNYON, Engineering Consultant, Roanoke, VA 24019
2003	BRIAN HATHAWAY, Consultant, Port Orange, FL 32129
2004	BILL LECHNER, Retired, Sr Genl Foreman-Insourcing-Air Brakes, Governors & Injectors, Norfolk Southern Corp, Altoona, PA 16601
2005	TAD VOLKMANN, Chief Consultant, Tadco Railroad Consultants, Omaha, NE 68179
2006	BRUCE KEHE, Retired, CMO, CSS&SB, Michigan City, IN 46360
2007	LES WHITE, Retired Applications Specialist, Bach-Simpson, London, Ontario N6A 4L6
2008	MIKE SCARINGE (Deceased), Director-Locomotives, Amtrak, Beech Grove, IN 46109
2009	DENNIS NOTT, (Deceased), Sole Member, Northwestern Consulting, Boise, ID 83703
2010	BOB REYNOLDS, Retired Sales Manager, Amglo Kemlite Laboratories, Calgary, Alberta T24 2V8
2011	JACK KUHNS, Retired, Director-Sales, Graham White, Salem, VA 24153
2012	RON BARTELS, Sr. Manager - Equipment Reliability and Electrical Engineering, Via Rail-Canada, Montreal, Quebec
2013	R. BRAD QUEEN, Manager of Locomotive Utilization - RCO, BNSF Railway, Fort Worth, TX
2014	DAVE RUTKOWSKI, President, JAB Rail Services, LLC, Green Cove Springs, FL
2015	BOB HARVILLA, VP-Sales, PowerRail, Inc., Duryea, PA
2016	STUART OLSON, Retired, Sales Director-Infrastructure, Wabtec Corporation, Alpharetta, GA
2017	JEFF CUTRIGHT, Contractor-L&J Services, Retired Norfolk Southern, Roanoke VA
2018	DWIGHT BEEBE, Temple Engineering, Liberty, MO
2019	IAN BRADBURY, President & CEO, Peaker Services, Inc., Brighton, MI
2020-21	TOM KENNEDY, President, Kennedy Rail Consulting, Omaha, NE
2022	TOM GALLAGHER, OEM Technical Liaison, Chevron Oronite, Allendale, MI
2023	TIM STANDISH, Quality Manager – Progress Rail-a Caterpillar Company, Winston-Salem, NC

Our Officers

President
KEITH MELLIN
Sales Manager
Peaker Services, Inc
Brighton, MI

1st Vice President
COREY RUCH
Director-Technical Research & Development
BNSF Railway
Topeka, KS

2nd Vice President
MARK DUVE
Director of Locomotive Engineering
Higher Power Industries
Yonkers, NY



3rd Vice President
AMARJIT SOORA
Senior Product Manager
ZTR
London, Ontario

Our Past Presidents

DWIGHT BEEBE
Temple Engineering
Liberty, MO

IAN BRADBURY
President & CEO
Peaker Services, Inc
Brighton, MI

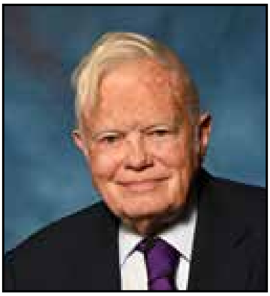
JEFF CUTRIGHT
Norfolk Southern Corporation
RETIRED
L&J Services
Roanoke, VA

TOM GALLAGHER
OEM Technical Liaison
Chevron Oronite
Allendale, MI

BOB HARVILLA
Outside Sales Support
PowerRail, Inc.
Duryea, PA

Our Past Presidents

TOM KENNEDY
Union Pacific, RETIRED
President
Kennedy Rail Consulting
Omaha, NE



ROBERT RUNYON
Norfolk Southern Corporation
RETIRED
Engineering Consultant
Roanoke, VA

DAVE RUTKOWSKI
President
JAB Rail Services
Davenport, FL

TIM STANDISH
Quality Manager
Progress Rail-A Caterpillar Company
Winston-Salem, NC

Our Regional Executives

BOB HARVILLA
LMOA Past President
Outside Sales Support
PowerRail, Inc.
Duryea, PA

JOHN HEDRICK
Principal Scientist
Southwest Research Institute
San Antonio, TX

JERAINNE HEYWOOD
Senior Fuels and Lubricants Engineeer
Wabtec Corporation
Fort Worth, TX

JASON FOX
Senior Director
Sr Director Locomotive Engineering & Quality
Union Pacific RR
Omaha, NE

2023 State of the Union Address

Tim Standish

October 3, 2023

Fort Worth, Texas

First I would like to thank the LMOA for having me serve as President for the last year; it truly has been an honor.

I would also like to thank all the presenters and contributors for the papers this year. Their hard work is obvious from the docket of presentations we have this year. Thanks to the committee chairs for their coordination of their committees, papers and meetings held throughout the year. Your work does not go unnoticed.

We had a great joint meeting in Montreal this year and I would like to thank David Caron from Ekyrail for organizing the venue, tours and sponsors in which I would like to thank the sponsors (Ekyrail, DLL, CAD Railway, Genesee and Wyoming and Wabtec) We had some really good tours at Ekyrail, DLL and CAD Railway. The passion they have for their products was truly impressive.

I would like to thank our advertisers in our proceedings book. Members-- please make sure to get your book from Ron. I would also like to thank Ron Pondel for all the behind the scenes work he does for the LMOA. This includes working closely with the RSI, keeping the membership informed of necessary details, getting the publication together and so on. Ron, thanks for all you do for us.

Of the various tasks to coordinate and accomplish as President, I tried to tackle a logo change. I thought that this would be simple task but little did I know the number of thoughts and opinions on getting the logo refreshed. Thanks for all the input and I will continue to work on this with the next president to get an updated logo that can show our heritage along with our bright future.

It's been an active year for the rail industry with the CP/KCS merger along with California's in use regulation for locomotive emissions which will be very challenging. We also had the EPA solicit input from the LMOA in which Peaker Services coordinated the meeting to get members of the LMOA, class ones and short lines together for a productive discussion of current fleet emission levels, challenges in the rail industry and technologies to help reduce emissions. It was great to see the input we had and to have the relationship and recognition with the EPA as contributors to future rulemaking.

When you look at the proceedings book, this is the 85th annual meeting. A proud history of helping the rail industry and a testament to the members to carry on. We have 335 LMOA members which includes 80 railroad members. 168 of our members are registered for this show.

So I have to say I'm proud of where the LMOA is today. We have a great membership with a combination of railroads, suppliers and consultants who have such a broad range of experience to be able share this knowledge to help the rail industry better serve their customers safely and efficiently.

Thank you!

2023 Acceptance speech

Keith Mellin
October 4, 2023
Fort Worth, Texas

Good Morning,

I am honored and humbled to accept the position of President of the Locomotive Maintenance Officers Association (LMOA).

For over 85 years, the LMOA has distinguished itself by collaborating with all stakeholders in the industry in the promotion of continual improvement of Locomotive Safety, Performance, Maintenance, and Technology. We are grateful for the dedication and service of all our members; Engineering Consultants, Parts Suppliers, Service Companies, Technology Integrators, OEMs and most importantly the railroads that we serve.

I would like to recognize Tim Standish from Progress Rail for his outstanding leadership & service over the last year, and his dedication to shaping our organization.

As William J Palmer said: "Railroads are the veins of the nations body" This is personal to me. Railroads carry the life blood of the nation and with any healthy body it needs good Fuel, Maintenance, Caution, Habits, Information and Knowledge to not only stay alive but to thrive!

I have been in this industry for over 41 years, all of which at Peaker Services in Technical and Sales Management roles on locomotives around the world. For the last 16 years I have served as a member, Vice Chair and Chairperson of the LMOA Electrical committee.

My experience in technical and sales management roles not only the rail, but power generation, Marine and Industrial engine markets has exposed me to a wide variety of technologies, practices, innovations and solutions, which can be applied to address numerous challenges in the rail industry.

Global industries are implementing technological advancements like never before. It is well known that rail is the most efficient means of transporting goods, and in order to maintain that high distinction we need to continue to evolve and adapt trends seen in other relevant industries. That emphasizes the need for organizations like the LMOA to thrive, where competing railroads and competing suppliers work together for the improvement of each other and the industry as a whole.

The LMOA is also engaged in developing our members technical knowledge and skills for meetings and presentations. This has helped me immensely with research, presenting and writing papers. We have had members who have never presented in front of anyone, let alone large audiences, gain confidence and have gone on to be great presenters.

I'm confident that our Mechanical Maintenance, Electrical Maintenance, Fuels, Lubricants & Environmental and Facilities, Material & Support committees' technical papers and presentations will deliver answers to these challenges and provide value to the entire locomotive rail industry. I'm looking forward to having the LMOA continue its collaborative spirit and having our members pump new life blood through the veins of all the locomotive industry.

Lets learn . . . Have fun . . . and make a difference.

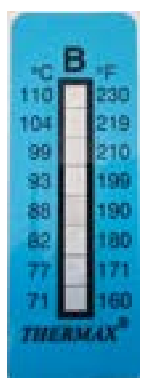
ACS Railroad Solutions

Get Early Indication of Bearing Degradation with Cost Effective and Easy To Implement Temperature Indicator Strips

Monitoring the working temperature of railcar wheel bearings provides an excellent indication of bearing status and can be an effective method to predict pending failure. Temperature indicator strips from ACS-RS are a perfect complement to Hot-Box detectors as the strips provide a permanent record, not just a snapshot of bearing temperature.

- Detects 8 different temperature levels between 160°F and 230°F (Other ranges and levels available upon request)
- Strips display an irreversible temperature reading, providing a history of the highest temperature reached
- Simple and Easy to put into use, no activation needed, and no need to build out any communications infrastructure or back-office integration
- Testing completed by MxV Rail, a subsidiary of the Association of American Railroads, for efficacy and adhesion over a wide range of potential railway conditions - view the report at www.acsrail.com

Strip applied to bearing cup



Untriggered Strip

Triggered Strip

678-722-5261 www.acsrail.com Sales@acsrail.com

Outgoing President Tim Standish hands gavel over to Newly Elected President Keith Mellin

Past President Dwight Beebe (r) presents LMOA watch to outgoing President Tim Standish

Michael Cleveland, Progress Rail, presenting paper on Future Fuels review on the morning of October 4th at Railway Interchange 2023 in Indianapolis. Keith Mellin, President of the LMOA, casually listens with a thought-provoking look. Editors Note: Michael is now with Peaker Services, Inc.

Report on the Committee on Mechanical Maintenance

Thursday, OCTOBER 10, 2024
9:30 AM

Chair

Frank Jalili

Director of Market Strategy

Frank Jalili Consultant LLC, Plano, TX

Vice Chair

Pat Roach

Vice President-Sales

Interstate McBee, Cleveland, OH

Commitee Members

E. Baldaccini	President	Quality Turbocharger	Houston, TX
A. Beitel	Fleet Manager	BNSF	Fort Worth, TX
D. Bellemare	Tech Director-Senior Project Manager	Rail Industries Canada	Montreal, Quebec
B. Bilokraly	Locomotive Quality Field Technician	Canadian National Railway	Edmonton, Alberta
I. Bradbury	President	Peaker Services	Brighton, MI *Past President*
J. Brunson	Head of Sales- North America	Medha Transportation	Fort Worth, TX
T. Casper	VP of Business Development	PowerRail, Inc.	Exeter, PA
M. Cleveland	Director-Advanced Energy	Peaker Services, Inc	Brighton, MI
W. Clevenger	Vice President-Locomotive Division	Metro East Industries	Fairview Heights, IL
B. Cothren	Dir Loco Maintenance Operations	Alaska Railroad	Anchorage, AK
S. Cullers	Director of Sales-East	NRE	Chattanooga, TN
J. Cutright	Consultant	L&J Services	Roanoke, VA *Past President*
J. Dempsey	Manager Railroad Seating	Seats, Inc	Baraboo, WI
E. Dillen	Advanced Engine Technology Leader	Wabtec Corporation	Erie, PA
A. Duncan	Dir-Diesel Engine Compliance Center	US-EPA	Ann Arbor, MI
M. Duve	Principal Consultant	Southeastern Locomotive Consultants	Alpharettta, GA *2nd Vice President*
R. Edgecomb	Senior Technical Advisor	Cummins	Columbus, IN
D. Fox	CSO	ACS Railroad Solutions	Norcross, Ga
C. Gibson	Asst Vice Preesident-Mechanical	Genesee & Wyoming	Webster, NY
J. Gravenkemper	Outside Sales Manager	Hatch & Kirk	Dallas, TX
J. Hedrick	Principal Scientist	Southwest Research Institute	San Antonio, TX *Regional Executive*

Commitee Members Continued

D. Hilliard	General Manager	Hilliard Enterprices /Unipar	Maumelle, AR
T. Kennnedy	President	Kennedy Rail Consulting	Omaha NE *Past President*
W. Kennedy	Consultant	Kennedy Consulting	Omaha NE
N. Kidd	Owner	Kidd Machine Works, LLC	Salem, VA
T. Kissick	General Manager	Elwood Crankshaft	Hermitage, PA
M. Kopitzke	National Sales Manager	JMA Railroad Supply	Seymour, IN
M. Macbeth	CMO-West	Genesee & Wyoming-Canada	Montreal, Quebec
S. Maynes	CEO	Deflect, LLC	New York, NY
S. Nirula	Director	Medha Transportation	Flower Mound, TX
D. Parsons	Senior Manager Engiineering-Diesel	Amtrak	Chicago, IL
N. Phares	Senior Account Manager-Rail	Railhead Corporation	Burr Ridge, IL
A. Pope	RR Professonal	Retired	Pueblo, CO
J. Rotondo	Shop Manager	CAD	Montreal, Quebec
D. Rutkowski	CMO Consultant	JAB Rail Svcs	Davenport, FL *Past President*
A. Sharma	Business Development Manager	Medha Transportation	Grapevine, TX
C. Shepherd	Chief Mechanical Officer	Arkansas & Missouri RR	Springdale, AR
P. Silvey	Vice President-Sales	Master Packing and Rubber Company	Cedar Rapids, IA
B. Singleton	Vice President-Sales	Transpar Corp	Sarasota, FL
P. Smith	Manager	US-EPA	Ann Arbor, MI
T. Standish	Quality Manager	Progress Rail	Winston Salem, NC *Past President*
C. Stoos	Lead Engineeer	Southwest Research Institute	San Antonio, TX
G. Trillanes	Chief Commercial Officer	HGmotive	Arkport, NY
C. Turner	Market Manager	Amot Controls	Houston, TX
K. Ulbick	Sales Manager	Peaker Services	Brighton, MI
G. Wilson	Superintendent of Cars	Iowa Interstate RR	Cedar Rapids, Ia

HONORARY MEMBERS:

Michael Fore	Director Technical Services	Association of American Railroads
Don Graab	Retired - VP Mechanical	Norfolk Southern
Mike Iden	Retired - Mechanical and Locomotive Reliability	Union Pacific

PERSONAL HISTORY

Frank Jalili

Frank has over twenty-seven plus years of Industrial, Business Development, Business Process Reengineering and Revenue Enhancement, Manufacturing process improvement and Documentation, Strategic Sourcing, Growth Strategy, and Supply Chain Strategy, and experience assisting and serving many of his clients. This includes low to mid-volume and high-mix, engine components, PTC, and Antenna Farms for locomotive, marine, stationary power generated, material handling equipment in mining, and aggregate markets serving OEM -Wabtec (GE Transportation), Progress Rail (EMD) - and Class 1 Railroads, and provided products and Services.

Frank has a diverse range of knowledge and expertise in many industries, including Railroad, Oil & Gas, Electronics/Telecommunication, and Industrial Products. Frank has held C-suite positions and as President of heavy and light industrial manufacturing companies serving Class 1 Railroads, and OEM in Dallas, Texas, and Cleveland, Ohio.

He has extensive Manufacturing Business experience encompassing Business Development, Business Process Improvement, Cost Saving and Turnaround, Operations Efficiency, Lean Manufacturing, Team Building, Manufacturing process improvement, Defect Analysis, and Supply Chain Management. He has established agility in interacting and serving his clients in domestic, and international markets.

Frank initiated and led collaborations with other locomotive component industry companies, resulting in successful meetings and negotiations with the Environmental Protection Agency (EPA) to protect and sustain the business of the aftermarket suppliers in 40 CFR1033 Control of Emission for Locomotives. CFR 1033.625 prevented over 30% lost revenue from the aftermarket suppliers, which is an over $500,000,000 industry

Frank has successfully and through the Operations strategy, promoted changes and introduced new products and services. Built strategic alliances with a few key OEM and Class 1 railroads, resulting in generating new revenues.

Outside of work, Frank enjoys tennis, bicycling, hiking, and traveling. He has been married to Ana for over 38 years and has a son who graduated with an MS in Bio-Medical Engineering and a daughter currently pursuing her MS in Forensic Psychology.

THE MECHANICAL MAINTENANCE COMMITTEE WOULD LIKE TO GIVE SPECIAL THANKS TO FRANK JALILI, LINKUP CORPORATION, AND THEIR TEAM FOR HOSTING THE COMMITTEE'S MEETING IN ROANOKE, TEXAS. THE MEETING WAS PRODUCTIVE, WELL ATTENDED AND WAS FOLLOWED BY A PLANT TOUR.

SPECIAL THANKS TO ERIC DILLON AND THE WABTEC TEAM FOR COORDINATING THE TOUR OF THE WABTEC LOCOMOTIVE PLANT IN FORT WORTH, TEXAS FOLLOWING THE WINTER MEETING

THE COMMITTEE WOULD LIKE TO EXTEND THEIR SINCERE APPRECIATION TO CHAD GIBSON AND GENESEE & WYOMING-BERKSHIRE AND EASTERN RAILROAD FOR HOSTING THE SUMMER MEETING IN MASSACHUSETTS ON JULY 16, 2024. IT WAS VERY PRODUCTIVE, WAS FOLLOWED BY A TERRIFIC LUNCH AND TOUR OF G&W. THIS MEETING WAS ORIGINALLY SCHEDULED FOR SUMMER 2023 BUT IT WAS DELAYED UNTIL THIS YEAR BECAUSE OF THE EPA MEETING THAT WAS HOSTED BY PEAKER SERVICES IN BRIGHTON, MI. CHAD GRACIOUSLY POSTPONED THE MEETING TO ALLOW COMMITTEE MEMBERS THE OPPORTUNITY TO ATTEND THE EPA MEETING IN SUMMER 2023. THANK YOU SO MUCH, CHAD

Why Injectors Need To Be Replaced

By:
Patrick Roach
Interstate-McBee

Diesel Fuel Injection Timeline:[1][1]

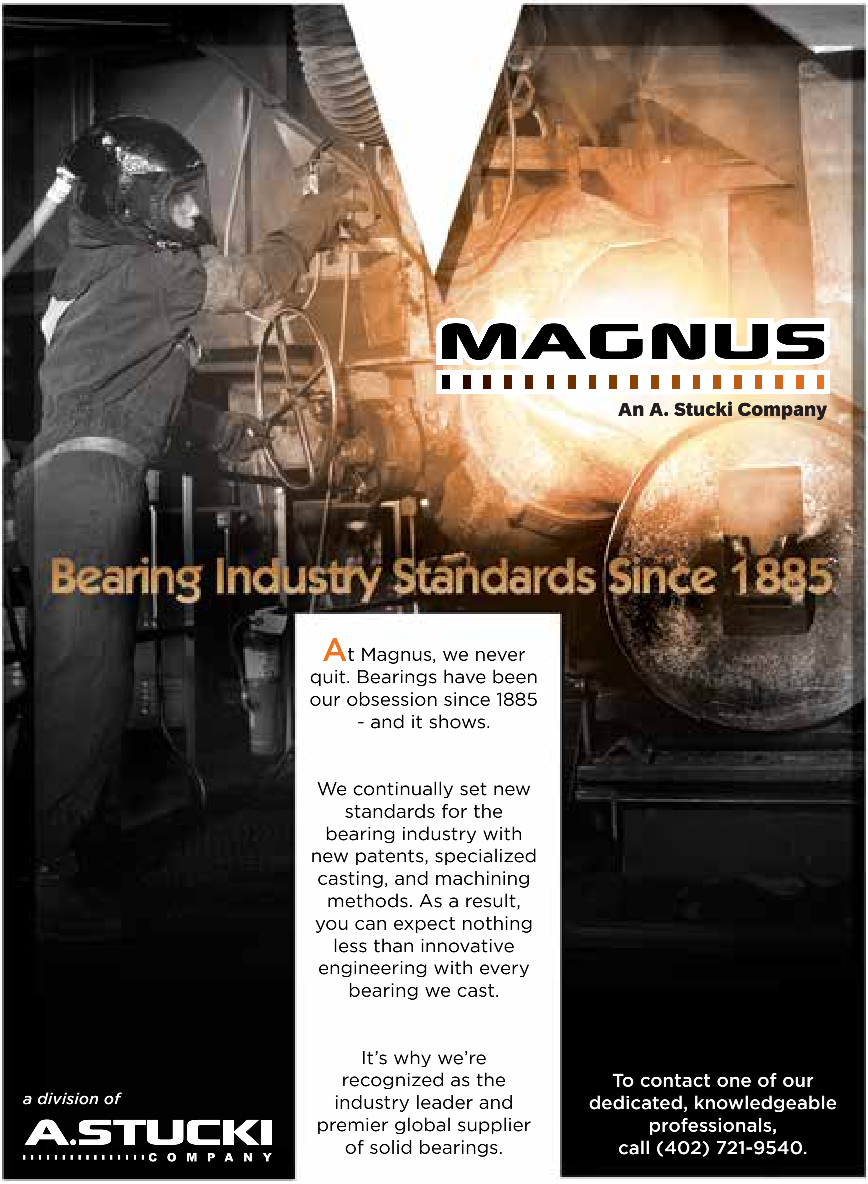
1. 1872 George Bailey Brayton obtained a patent on an internal combustion engine that used pneumatic fuel injection.
2. 1884 First manifold injection system was designed by Johannes Spiel.
3. 1891 The British Hebert-Akroyd oil engine became the first engine to use a pressurized fuel injection system.
4. 1894 Rudolf Diesel copied Brayton's air-blast injection system for the diesel engine.
5. 1911 The "Unit Injector" was invented by Frederick Lamplough.
6. 1919 Pre-combustion chamber invented by Prosper L'Orange.
7. 1924 MAN Truck & Bus presented the first direct-injected diesel engine for trucks.
8. 1927 Higher pressure diesel injection pumps were introduced by Robert Bosch.

Diesel engine performance hinges on the effective delivery of fuel into engine cylinders through intricate fuel injection systems. Innovations in these systems have driven engine advancements, affecting emissions, noise, and efficiency. Ever since the introduction of diesel fuel injection, injector failures have been happening. This paper will examine why injectors fail, when they fail, why they need to be replaced and when they need to be replaced.

Diesel engine performance depends on a multitude of components working together to generate power and this performance is heavily dependent on the fuel delivery system most notably the injectors. Significant advances in diesel technology can often be traced to the specific advancement of fuel injectors. Power, emissions, noise, and fuel economy are all tied directly to the performance of the fuel injectors. For these reasons, knowing when and why to change injectors should be essential to any diesel engine maintenance program.

In this paper we will examine the reasons for injector degradation which occur during the normal life of an injector. In addition to normal wear, there are various reasons for an injector to be damaged during normal operations such as dirt in the fuel, dirt in the oil and overheating (to name just a few). These factors

1 [1] Wikipedia


MAGNUS
An A. Stucki Company
Bearing Industry Standards Since 1885
At Magnus, we never quit. Bearings have been our obsession since 1885 - and it shows.
We continually set new standards for the bearing industry with new patents, specialized casting, and machining methods. As a result, you can expect nothing less than innovative engineering with every bearing we cast.
It's why we're recognized as the industry leader and premier global supplier of solid bearings.
a division of
A.STUCKI COMPANY
To contact one of our dedicated, knowledgeable professionals, call (402) 721-9540.

will not be covered here as they are not considered normal wear, but indeed caused by external factors not related directly to the operation of the injectors. Normal wear will not cause an injector to fail (unless used well beyond the useful life of the injector) but will cause internal components to degrade past the point of adequate performance.

Top reasons injectors lose performance during normal operations:

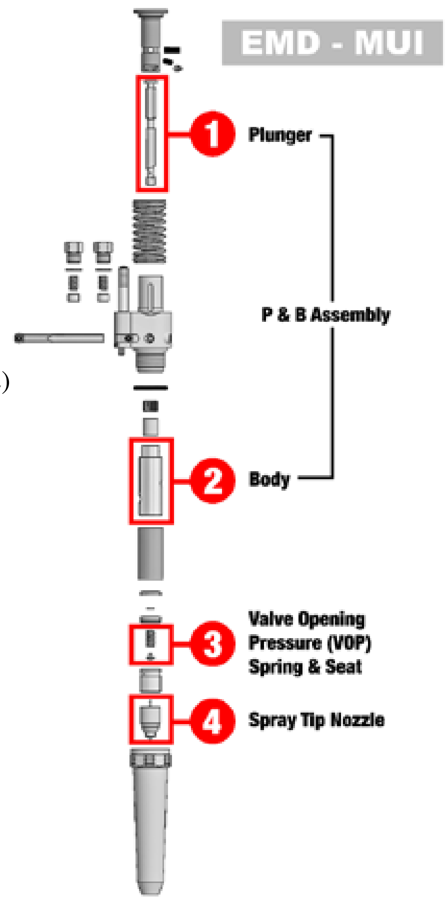
1. Spray Tim Nozzle (#4 in pic) Orifice holes degrade leading to:
   a. Poor atomization
   b. Improper spray angle
   c. Increase emissions

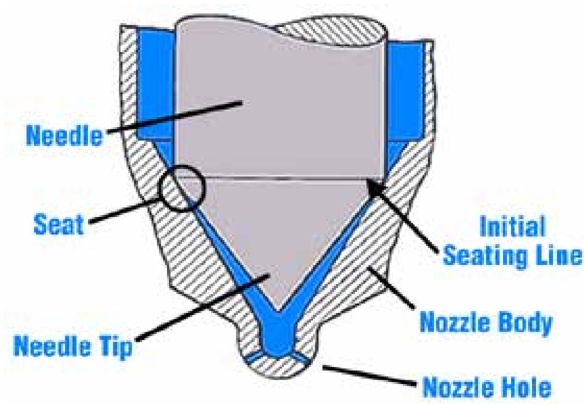
2. Nozzle Needle seat wear leading to:
   a. Leakage
   b. Smoke
   c. Loss of power
   d. Increase emissions

3. Plunger and / or Bushing bore (#1 + #2) wear leading to:
   a. Leaking
   b. Smoke
   c. Loss of power
   d. Increase emissions

4. Control valve seat wear (EUI #5) leading to:
   a. Poor timing
   b. Smoke
   c. Loss of power
   d. Increase emissions

5. Valve opening spring wear (#3) leading to:
   a. Poor timing
   b. Poor atomization
   c. Increase smoke
   d. Increase emissions





 # 4 Spray Tip Nozzle Key Components:

There are four essential aspects to fuel injections:

1. Fuel Atomization

a. Pressurized fuel flows through the spray tip orifice holes so that as the fuel is delivered it atomizes into a fine mist.
b. The atomized fuel combines with the pressurized air in the piston cylinder and ignition results in combustion.
c. The angle of the spray and the size of the fuel droplets are key to proper combustion.

2. Timing

a. When an injection "event" begins, how long it lasts, and when it ends combine to create the timing of injection.
   i. Start of injection
   ii. Start of fuel delivery
   iii. End of injection
b. Mechanical injectors are timed via the helix cut on the injector plunger.
c. Electronic injectors are timed via the engine electronic control module (ECM) and the actuator assembly which is often, but not always, attached directly to the injector.

3. Injected fuel quantity

a. The amount of fuel delivered in an injection event.
b. Often calibrated by mm^3 per stroke
c. Injection duration (the difference between start of injection and end of injection)

4. Air / Fuel ratio

a. The amount of air needed for desired power.
   i. Enough oxygen needed to completely evaporate the fuel.
b. The correct amount of fuel to utilize all the oxygen in the cylinder.

Although each of the four aspects of fuel injection are critical to performance, fuel atomization may be the most important and the one which tends to degrade most quickly. As atomization deteriorates, combustion efficiency degrades and in turn increases hydrocarbon emissions. Depending on the injector part number. the orifice holes vary in number (usually 6 or 7), size and angle. Over time as the pressurized fuel erodes the orifice holes the holes will enlarge, and the angles change. As the holes enlarge, atomization (the size of the fuel droplets) degrades resulting in less effective fuel burn. The result is higher emissions, poor fuel economy and liner wash from unburned fuel.

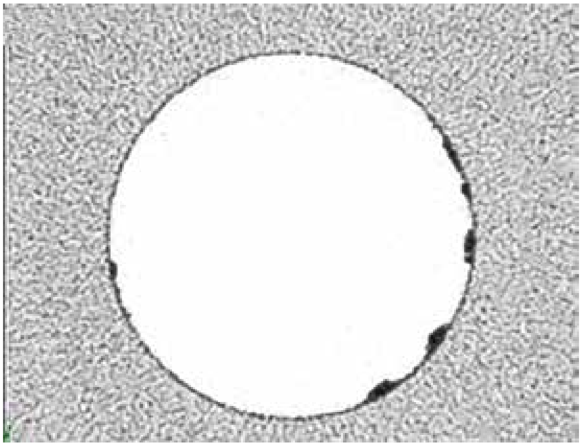
On the left is a used nozzle and the right is new. You can see on the left that the orifice holes are larger which indicates this nozzle is worn beyond its useful life.

In addition to the orifice holes modern fuel injectors utilize a “needle valve” incorporated into the spray tip. At the start and end of injection the needle valve in the interior of the nozzle body is held down on the nozzle body seat by the valve spring. The needle to seat fit prevents fuel from passing through to the orifice holes. During normal operations the needle moves up and down in milliseconds millions of times over the life of the injector and over time the needle seat will wear causing fuel to leak past the seat after the end of the injection event. This excess fuel drips out of the orifice holes as unburnt and excess fuel and then before the following injection event resulting in higher emissions, poor fuel economy and perhaps damage to the power assembly components.

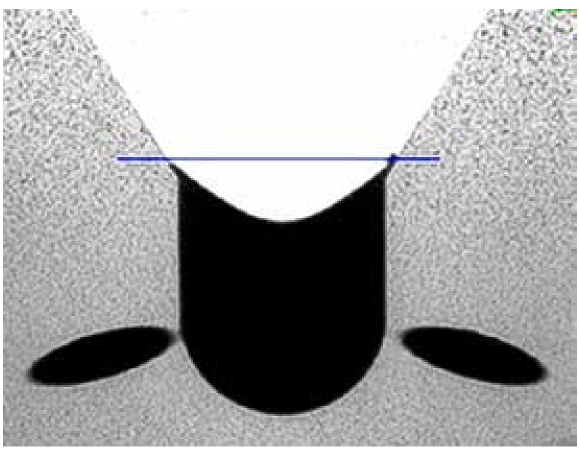
Let's talk about springs. The needle valve in a spray tip is held down on the nozzle body seat by a spring called the Valve Opening Pressure Spring or VOP spring. The spring itself sits on a "seat" which in turn presses against the top of the needle valve. As fuel is pressurized from the plunger into the nozzle, the pressure of the fuel becomes greater than the pressure from the VOP spring holding down the needle. As the needle lifts against the spring seat, the VOP spring compresses until enough pressure is released through injection that the spring can then decompress. This action takes place with every injection cycle (think 900 rpm). As with any spring, over time the VOP spring loses some of its compression forces and lessens its ability to keep the needle closed on to the nozzle seat. The result is that less pressure is required to open the needle valve, so injection begins earlier and the needle valve stays open longer. All this happens in micro-seconds but over time the injector begins to slightly over fuel resulting in higher fuel consumption, greater emissions and the likelihood of visible smoke.

In addition to the VOP spring, the valve seat also wears. The lift of the needle is fast and furious, so the valve seat receives a pounding during each injection event. As the seat wears the needle has more lift and recedes from the seat a little higher. Again, this means the valve stays open longer contributing to a reduction in performance. All rebuilt injectors, no matter what engine model, should use new VOP springs and new valve seats 100% of the time.

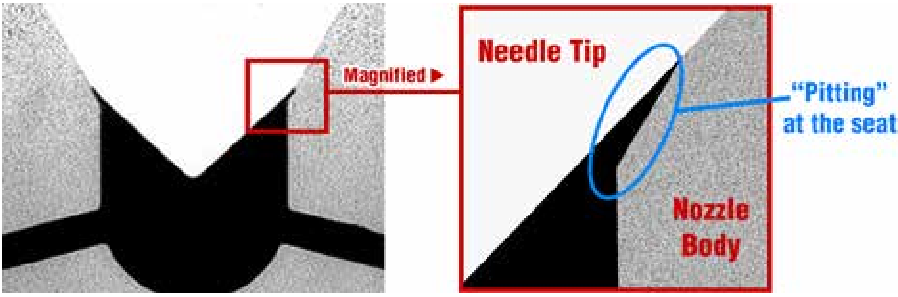
Needle valve nozzle seats, VOP springs and spring seats are all key components of a diesel injector. As they are internal to the assembly, they are not visible to anyone other than an injector builder but together they can mean the difference between a high performing engine and a fuel guzzling smoker.

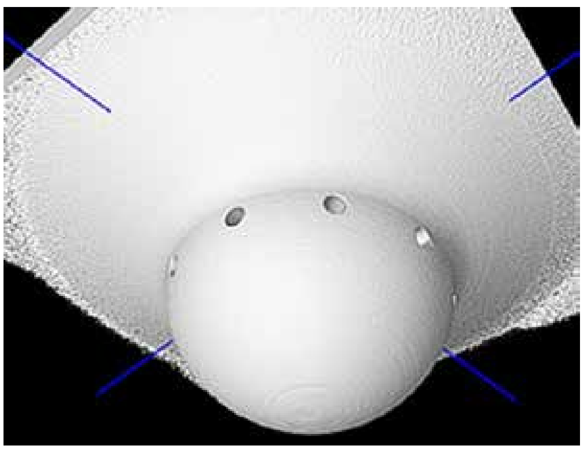


Looking down nozzle body ID

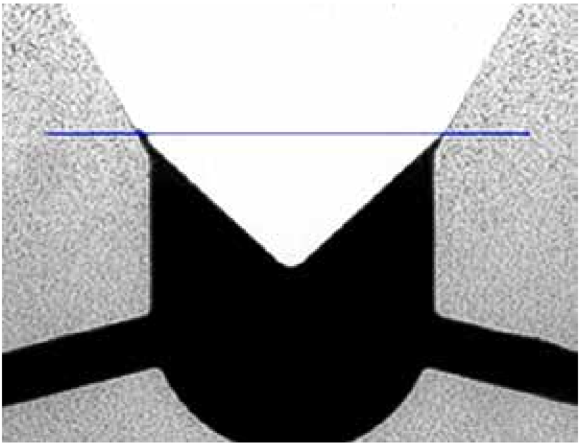


Nozzle Seat (blue line)





Orifice Holes



Needle after three years of use Beyond three years of use

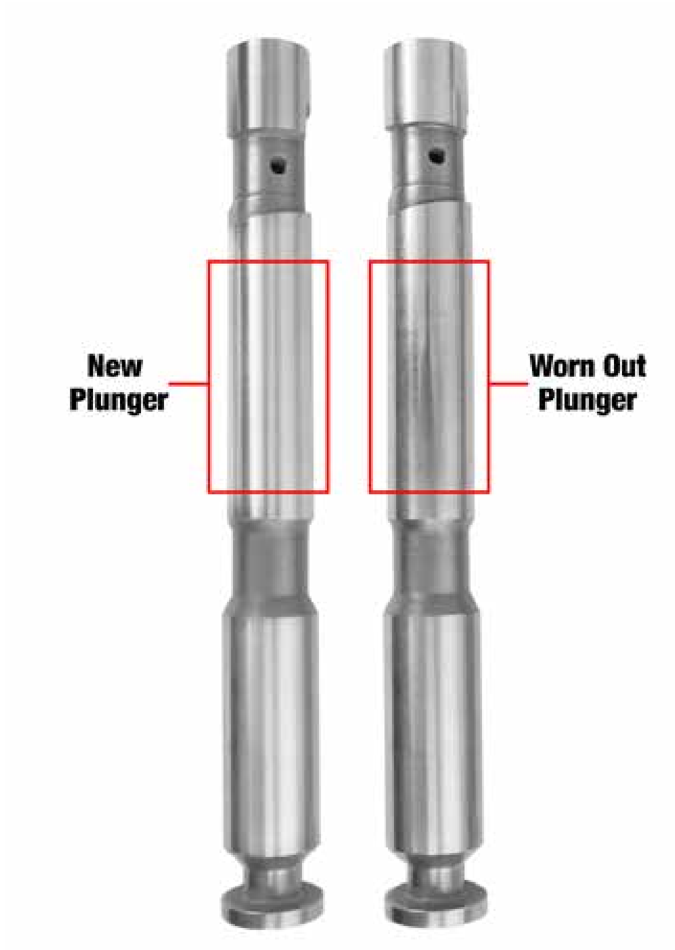
Over time, the needle valve will wear at the area where it hits the valve seat causing leakage out of the orifice holes.

Mechanical injectors have a Plunger & Bushing (P&B) assembly where the plunger Outside Diameter (OD) is a matched fit to the bore (Inside Diameter; ID) of the bushing. The bushing has an upper and lower port which are opened and closed as the plunger moves up and down from the motion of the cam follower. Over time the inlet and outlet ports within the bushing bore wear causing fuel leakage between the plunger and bushing along with small changes in timing.

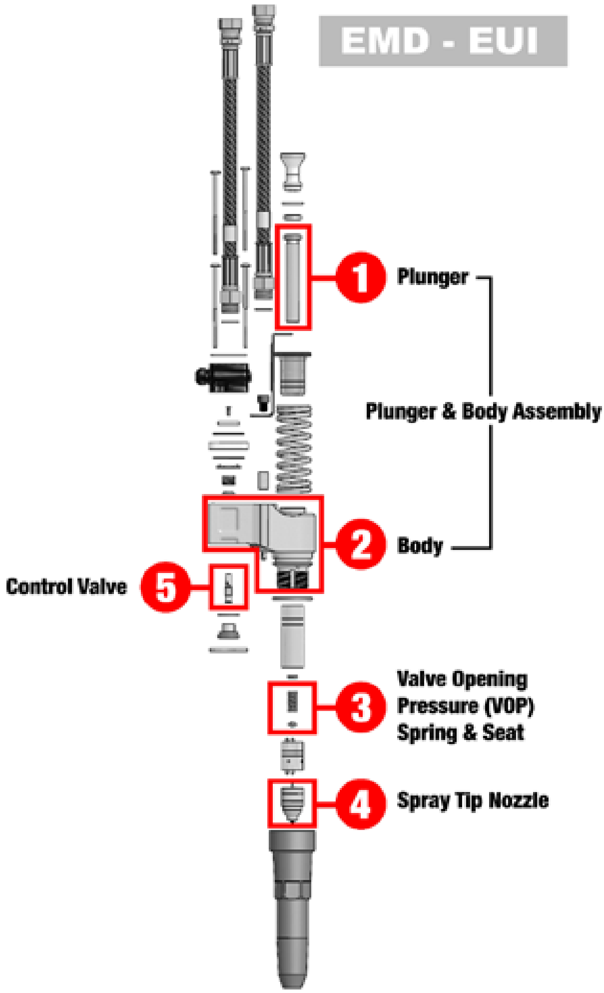
The plunger has a helix cut which rotates with the longitudinal movement of the injector rack. In conjunction with the opening and closing of the bushing ports, this repositioning of the helix cut meters the amount of fuel and the timing of combustion. Over time the motion of the plunger up and down within the bushing causes wear on both the bushing bore and plunger OD resulting in fuel leakage.

P&B wear contributes to smoke, loss of power and higher fuel consumption. This wear happens over an extended period, so it is often difficult to perceive the deterioration of injector performance without specific testing for fuel consumption and emissions. There is no doubt a poorly performing P&B assembly will increase emissions, which is the primary reason the manufacturers of engine overhaul kits require regular injector changeouts.

Plunger & Bushing Assembly: left side used; right side new



Note the wear on the used plunger on the right compared to the new on the left



Just like mechanical injectors, an electronically actuated injector has a needle valve style nozzle assembly (#4). Due to much higher pressure in an electronic injector the spray tip design has variations which help reduce cavitation but as a wise engineer once told me "When it comes to electronic injectors, it's not 'if' you get cavitation, it's 'when' you get cavitation". Higher pressures reduce the life cycle of spray tips as orifice holes deteriorate more quickly and cavitation will contribute to leakage.

Electronic injectors do not have a traditional Plunger & Bushing assembly like a mechanical injector, but they do have specific components that wear over time. EMD engines use what is termed an Electronic Unit Injector (EUI) which like a mechanical injector, uses a cam actuated plungers, but the plunger has no machined helix cut because fuel is metered and timed via the electronic actuator assembly. The plunger is matched fit to the upper bore of the injector body (#1 + #2) so like the wear on a mechanical injector bushing, the body itself will deteriorate as the plunger moves up and down millions of times over the life of an EUI. The body will begin to leak at the plunger / body assembly with the similar effects as a worn P&B assembly in an MUI.

One important difference between an EUI and an MUI is that within an EUI actuator assembly there is a control valve which is critical to the fuel output and timing of the injector. The control valve (#5) has an extremely close fit to the injector body (think single digit microns).

The control valve "seats" on the body as well as moving up and down within a bore of the body and like the nozzle, due to high pressure the control valve / seat combination is susceptible to cavitation. When the control valve seat and body bore begin to wear there are timing changes and leakage which affect injector performance.

Both the MUI and EUI use a spring / seat assembly (#3) to hold the spray tip needle down to prevent fuel from escaping through the orifice holes. As the cam follower is driven down the fuel inside the injector builds pressure which then overcomes the force of the spring holding down the spray tip needle. As pressure is released through injection, the spring will force the needle back into the seat of the spray tip body thereby closing off the orifice holes. Over time the spring and spring seat will wear and lose some of its strength. As this happens the needle will begin to open more quickly and close more slowly (think milliseconds) which allows more fuel to be injected, causing a longer injection event. As more fuel is injected, less is completely burned, causing smoke and of course higher fuel consumption.

Fuel injector pressure and the slow deterioration over the number of injection events will affect the performance of the injector and therefore the emissions and fuel economy of the engine. Data has shown that increasing injection pressure will cause a reduction in soot formation. Studies have shown that the same fuel mass injected at higher pressures, results in optimization of the injection and combustion process. The combustion times are significantly reduced by the increased pressures as the atomization and vaporization efficiency are improved.[2] Injector pressure contributes to the timing of the injection event. Bottom line is that over time injectors lose their optimal injector pressure due to wear on the valve opening spring & seat along with wear on the spray tip needle valve & seat. These are small dimensional changes but over time they have a big impact.

2 MDPI article "Transient Cavitation and Friction-Induced Heating Effects of Diesel Fuel during the Needle Valve Early Opening Stages for Discharge Pressures up to 450 MPa

Of course, the fuel injector is just one part of the entire system which creates the power of a diesel engine. The air fuel mixture is also a key component for proper combustion and optimal performance. As intake air is introduced into the combustion chamber it has a swirling motion to create the intensity needed for combustion efficiency. Injection timing, including retarding or advancing contributes to controlling emissions. This is a key reason why timing the injection event is important and where injector wear is crucial. Since the actual injection event is quite short, it is imperative that is completed as close to piston Top Dead Center (TDC) as possible for maximum efficiency. Nozzle orifice holes are designed to utilize all the air compressed in the chamber, but as the holes wear their size and angle can and will change and the oxygen will be underutilized to the detriment of both fuel economy and emissions.

In the 1960s and 1970s most Class I railroad performed their own engine and components rebuilds, which in some cases included EMDs unit injectors. The goal among railroads was uniform in that mechanical departments sought to reduce their costs by testing the limits of the locomotive builders recommended maintenance practices. Many (if not most) railroads ignored the OEM maintenance instructions recommended changeout period for injectors and rebuilt injectors purchased as replacements for failed injectors were often sourced from the lowest bidder with less regard to performance.

In the late 1990s a Class 1 RR conducted a test to determine a more definitive time interval to replace injectors. For this test, injectors were removed from five GP38 locomotives which were one, two, three, four and five years off engine overhaul during a time when injectors were changed at approximately 8-year intervals. A reputable third party was contracted to conduct testing of fuel efficiency only as emissions testing was not routinely performed at that time.

Testing results validated the EMD 36-month recommended injector change out interval in so far as fuel efficiency was markedly degraded after three years. Testing was also performed on new injectors from EMD and non-OEM suppliers. Results showed a correlation between injector performance (fuel efficiency) and cost. As a result, the RR changed sources of rebuilt injectors and introduced a "mid-life" tune up on all EMD locomotive models halfway between their scheduled engine overhauls.

When we think of the old adage "nothing lasts forever", for any device with high-speed moving parts and very close tolerances, we can substitute the adage "they don't last as long as you might think". Even the best maintenance practices, including the use of high-quality lubricants and fuels, will not prevent component wear and therefore, degradation of performance is inevitable. Indeed, injectors will "work" (e.g.: inject fuel for combustion) for many years beyond their initial peak performance, but the increased cost of fuel alone becomes greater than the cost of injector replacement. When both increased fuel usage and emissions are considered, the higher costs to a railroad using injectors past their useful life becomes untenable.

Suggested further reading:

"Combustion Systems" by Hanna Jaaskelainen & Magdi K. Khar / DieselNet Technology Guide.

AESS Issues and Challenges

By:
Chris Stoos – Southwest Research Institute
Daniel Bellemare – Rail Industries Canada

1.0 AESS Background

Automatic Engine Stop/Start (AESS) systems are an EPA verified Idle Reduction Technology, which allows the locomotive to shut down its engine when certain requirements are met to reduce excessive idling, which in turn reduces fuel consumption, emissions, and noise. These systems are made by various manufacturers, but all generally operate in the same way, as specified in AAR S-5502[1]. While setpoints can vary, the requirements for AESS shutdown are usually based on the following in some way:

Table 1. AESS Monitor Parameters

Battery State of Charge	Generally has minimum voltage and maximum charging current requirements
Main Reservoir Air Pressure	Usually based on Main Reservoir 2 pressure, though constant compressor cycling can also delay or eliminate shutdowns
Ambient Temperature	AESS will disable at high and low ambient temperatures
Crew Input	Crews are capable of delaying shutdown
Distributed Power Status	Often locomotives in DP will not shut down
Number of Restarts Day/Week	Some AESS Systems limit the number of restarts, and will no longer shut the engine down once that limit is reached

1 *S5502 Automatic Engine Start/Stop System* - AAR Manual of Standards and Recommended Practices

The AESS system monitors the parameters and determines if the locomotive can be shut down safely. To do this, it breaks down idle into two categories. Those idle categories are defined below.

> ***Essential Idle*** – Any time the locomotive is idling and one or more of the AESS requirements for shutdown are not satisfied.
>
> ***Non-Essential Idle*** – Any time the locomotive has been idling for over 15 minutes after all AESS requirements for shutdown are satisfied.

AESS systems cannot reduce essential idle time, as it determines that it is unsafe to shut the engine down.

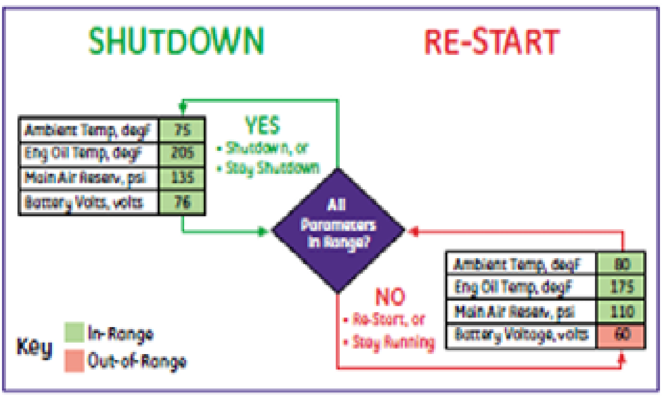


Figure 1. Example AESS Logic Chart

1.1 AESS Impact on Fuel Consumption

In order to estimate the impact of AESS systems on fuel consumption, we will look at three typical locomotive types and estimate the average fuel consumption (and fuel consumption savings). Table 2 shows these three scenarios.

Table 2. Idle Fuel Estimates for Various Locomotive Use Cases

	Locomotive 1	Locomotive 2	Locomotive 3
Power Rating	2,000 THP	3,000 THP	4,500 BHP
Duty Cycle	Switch	Medium	Linehaul
Hours/Day	8	12	16
Operating Days/Year	260	300	330
Gallons/year (total)	29,500	118,000	310,000
Gallons/year (idle)	5,800	8,500	10,200
% of fuel consumption at idle	19.7%	7.2%	3.3%

In the above scenarios, if we assume that on average the split between "Essential" and "Non-Essential" idling on the current locomotive fleet is 50/50, and we assume that currently AESS systems eliminate half of all non-essential idling time, this implies that currently AESS systems reduce fuel consumption on the order of 1,500-2,500 gallons per year per equipped locomotive, which is good but could be greatly improved.

There are two ways to increase the fuel savings from AESS systems. The first way to accomplish this is to increase the shutdown percentage during non-essential idling. This can vary locomotive to locomotive and by AESS system, but is generally a byproduct of the AESS system algorithm and railroad requirements for shutdown. While this is possible with better technology and better AESS systems, it is not the subject of this paper.

The second way to increase the fuel savings from AESS is to reduce the amount of essential idling. As noted above, essential idling is any time the AESS parameters for engine shutdown are not met. Often, but not always, this is the results of a maintenance issue on the locomotive or rail cars and can be prevented. By addressing these maintenance issues, AESS functionality can be increased which in turn will reduce fuel consumption and locomotive based emissions[2]. This paper will cover common maintenance-related issues that have a large effect on AESS system performance.

1.2 AESS Limitations

Locomotive engines, especially older ones, are not designed to be turned on and off in the same way as automobiles are. There's a limit to how many times a large diesel engine can be shut down and started in any given 24-hour period, otherwise you begin to prematurely wear out your engine starting system

2 *"Emission Reduction Technologies"*, Amarjit Soora – LMOA Annual Meeting Proceedings, 2022

components like starters, ring gear, batteries, and contactors. Road failures caused by starting system problems can magnify the cost impact on the railroads – it isn't just about maintenance and component costs. AESS performance depends on overall health of the equipment. In the following sections we will discuss the common issues that can reduce the effectiveness of AESS systems, how to spot them, and potential solutions.

2.0 Air Leaks

Air leaks on locomotives and rail cars are common and they can have large impacts on both fuel consumption and AESS performance. As an example, Figure 2 below shows the engine speed profile of a locomotive idling over a twenty-four-hour period. Note that the air leaks on this were within all applicable FRA air test limits. The unit started, on average, nine times every twenty-four-hour period and, while running, would consistently have to increase engine speed to run the compressor.

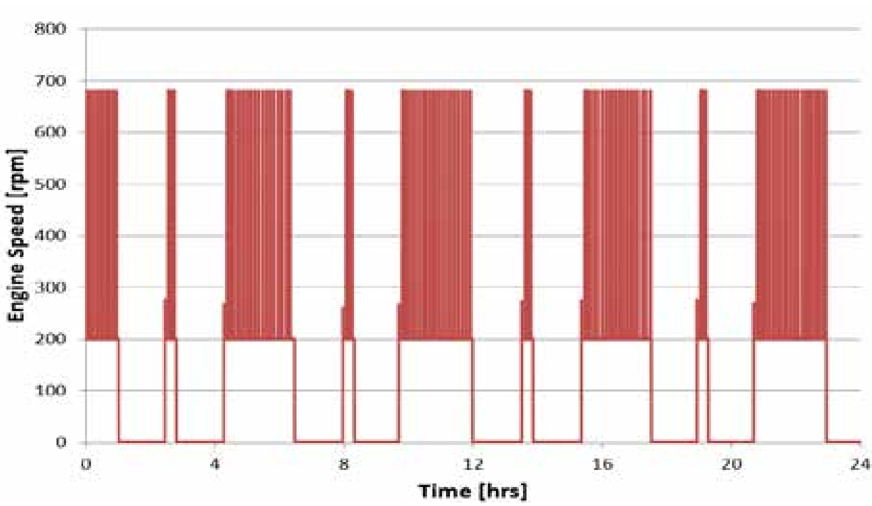


Figure 2. Locomotive engine speed profile over a 24 hour period before air leak repairs

After numerous air leaks were repaired (Figure 3), a significant change to the AESS profile was noted. The locomotive went from an average of nine restarts per day to an average of one restart per day. The result was a reduction in fuel consumption of 62% (43 gal/day) and a reduction in overall engine on time of 60%. On locomotives that have daily and weekly restart limits, the impact of air leaks on fuel consumption and emissions can be even more severe as a leak can exhaust all of the allowed restarts in hours, causing the locomotive to then idle continuously for the remainder of the day or week.

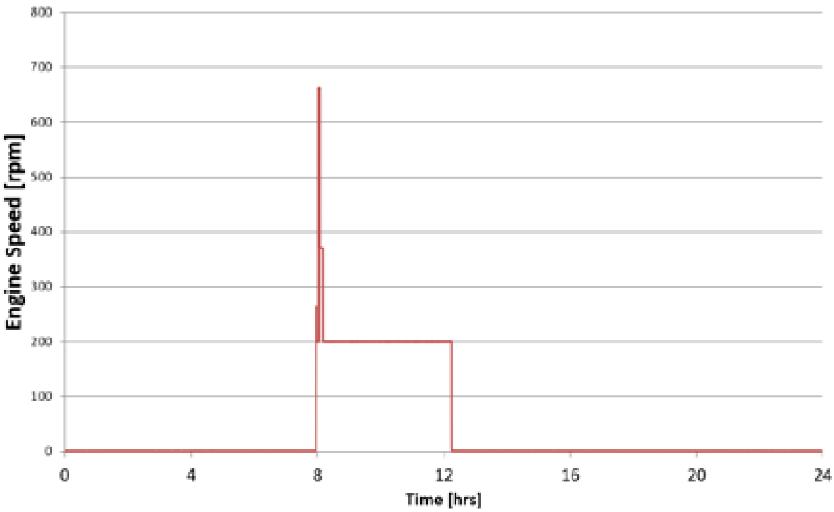


Figure 3. Locomotive engine speed profile over a 24-hour period after leak repairs

In addition to their effects on AESS performance, air leaks also cause significant increases in locomotive fuel consumption during normal operation[3]. Repairing air leaks is an easy concept, but not always easy in practice. Finding air leaks alone is a labor-intensive process, as air leaks are invisible and often difficult to hear, especially in rail environments. There are commercial tools available to help shop personnel with detection, which range from simple sensors that require the operator to point directly at a leak location to advanced detection systems that can pinpoint a leak from 20 feet away. The prices of these systems vary in the range of $1,000-$30,000 per unit.

In addition to handheld detection systems, the Federal Railroad Administration (FRA) is currently funding an ongoing field development of a wayside air leak detection system, which will be available for use at the conclusion of that development effort. Wayside detection could further reduce the labor necessary in finding air leaks on rolling stock, as mechanical personnel would know the location of leaks before the equipment ever entered the shop.

Finding the leaks is only the first part of the equation though, as repairs must be made to realize a significant improvement in AESS performance and overall

3 *"Autonomous Detection of Compressed Air Leaks on Trains"*, Christopher Stoos – LMOA Annual Meeting Proceedings, 2022

fuel consumption. Mechanical personnel will need to be given the time and resources necessary to perform these repairs and railroads will need to implement leak checks/limits that go above and beyond the current FRA requirements.

3.0 Locomotive Batteries

Railroads struggle with maintaining their locomotive lead acid batteries in an optimal way. That fact alone could hinder the possible gains in emissions reduction & fuel consumption. With more on-board electronics like positive train control (PTC), locomotive digital video recorder (LDVR) as well as powerful locomotive computers being introduced in newer locomotives, battery depletion leading to shortened battery life and start failures are a real concern when locomotive is shut down on AESS mode. Figure 4 shows an example of battery voltage and current during AESS. The current draw on the battery of this particular locomotive (with lights and HVAC system off) averaged 10 amps continuous while the locomotive was off. It is time to look at newer battery technology as well as addressing these new essential load requirements where possible.

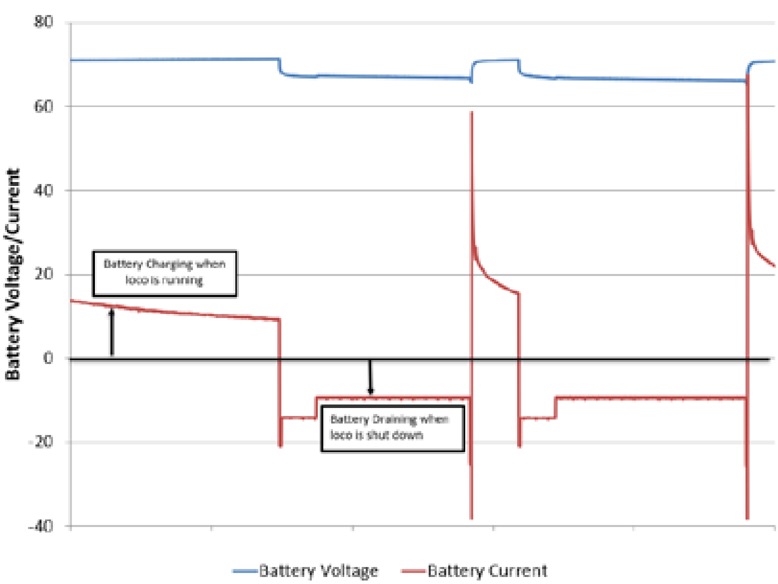


Figure 4. Example Battery voltage and current during AESS restarts

3.1 Battery Chemistries

There are quite a few locomotive starting battery chemistries available on the market in varying stages of technology readiness available for potential use in the rail industry. Below is a list of a few of those that are available:

1. Lead-acid battery:
Traditional type with relatively low cost.
Widely used in various industries.
Essentially 100% recyclable.

2. Maintenance-free lead-acid battery locomotives:
Adopt maintenance-free technology, reducing manual work and maintenance costs.
Suitable for applications where frequent maintenance is difficult or inconvenient.

3. Lithium-ion battery:
High energy density and long service life.
Gradually replacing lead-acid batteries due to superior performance and efficiency.
Higher initial cost compared to lead-acid batteries.

4. Supercapacitor battery:
Feature rapid charging and discharging, long lifespan and environmental friendliness.
Emerging technology with great potential for future development.

5.Nickel-Metal Hydride (NiMH):
Another high energy density, lead-free option for locomotive starting batteries is Nickel-Metal Hydride (NiMH) Batteries. NiMH batteries are generally cheaper than Li-Ion batteries, but do self-discharge over time. The energy density of these batteries is higher than lead-acid, but lower than Li-Ion batteries.

6. Lithium iron phosphate (LiFePO4/LFP) batteries :
A newer subset of Li-ion chemistry that offers numerous advantages over traditional lithium-ion batteries as well as NiCd and lead acid. LiFePO4 batteries were invented in 1996, but the technology has vastly improved and has seen much broader adoption in recent years. LFP batteries are not in the locomotive batteries yet but may be a contender in a few years.

While these various battery chemistries all have pros and cons associated with them, the two most likely in the short term are:

- **Lead Acid batteries** who have been in use for many decades in the railway industry
- **Lithium-ion batteries** who made their debut in the railway industry in the mid 1990's.

There are pros and cons for each of these two battery types, some of which are discussed in detail below.

Figure 5. Traditional Locomotive Lead-Acid Battery Cell

Advantages of Lead-Acid Batteries:

1. Cost-Effective: Lead-acid batteries are cost-effective to manufacture, resulting in more budget-friendly options for locomotive purchases.
2. Mature Technology: Lead-acid battery technology is well-established, with stable market availability. Maintenance and upkeep are relatively straightforward, but often ignored.
3. Vibration Resistance: Lead-acid batteries exhibit robust resistance to vibration and rough conditions, making them suitable for use in challenging work environments.
4. At or nearly 100% recyclable.

Disadvantages of Lead-Acid Batteries:

1. Lower Energy Density: Lead-acid batteries have lower energy density compared to Li-ion batteries.
2. Shorter Lifespan: Lead-acid batteries have a comparatively shorter lifespan, necessitating more frequent replacement and maintenance, which can increase operational costs and downtime.
3. Explosion Risk: Though rare, lead-acid batteries produce hydrogen and oxygen when charging which can cause explosions if not ventilated correctly.
4. Corrosion: The acid in Lead-Acid batteries is highly corrosive and can deteriorate the surrounding steel if spilled during battery maintenance.
5. Maintenance: Lead-Acid batteries require continual maintenance with deionized water.

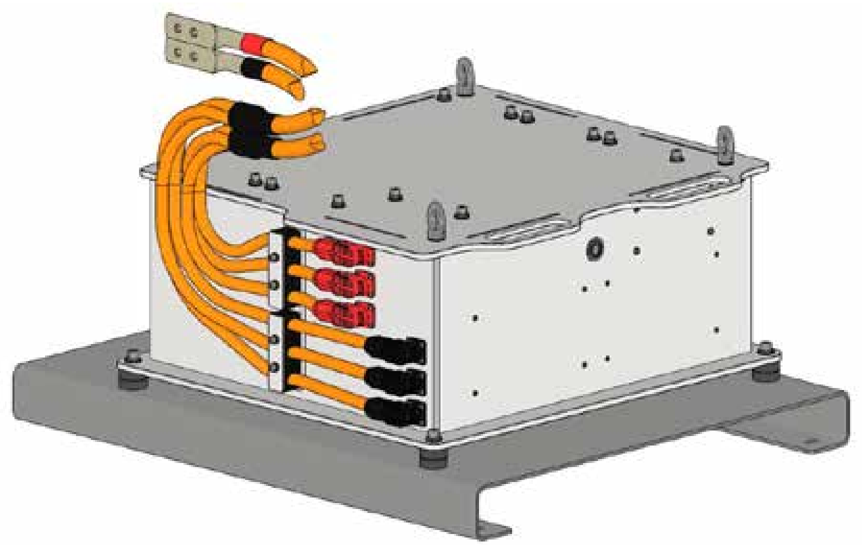


Figure 6. Example of lithium-ion battery packaging

Advantages of Lithium-Ion Batteries:

1. High Energy Density: Lithium-ion batteries boast a significantly higher energy density and increased power output.
2. Lightweight: In comparison to lead-acid batteries, Li-ion batteries are notably lighter. This makes replacing the batteries safer and easier for mechanical personnel.
3. Longevity: Lithium-ion batteries exhibit a longer service life, enduring more charge and discharge cycles. This reduces the frequency and cost of battery replacements over the locomotive's lifetime.

4. Rapid Charging: Li-ion batteries charge swiftly and efficiently, reaching full capacity in a short time frame.
5. Half the size: A single lithium-ion battery replaces two traditional lead acid batteries, allowing the existing battery space to be utilized for an additional battery for hotel loads if desired.
6. Lower Voltage Sag: Lithium-Ion batteries give less voltage sag in high load conditions, like starting. The consistently higher voltage means less current and therefore less heat, improved starter life and higher efficiency.
7. Maintenance free.

Disadvantages of Lithium-Ion Batteries:

1. Higher Cost: Manufacturing Li-ion batteries comes at a higher cost compared to lead-acid batteries.
2. Fire Risks: Though rare, Lithium does carry some inherent safety risk during accidents or during the charging and discharging processes, including issues such as overheating, short-circuiting, and fire hazards. Managing and safeguarding against these risks may necessitate special precautions.
3. Environmental Impact: The production and recycling processes of lithium-ion batteries can have environmental implications, including resource consumption and waste disposal considerations.

3.2 Smart Batteries and Battery Management Systems

***NOTE**: The AAR has set up a TAG committee to establish standards for Smart Batteries.*

A smart battery pack is a rechargeable battery pack with a built-in battery management system (BMS) which consists of built-in electronics system with information about its power status to conserve power intelligently. Smart batteries are designed to constantly track their own capacity whether they are being charged, discharged or stored.

Internally, a smart battery can measure voltage and current and deduce charge level and SoH (State of Health) parameters which can indicate the health of the cells. Externally, a smart battery can communicate with a smart battery charger and the locomotive via the CAN bus interface. A smart battery can demand that the charging stop, request charging, or potentially demand that the locomotive switch the secondary battery (if equipped).

Smart Battery technology permits features like:

- Onboard monitoring of critical cell and power electronic parameters, short circuit & over current protection, charge & discharge voltage protection, high and low temperature protection
- Sensing feature that will reduce potential of flattened battery fail to start occurrence
- Smart battery - functions like LCS and others available. Communications outputs to integrate the system into a locomotive log event. Onboard monitoring for performance and safety.
- User interface - simple LED indications of status and modes. Button switchable for further function and safety
- Remote fault analysis - cloud based battery parameter upload available to have vendor assistance/diagnose issues.
- AESS extension – certain battery chemistries increased power output and capacity, which means high demand items like HVAC could run off the batteries during AESS shutdown time. This has the potential to reduce operator overrides that account for a significant portion of excess idle time
- Adjusting the battery charging strategy based on battery age and health

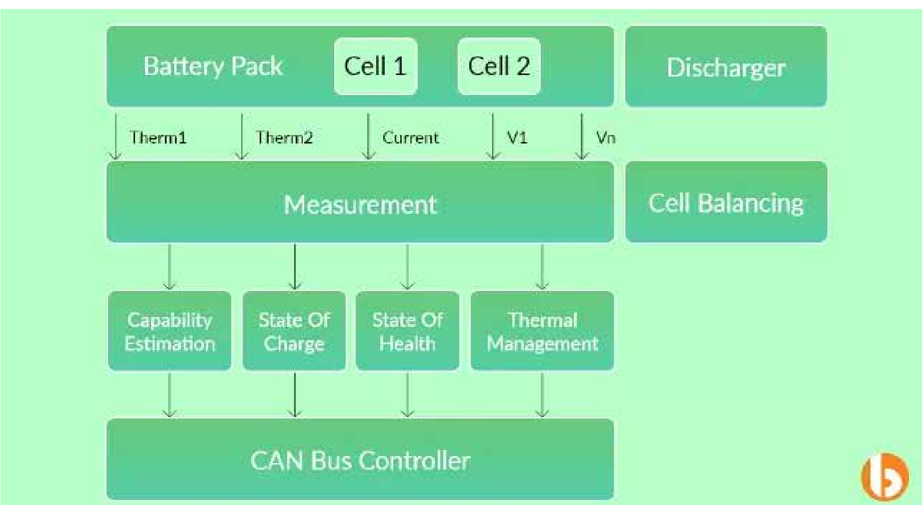


Figure 7. Example of smart battery communication diagram

Battery Management Systems (BMS) have become crucial due to the increasing intricacy of battery technology, especially in lithium-ion systems. The role of a smart BMS is to monitor and report the associated battery's health, performance, and maintenance. Key features of BMS include:

- **Battery Health Monitoring:** The BMS oversees elements such as voltage, temperature, and current movement. This guarantees that the battery operates within secure limits, reducing any potential harm.
- **Enhancing Performance:** The system manages the charging and discharging cycles to optimize both battery longevity and effectiveness.
- **Avoiding harm:** The battery management system identifies possible problems such as overheating or excessive discharge and can implement necessary measures to protect the battery.

4.0 Ambient Conditions

Ambient conditions can cause AESS systems to become less effective. This is especially a concern for railroads that operate in extreme temperatures. There is very little a railroad can do to truly mitigate ambient temperatures, but there are things that can be done to reduce the impact of extreme ambient conditions on the fuel consumption and emissions of a locomotive.

The most prevalent solution to countering the effects of extreme ambient conditions is Auxiliary Power Units (APU). APUs are made by various manufacturers and generally consist of a diesel burner or a small engine, pumps, and heating elements. It allows the oil and engine coolant to be kept warm while burning significantly less fuel than would be used by the running the prime mover. APUs can also be paired with a small generator to power hotel loads and charge the locomotive batteries and even a small air compressor to maintain main reservoir pressure when the locomotive engine is shut down.

Figure 8. Examples of production APUs designed for locomotive use

The benefits derived from APUs are that they allow you to run a much smaller, efficient engine instead of the prime mover. This means a significant reduction in fuel consumption and emissions[4].

APUs are not without their issues though, as space limitations and the necessity of maintaining another engine has greatly limited their adoption. APU maintenance requirements (and the complete lack of maintenance) are also a significant issue which has caused railroads in the past to abandon the technology. While unpopular and potentially a touchy subject, APUs remain a realistic, commercially available solution to reducing fuel consumption and emissions from idling locomotives.

5.0 Train Crews

Train crews often are responsible for delaying or disabling AESS shutdowns and systems. This occurs for various reasons, but often it is associated with crew comfort or convenience. When on board, keeping things like air conditioners or heaters running is one cause, and in switching operations it can be as simple as the crew not wanting to go through the startup process when they get back from their break.

Crews often come up with rather ingenious ways of bypassing AESS systems, and it isn't always easy to tell the difference between an underperforming locomotive and a locomotive that has been altered to underperform (Figure 9) without inspection.

Figure 9. Crew "modifications" to AESS systems

One potential solution is having a dedicated battery set for starting the locomotive diesel engine and use a second battery that would look after hotel/essential loads when locomotive is shut down by AESS. While not feasible when using traditional lead-acid batteries, a single lithium-ion battery replaces two

4 *"Reducing Locomotive Idle Fuel Consumption and Exhaust Emissions by Applying an Auxiliary Power Unit (APU)",* L. Biess, T. Stewart, D. Miller, and S. Fritz – ASME ICES 2003

lead-acid batteries on a locomotive, enabling the second available battery box on the locomotive to be used by another lithium-ion auxiliary battery. This could allow the cab HVAC to be operated for a few hours while the engine is shutdown. Other motor-driven accessories and cab electronics can also be run off this battery.

Other potential solutions for crew related issues are covered above, as APUs have the ability to keep crews comfortable even when the prime mover is shut down. Additionally, incentivizing crews has worked for some railroads in the past with respect to fuel consumption. This is a complex, human issue though and unfortunately there is no "one size fits all" solution to human behavior.

6.0 AESS Tracking

As AESS systems and locomotives in general have become smarter, the ability to track AESS data electronically has grown. Whether through the cab screen or with an electronic report (often as a subscription), railroads can now track the AESS status of their locomotives. This data can vary in how much information is available depending on age, manufacturer, etc. An example of the cab data available on some locomotives is shown in Figure 10.

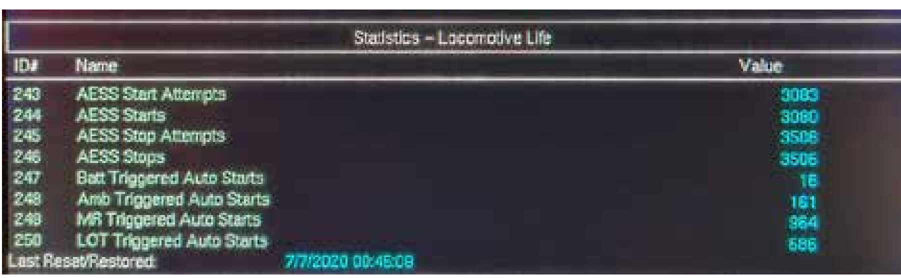


Figure 10. AESS data is available in the cab screens of some locomotives

Looking at and analyzing this AESS data provides the opportunity to spot locomotive health issues long before they become a problem in the field. Flagging locomotives that restart more often (or never shut down) and repairing the issues causing the restarts can significantly reduce fuel consumption and, in turn, emissions.

There is no standard solution to AESS tracking, as each AESS system vendor and each railroad approaches the situation differently, but taking advantage of the data available is paramount to increasing the effectiveness of AESS systems.

7.0 Conclusions

While there are many issues that contribute to AESS systems underperforming, there are solutions available to make AESS work as intended. Increasing the effectiveness of AESS systems is extremely important to increase the lifespan of key components, reduce railroad fuel consumption, and in turn, reduce greenhouse gas and constituent emissions.

Locomotive and railcar maintenance is key to this effort. It may require going beyond the FRA required checks, meaning "good enough" is no longer good enough and railroads may need more stringent requirements built into their maintenance practices. Railroads need to provide mechanical forces with the time and labor necessary to address issues prohibiting AESS from functioning as intended. This may require incentivizing the additional maintenance needed or, at a minimum, removing disincentives that exist that are currently preventing this from being done.

Railroads also should seriously look at other possible solutions to reduce the necessary idle time, like APUs and different battery chemistries, to allow AESS systems the ability for even further idle reduction. All together the reduction in idle time will help railroads towards their GHG goals, reduce community complaints, and save railroads significant money in unnecessary fuel consumption.

Analytical Approaches to Validating Railroad Fuel Saving Technology

By:
Wayne A. Kennedy, Kennedy Consulting
Robert Stevens, First Analytics
Bret Lanz, Kansas State University
Spencer Maynes, Deflect Inc

Abstract

Class I railroads in North America have partnered with the Science Based Targets initiative during the last five years for very aggressive GHG emission goals by 2030 to 2034. Two of the six Class I's have committed to a net-zero target emissions profile by the year 2050. Historically, the rail industry has improved their fuel efficiency by an average of 1% per year going back two decades. If they continue on that glide slope to 2030, they will collectively have a 26% gap between where their current improvement trend will take them and where they will need to be in order to meet their SBTi goals. Clearly new approaches will be required in the immediate future to help close that gap.

In 2023, Class I railroads consumed approximately 3.6 billion gallons of diesel fuel including a small percentage of biodiesel, roughly 3% of the total. Total spending on this fuel was ~$11.9 billion, therefore a technology that can reduce this spend by 1% would save ~$119 million annually.

This paper focuses on various statistical analysis tools to validate the level of locomotive or train fuel savings for various technologies in the 1% to 3% range. The ability to prove fuel savings in a railroad operating environment at this "low" level of fuel savings is challenging for a variety of reasons. Inaccurate locomotive on-board fuel gauges is certainly one issue, another being the amount of inherent variability in overall fuel consumption in revenue freight railroading. There are so many different aspects which affect the amount of fuel for any given trip segment, all of which introduce a large amount of variability which makes proving low level fuel savings problematic at best, almost impossible at the worst. However, this paper outlines how it can be done, with appropriate design of experiments and statistical analysis.

SBTi Scope Emissions and Reduction Goals for the Industry

The Science Based Targets initiative (website sciencebasedtargets.org) was established in 2015 to help companies set emission reduction targets in line with climate science and the Paris Agreement goals. The Paris Agreement's long-term temperature goal is to keep the rise in mean global temperatures to well below 2 degrees Celsius above pre-industrial levels, and preferably limit the increase to 1.5 degrees Celsius. As of April 2024, there are almost 8,000 companies worldwide taking action.

Figure 1 shows the differing scopes and a brief description of each scope. Scope 1 covers direct emissions from owned or controlled sources, diesel fuel burned in locomotives in this case for rail. Scope 2 covers indirect emissions from the generation of purchased electricity, steam, heating and cooling consumed by the rail reporting company. Scope 3 includes all other indirect emissions that occur in a company's value chain.

There are two main metrics used for GHG emission measures; an absolute metric which is directly tied to how much diesel fuel is burned and is referenced in metric tons of CO_2 equivalent, and the more common measure based on intensity using either gross ton miles or revenue ton miles, as a base measure producing an intensity rate which is volume neutral. Example units are $MtCO_2e$/GTM (gross ton mile).

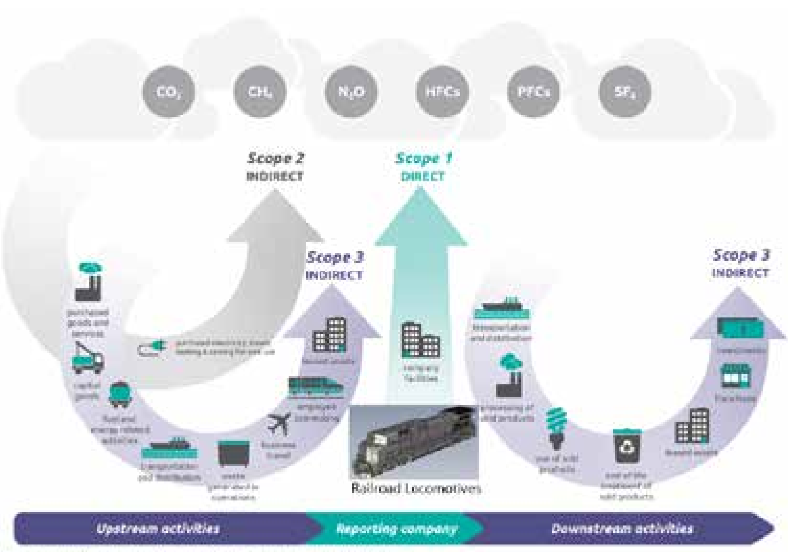


Figure 1 – Emissions Scope Definitions

Table 1 is directly from the SBTi website and shows all Class 1 goals. The goal dates vary but are mostly centered around the 2030 timeframe. They have all chosen a "well below 2 degrees Celsius" goal for limiting long term global warming. Further, the CN, CPKC and UP have committed to a Net-Zero goal by 2050.

Both BNSF and UP railroads have chosen the Absolute goal measure, where future growth and volume increases will make their GHG reduction goals more challenging to achieve. Though, to-date, traffic volume loss of 14% as measured by Gross Ton Miles or GTMs from their SBTi base year of 2018 has helped both railroads make significant progress towards achieving their SBTi goals.

Class I Railroads and Description of GHG Emissions Reduction Goals

All railroads will need to submit more aggressive goals no later than 2025 to meet SBTi's preferred ambition moving from the current "well below 2 degrees Celsius" to a new "1.5 degree Celsius". The new strategy has been rolled out in response to increasing urgency for climate action and the success of science-based targets to-date.[1] Union Pacific was the first railroad to have their 1.5-degree Celsius goal approved by SBTi the end of March 2024, moving from a 26% to a 50% absolute reduction in GHG emissions.

Company Name	Full target language	Company Temperature	Scope	Target Value	Type	Base Year	Target	Date Published
BNSF Railway	BNSF Railway commits to reduce absolute scope 1 and 2 and well-to-wheel locomotive GHG emissions 30% by 2030 from a 2018 base year*. *The target boundary includes biogenic emissions and removals from bioenergy feedstocks.	Well-below 2°C	1+2	30%	Absolute	2018	2030	2022-05-[illegible]
Canadian National Railway Co	CN commits to reduce scope 1 and 2 GHG emissions 43% per gross ton miles by 2030 from a 2019 base year*. CN commits to reduce scope 3 GHG emissions from fuel and energy related activities 40% per gross ton miles by 2030 from a 2019 base year. *The target boundary includes biogenic emissions and removals from bioenergy feedstocks.	Well-below 2°C	1+2	43%	Intensity	2019	2030	2022-07-[illegible]
CSX Corporation	CSX commits to reduce scope 1 and 2 GHG emissions intensity 37% per million gross ton miles by 2030 from a 2014 base year.	Well-below 2°C	1+2	37%	Intensity	2014	[illegible]	2020-[illegible]
Norfolk Southern Corporation	Norfolk Southern commits to reduce scope 1 and 2 GHG emissions 42% per million gross ton miles (MGTM) by 2034 from a 2019 base year*. *The target boundary includes biogenic emissions and removals from bioenergy feedstocks.	Well-below 2°C	1+2	42%	Intensity	2019	2034	2021-07-[illegible]
Union Pacific Corporation	Union Pacific commits to reduce absolute scope 1 and 2 GHG emissions 50.4% by 2030 from a 2018 base year.* Union Pacific also commits to reduce scope 3 GHG emissions from purchased goods and services, capital goods, and fuel and energy related activities 50.4% within the same timeframe. *The target boundary includes land-related emissions and removals from bioenergy feedstocks.	1.5°C	1+2	50%	Absolute	2018	2030	2024-[illegible]
CPKC	CPKC commits to reduce scope 1, 2, and 3 well-to-wheel locomotive GHG emissions [illegible] per gross ton miles by 2030 from a 2020 base year.	Well-below 2°C	1+2+3	[illegible]	Intensity	2020	2030	2023-[illegible]

Table 1 – SBTi Goals by Railroad

Figure 2 shows an equal weighting of the four Class I railroads that have chosen an emissions intensity goal. Note that improvement has stalled and actually worsened in the last two years and on average, they are now 15% above their SBTi glideslope goal. Current year is an estimate based on YTD fuel efficiency performance reported during quarterly earnings.

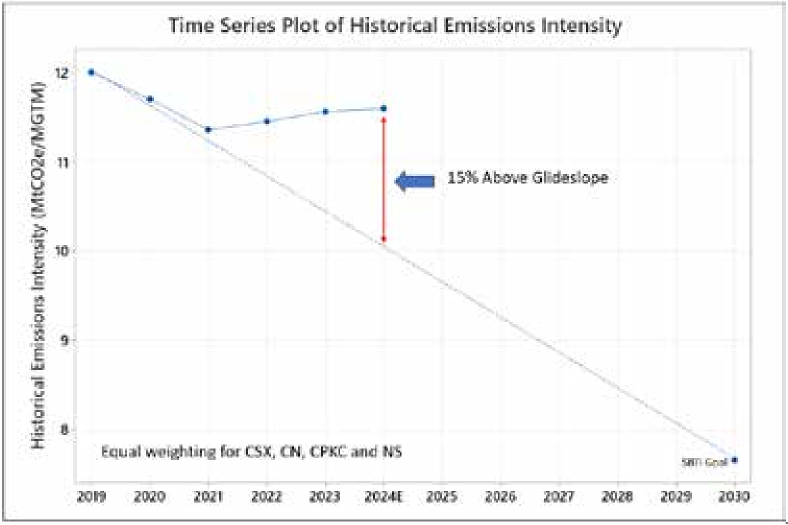


Figure 2 – Average Performance of Four Intensity Based Railroads Showing Glideslope to SBTi Goal

Figure 3 shows an equal weighting of the two Class I railroads that have chosen an absolute emissions goal. Given the significant drop in traffic volumes since the SBTi baseline year of 2018, it is not surprising that they are roughly on track for their required SBTi glideslope goal. Current year is an estimate based on YTD fuel efficiency performance reported during quarterly earnings.

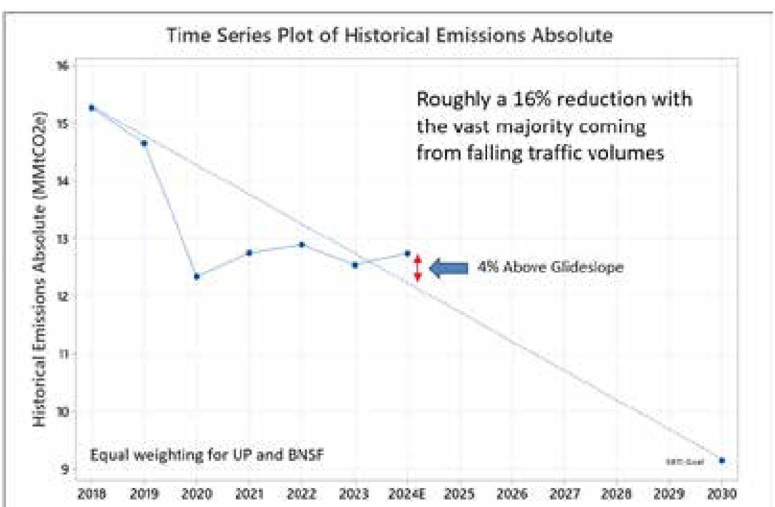


Figure 3 – Average Performance of Two Absolute Based Railroads Showing Glideslope to SBTi Goal

Historical Fuel Efficiency Industry Performance

The rail industry commonly uses a fuel efficiency measure of Gallons per Thousand Gross-ton-Miles which has been tracked for many decades. Figure 4 shows each of the seven Class 1 railroads going back to 2000. Notice the Canadian railroads have generally been the best performers and starting in 2013 both distanced themselves from their US peers.

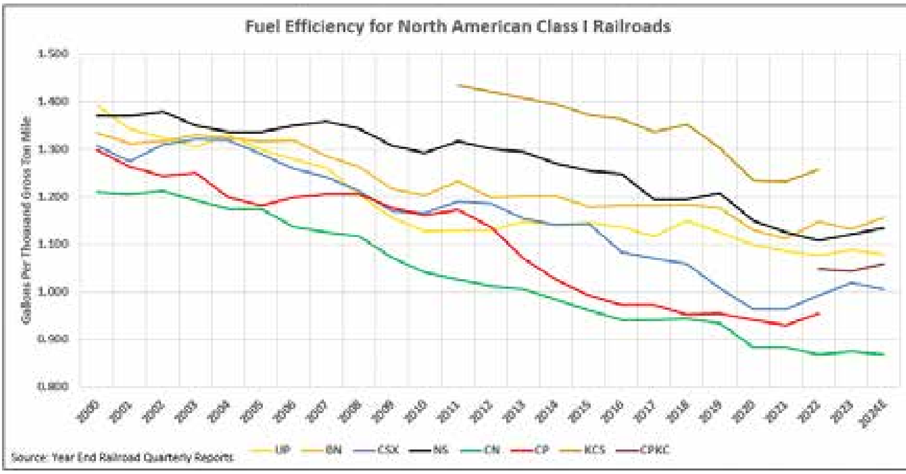


Figure 4 – Fuel Efficiency for Class 1 Railroads

Figure 5 shows the weighted average performance of the Class I railroads, so it is an industry performance metric that indicates a 1.0% annual improvement in fuel efficiency going back to 2011. This gradual improvement has been gained largely through:

1. Purchasing newer, more fuel-efficient locomotives
2. Precision Scheduled Railroading (PSR) which has reduced the Horsepower Per Trailing Ton (HPTT) through building longer trains with fewer locomotives pulling them
3. HPTT rules and enforcement, shutting down or idling locomotives on trains when they are not needed for a crew trip
4. Idling reduction technologies and rules such as Automatic Engine Start Stop (AESS)
5. The implementation of Energy Management Systems (EMS)

If we look at the aggregate SBTi goals out to 2030 and the glide slope required for the industry to achieve that goal, it will require from the current year forward, a 6.8% year over year improvement in fuel efficiency to meet the SBTi targets.

Whereas on the current historical glide slope, that would create a 40% percent gap between where railroads need to be and where they likely will be on their current trajectory or historical glide slope. Per the more challenging 1.5 degrees Celsius SBTi goals to be approved in the future as with UP, this will likely mean the slope of the line shown in Figure 4 will become even steeper.

Note that the use of biofuels such as biodiesel and renewable diesel which have roughly two thirds less life-cycle CO_2 compared to regular diesel fuel will likely shrink this large gap. For example, if the industry adopted an average B20 blend (20% biofuels) by 2030, that would shrink the 40% gap to roughly 27%. In addition, if traffic volumes continue to shrink at the historical rate of approximately 0.9% per year – given the two largest railroads have absolute goals – that would further shrink the gap closer to 20%. As the trucking industry has much higher CO2 emissions per ton mile than rail the overall impact of this traffic reduction on the climate would be negative, however.

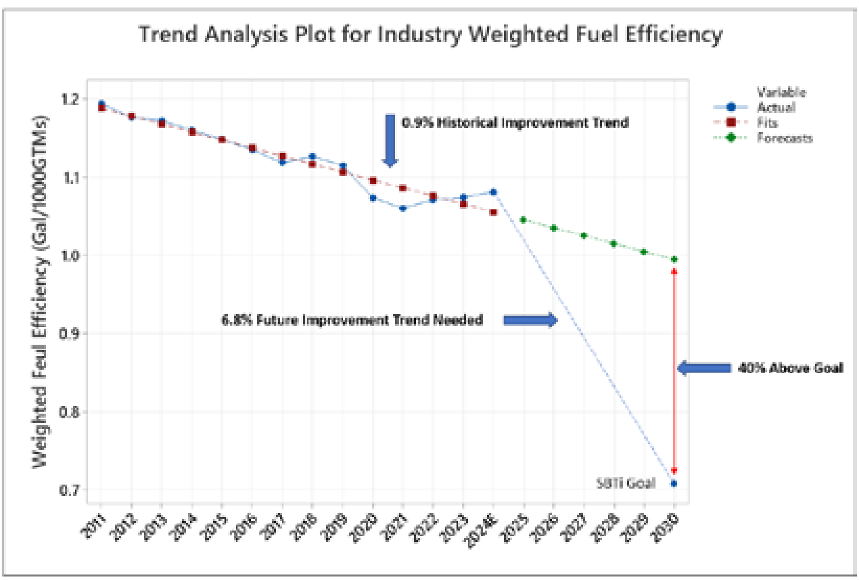


Figure 5 – Historical Rail Industry Glide Slope versus SBTi 2030 Goal

Overview of Available Technologies in Various Stages of Adoption

There are a myriad of technologies or operational approaches available to further reduce railroad fuel consumption. Figure 6 outlines two dozen different technology applications in four general categories:

1. Engine Efficiency
2. Locomotive Power Utilization
3. Train Drag Factors
4. Other

Many of these technologies are in low levels of adoption. There are a variety of reasons for this, but the main culprit is the inherent difficulty in validating small (but important) levels of fuel savings in the 1% to 3% range. There is a large amount of variability in fuel consumption in revenue freight service and the accuracy and reliability of on-board fuel gauges is often problematic. Looking for a 1% to 3% fuel savings when your fuel data is lucky to be within 5% accuracy creates a very large noise to signal ratio. Advanced statistical modeling tools as well as the proper segmentation (grouping based on chosen parameters) of fuel consumption data is required to reliably validate "low level" fuel savings for various technologies or operational approaches.

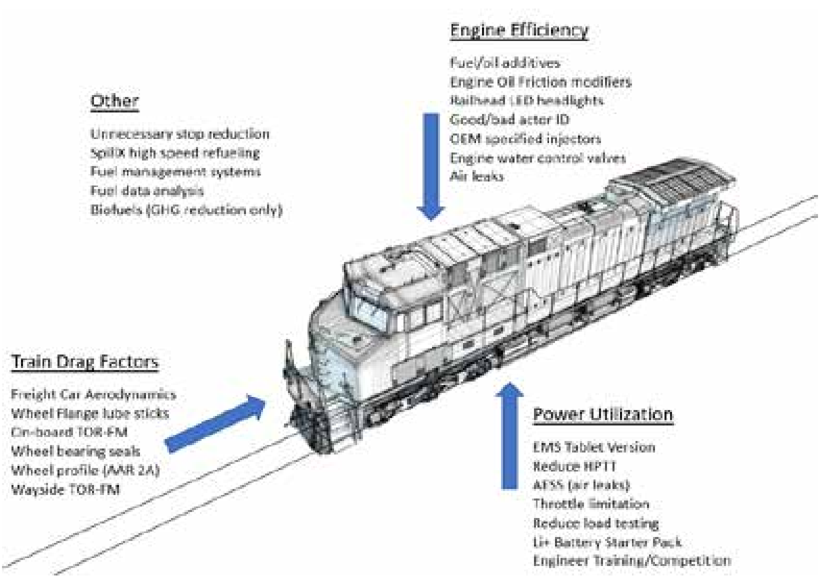
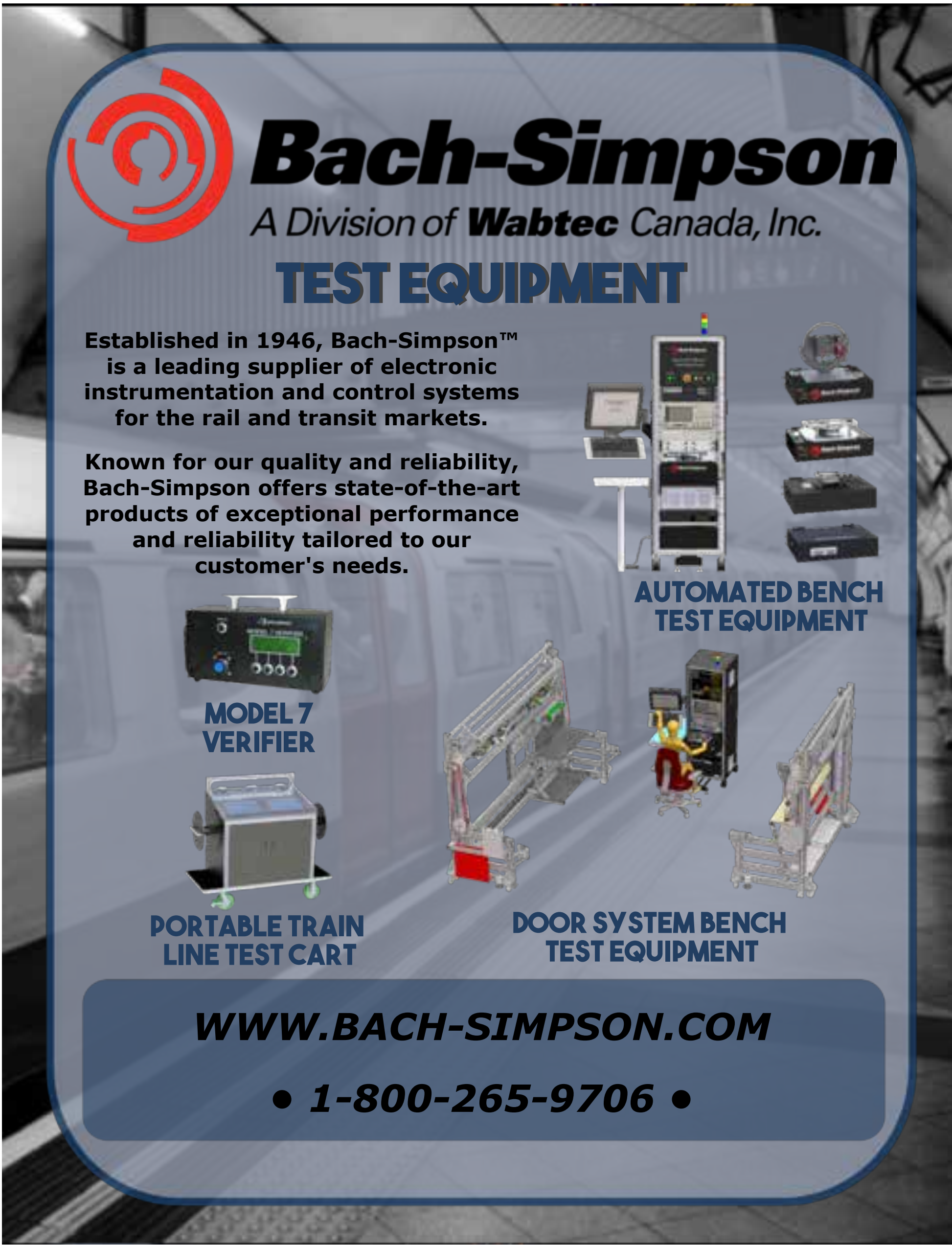


Figure 6 – Various Fuel Savings Technologies and Operational Approaches

VARIABILITY DISCUSSION

Common measures of variability in statistics include range, median absolute deviation (MAD), variance, and standard deviation (sd). You generally want variability to be as small as possible. In a manufacturing world, variability has to be very low or piece parts won't fit together and function as designed or intended.


Bach-Simpson
A Division of Wabtec Canada, Inc.
TEST EQUIPMENT
Established in 1946, Bach-Simpson™ is a leading supplier of electronic instrumentation and control systems for the rail and transit markets.
Known for our quality and reliability, Bach-Simpson offers state-of-the-art products of exceptional performance and reliability tailored to our customer's needs.
AUTOMATED BENCH TEST EQUIPMENT
MODEL 7 VERIFIER
PORTABLE TRAIN LINE TEST CART
DOOR SYSTEM BENCH TEST EQUIPMENT
WWW.BACH-SIMPSON.COM
• 1-800-265-9706 •

In the real world of railroading, fuel burn variability is (unfortunately) quite high. There are a lot of reasons for this, and not many are within our ability to control. Below is a partial list of drivers of variability of fuel consumed for a given train:

Variability Drivers

1. Train length
2. Weight or tonnage
3. Train type (coal, intermodal, mixed freight, auto, etc…)
4. Loaded or empty status
5. Horsepower per trailing ton or the number of locomotives pulling the train compared to the total tonnage
6. Topography or the amount and steepness of grade
7. The degree of track curvature
8. Weather conditions such as rain or ice which affect adhesion or traction
9. Wind speed and direction
10. Air pressure due to elevation
11. Ambient temperature
12. Training and skill of the locomotive engineer
13. Age and health of the locomotives pulling the train
14. Age and health of the freight cars on the train
15. Age and health of wheels, trucks and bearings
16. Age and health of air brake system, leakages.
17. Congestion along the route or how often the train stops, either intentionally or otherwise
18. Condition of the track system and underlying ballast
19. The presence of lubrication technologies either wayside or on-board the locomotive or cars
20. Average train speed and associated aerodynamic losses
21. Impact of train makeup and railcar designs on aerodynamics
22. On-board locomotive fuel saving technology such as Energy Management System (EMS)

Additionally measured fuel consumption may not match actual due to

23. Inaccurate fuel gauge
24. Slosh in fuel tank
25. Rail grade impacting fuel tank measurements
26. Incorrect fueling event records
27. Event recorder throttle notch measurements not matching actual fuel burn
28. Wattmeter not measuring fuel burn outside of traction power i.e., not counting accessory loads such as radiator fans, air compressor, etc.

The above list is by no means a comprehensive or complete list of what drives excessive variability in railroad fuel consumption – but we've hit most of the major high points. Due to the large number of variability drivers, it is not uncommon for what is considered the "same" train to burn significantly less or significantly more fuel than the average for that train type and location. Train fuel consumption segment burns 40% higher or lower than the average amount are certainly possible under typical operating conditions.

CREW SEGMENT FUEL MEASUREMENT METHODOLOGY

Accurate fuel consumption data for each locomotive on a train is the crucial input needed to calculate fuel burn at a train level. Segmenting the data by crew segments (crew on to crew off) is a convenient and useful methodology, given crew segment data can be used for many other purposes such as grading locomotive engineer performance and training initiatives or operational changes that may be geographically constrained.

Back to our discussion on sources of variability, there are some sources that can and should be accounted for and which determine how data is gathered, compiled, and segmented to be used for future fuel analysis of any kind. There are a few discrete measures that need to be addressed, such as:

1. Number of locomotives pulling the train - this assumes there may be some locomotives shutdown (DIC or Dead-in-Consist) or idling
2. Type of train (coal, intermodal, mixed freight, auto, etc…)
3. Train length
4. Tonnage
5. Geographic location, or crew point A to crew point B which must include direction as well

Fuel consumption can be obtained from changes in the fuel gauge after accounting for fueling events, the event recorder of throttle notch information, and the on-board Wattmeter. A weighted average of these variables will typically provide the most accurate measurement of fuel consumption when combined with careful error handling to account for locomotives where information is missing or inaccurate. Throttle information is typically the most accurate so it should be weighted the most heavily, however a weighted average of all three will typically be more accurate than throttle information by itself.

The proper dependent variable to use in analysis of fuel consumption technologies is usually what different railroads refer to as either the fuel efficiency (FE) or c-rate and is calculated as 1000*Gallons/(Tons*Miles). This was also described above for Figure 4. Most technologies can be assumed to save more fuel linearly as tonnage and miles increase, so looking at impacts on raw fuel burned will give biased results. The natural logarithm of FE may also be the better variable to use in some cases compared to raw FE as its distribution can be right skewed and it is sometimes more useful to describe treatment impacts as a percentage. Figure 7 below shows the distribution of FE for a given Automotive train crew route on a Class I railroad, there are quite a few outliers in the data. Trains with higher tonnage generally had better fuel efficiency but the data shows a great deal of noise.

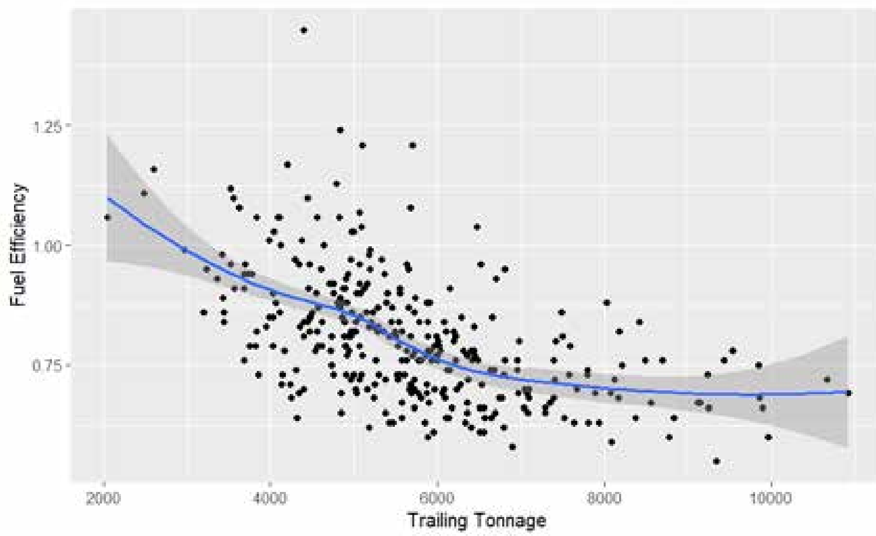


Figure 7 – Representative Regression Graph of Tonnage and FE (gallons per thousand gross ton miles)

Once data has been collected and FE has been calculated, a full regression should be run using a variety of data points as explanatory variables to increase statistical power (probability of obtaining a true positive result) and account for potential sources of bias. It is critical to remember that the results of most field tests should be treated observational studies as fuel saving treatments are often not randomly applied to trains. For instance, many railroads have made a rule that if an EMS equipped locomotive is on a train it should be used as the lead locomotive to run the train. As longer trains will therefore be more likely to have an EMS equipped locomotive with more total locomotives, and as longer trains generally have better/lower FE due to lower HPTT and lower aerodynamic drag per ton (only one front of the train) this will create a source of bias in any study of EMS technologies that does not include tonnage and HPTT as predictors of FE. A list of potential covariates that can be included in a model is shown below. Models should generally include only one rail category as all coefficient estimates will likely be different between Manifest and Intermodal etc. Additional variables which will be useful if obtainable are what % of the locomotives are Tier 4, average locomotive age, average wind speed on the day of the trip, and engineer as a random effect.

Predictor	Type	Explanation
HPTT	Fixed Effect	Locomotives are generally more efficient in higher throttle notches, so fewer locomotives per ton often means better efficiency
Length	Fixed Effect	Longer trains are more efficient, only one front of train
Length/Tons	Fixed Effect	A rough measure of aerodynamic drag per ton, also an impact on wheel/rail friction
Season	Fixed Effect	Can be handled using terms for month or sine(Time) and cos(Time)
Time trend	Fixed Effect	Change over time
Route	Random Effect	There will typically be many routes in a data set so information can be shared between them using a random effect model structure.
Train	Random Effect	A typical train goes through several crew trips over a route. Usually identified using train symbol, train day and train section.

Table 2-Explanatory variables for FE

Table 3 illustrates how different modeling methods can impact the power of a study (probability of obtaining a true positive result) along with the false positive rate (probability of declaring a statistically significant result at the 0.05 level when there is no true effect). These results were obtained from real railroad fuel consumption data from a Class 1 railroad, with a simulated treatment being applied to half of the crew trips and then repeated using bootstrapping (randomly sampling from the full data set with replacement with a treatment randomly applied to half of the sample) to test the accuracy of different modeling methods. Bootstrapping allows one to test the accuracy and unbiasedness of statistical techniques on real data instead of fully simulated data in addition to other uses.

As seen in Table 3, the mixed effects regressions on FE or logged FE greatly outperform the others, with an accurate false positive rate of ~0.05. Mixed effects regressions allow for random effects such as train in the model structure, because a typical treatment is applied to trains and not individual crew trips a model that doesn't include train as a variable or uses it as a fixed effect will break the assumptions of linear regression and give a very high false positive rate of around 0.09 as shown below. This means that when there is no true effect the model has a 9% chance of estimating a "statistically significant" difference with a p-value less than 0.05. Not adjusting for any covariates leads to greatly reduced power as shown in the results from T-tests with a true positive rate or power less than 0.2. The True SE or true standard error in the table measures how much noise a model's estimate of the treatment effect has, the lower the better, while the Model SE measures how well a model is able to calculate its own noise. The Model SE should be very close to the True SE, otherwise there is an isse with the method being applied to the data.

Model	False Positive Rate	True SE of Effect Size	Model SE of Effect Size	True Positive Rate (Power)
Ideal Model	0.05	0	=True SE	1.0
T-Test	0.028	4.35	-	0.19
T-Test log(FE)	0.038	5.47	-	0.151
Regression	0.095	2.33	2.01	0.686
Regression log(FE)	0.082	2.59	2.25	0.606
Mixed effects regression	0.054	2.32	2.23	0.588
Mixed effects regression log(FE)	0.055	2.70	2.57	0.507

Table 3-Performance of Different Statistical Methodologies

As fuel data also typically contains outliers, different outlier handling methods can also be used to fix the issues that they can create. Table 4 shows how two different methods for handling outliers, trimming where the outliers more than 2 standard deviations (sd) from expected values are deleted, and censoring where outliers more than 2 sd from expected values are replaced with the expected value plus or minus 2 sd depending on its location. As seen in Table 4, censoring greatly outperforms trimming which inflates the false positive rate due to a model SE that is biased low because of the removal of a great deal of variation in the data. In general, blindly deleting outliers or outlier trimming should be avoided whenever possible as they are often at least partly due to real factors in the underlying data, and methods such as censoring or the use of extreme value distributions should be strongly preferred. Outliers can also be a source of knowledge for operational improvement if the causes for very low or high values can be determined, knowledge that will be discarded if outliers are deleted prior to modeling.

Model	False Positive Rate	True SE	Model SE	True Positive Rate
Ideal Model	0.05	0	=True SE	1.0
Original Model	0.042	2.61	2.65	0.49
Censored Model	0.054	2.51	2.48	0.536
Trimmed Model	0.071	2.52	2.22	0.615

Table 4-Performance of Different Outlier Handling Methodologies

Too often, a technology is tested using an unstructured and haphazard approach, perhaps for a week or a month with no plan as to how the fuel savings will be validated. At the end of the test, if no fuel savings are found, it doesn't mean that fuel savings don't exist, it may mean that they are just being masked by a poorly structured test plan and a lack of statistical rigor in approaching the validation of a certain technology or operational change.

Dedicated Rail Test Facilities

Pueblo Colorado is home to two dedicated facilities for railroad testing. The Transportation Technology Center or TTC[2] (Formerly TTCI) operated by Ensco for the Federal Railroad Administration (FRA) and the Department of Transportation (DOT) and the relatively new MxV Rail[3] facility supported by the Association of American Railroads (AAR).

These facilities offer a unique opportunity to test fuel saving technologies without the inherent noise of revenue freight fuel consumption variability, where train operations are constrained by the necessities of running a railroad. Different track loops of varying track length and curvature with known elevations and grades are available with dedicated test trains measuring precise fuel consumption and drawbar coupler forces which equate to the amount of friction present while pulling the test train.

Testing energy savings technology and aerodynamic treatments on locomotives and rail cars provide a controlled window which can assess the general capability of a given fuel or energy conservation technology. This can be used as a floor once testing progresses to revenue freight service even with the inherent variability of regular train operations.

Case Study: Locomotive Wheel Flage Stick Lubrication

Presented below is a case study or example of a systematic, credible, and carefully designed and executed validation test program of a fuel conservation technology; (locomotive wheel flange stick lubrication).

There have been many attempts to develop formulations to provide lubrication to rolling/sliding elements such as wheel and rail contact in railroads. These formulations range from liquid and grease systems, which generally require more expensive application equipment, frequent monitoring and suffer from plugging applicators which limit effectiveness and reliability, to solid stick formulation which can be applied directly to the wheels or the rails.

These solid stick formulations are generally comprised of some type of binder material and a range of various lubricants. The binder material holds the lubricating materials in place and typically dictates the rates at which these lubricants are applied to the wheel or rail. An extremely hard or wear resistant binder material limits the amount of lubricant applied to the steel surface and a soft material will allow much more lubricant to be transferred to the steel surface.

The goal of applying lubrication is to reduce friction and thereby reduce energy consumption. In order to determine the optimal solid lubricant binder strength needed, testing on actual trains was required to determine the amount of lubrication required to have a measurable fuel consumption reduction benefit. Early testing provided a range of binder strength required to provide the optimal friction reduction benefits between the wheel and rail interface.

In an effort to provide a truly environmentally friendly lubricant, researchers at the Kansas State University Technology Development Institute began investigating a wide range of biopolymers that could be used as a binder material and the possibility of incorporating a vegetable based oil to add friction reduction and improve transfer of the lubricant from the wheel of the locomotives where it was being applied down to the rail, and ultimately onto subsequent wheels of the train providing friction reduction for all wheels of the train adding to fuel savings. Using Polyethylene as baseline for strength and hardness, all commercial biopolymers were investigated to identify a biodegradable and renewable binder material that could be incorporated into the wheel/rail lubrication process.

A range of vegetable oils were also investigated to determine which oil provided the best lubrication benefits. The Tribology Handbook was consulted to determine which vegetable-based oil provided the greatest wear reduction using the standardized 4 ball wear test. Castor oil provides the highest lubrication benefit of all vegetable oils tested.

Once a range of biopolymers had been identified and castor oil selected as the oil of choice, over 200 samples of various blends were created and tested for strength and lubrication efficiency at the K-State labs. This testing narrowed down the formulation and lead to the discovery of a blend of multiple biopolymers that provided the best application rate of material.

Once the formulation had been optimized, production scale-up enabled sticks to be produced that could be installed in locomotive applicators and tested at the TTCI facility on locomotives to determine the coefficient of friction (CoF) reduction on the gauge face of the rail and the energy savings provided by the lubricant.

Analysis of Tests Undertaken at Test Facilities

As mentioned previously, too often, a technology is tested using an unstructured and haphazard approach, perhaps for a week or a month with no plan as to how the fuel savings will be validated. Performing a test in dedicated rail test facility brings structure, yet the data still requires statistical rigor to confidently establish or quantify the fuel savings of a technology.

The following discussion describes such an analysis performed on two separate tests of a fuel saving technology. The tests were run at TTC^2 (Formerly TTCI), in 2012 and 2014. Each test consisted of baseline, or "dry" laps, as well as "lube" laps where an environmentally friendly solid polymer friction modifier formulation was applied.

The objective of the study was to quantify the difference between the lubricated versus dry conditions. Statistical analysis brought rigor into the tests to (1) provide a formal statistical test as to whether there were any effect of the claimed energy or fuel savings benefits and (2) if there were a benefit, provide a statistically determined estimate of its likely range (versus a point estimate).

Tests were conducted at TTCI in 2012 on the Wheel Rail Mechanism (WRM) loop and in 2014 on the Transit Test Track (TTT). These tracks have different profiles with respect to curves, and to some extent, elevation changes. Figure 8 depicts the tracks and aspects of the tests.

Methods for analysing data from track tests with proper treatment designs can often be much simpler than those needed for revenue testing, t-tests with no covariates or outlier handling can be appropriate when a test is fully balanced with all other variables such as engineer behavior, weather, and train build held constant.

The results of this testing indicated that within a short time period of application, energy savings provided by the lubricant ranged between 2% and 4.5% for both mechanical and electrical energy and the material was able to immediately reduce the outside rail gage face CoF from 0.44 down to 0.26 based on tribometer measurements in a single pass from 2 locomotives and 30 loaded hopper cars.

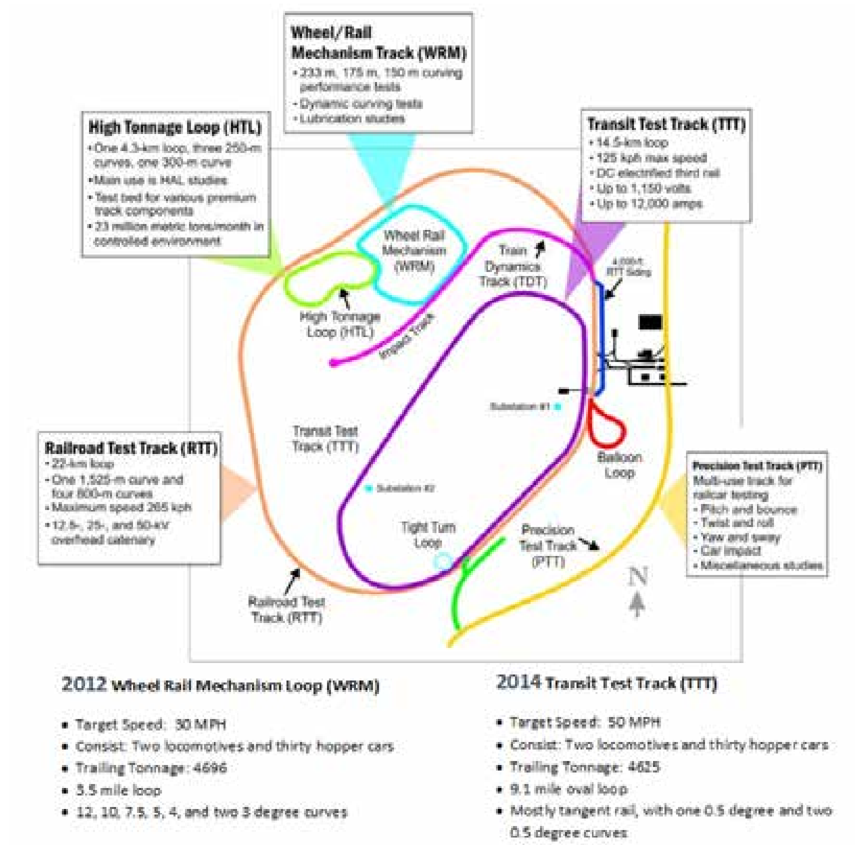


Figure 8 – TTCI Test Track Configurations[2]

The locomotives were equipped with wattmeters for traction power as well as a secondary drawbar mechanical coupler. From these two sources we were able to compute both electrical and mechanical work, in kilowatt hours (KWHR). Our target metric for estimating energy savings is electrical energy in KWHR. A check was performed to ensure that electrical and mechanical work were closely correlated, to build confidence in the measurement systems. The correlation coefficients were 0.9999 for the 2012 WRM test, and 0.9996 for the 2014 TTT test.

A GPS system provided the location (latitude and longitude) of the locomotive on the track. This allows us to augment the core energy data with:

- **Train speed**. Speed does vary slightly from the target speed, especially on the WRM which has more curves and grade changes.

- **Heading**. This allows us to examine potential correlations of curvature with power consumption.
- **Elevation**. Latitude and Longitude information was used to obtain elevation information from government sources, allowing us to examine potential correlations of grade with power consumption.
- **Mileage Traveled**. Though this may not be a modeled measure, it does help us in the computation of measures such as speed and grade change.

Measurements were recorded at one-second level (one-hertz data). Information about the lap number and the lubricating condition (lube or dry) was provided. Some filtering was applied to exclude records (laps or portions of laps) that were designated as conditioning laps. Conditioning laps have the purpose of drying up and dispersing any residual grease from prior tests such that there is a dry coefficient of friction as the new test begins. The goal in filtering the data was to have a clear, contrasting picture of the lubricating versus the dry condition.

When a single treatment condition B is compared to a control condition A using time series data as at TTCI, it is generally best to format the order of tests where possible as A-B-B-A, referred to as an ABBA treatment design, where an A refers to a loop run or set of loop runs with no lubricant present and B refers to an equal set of loops with the lubricant applied. When an AABB treatment design is used instead, the impact of the treatment will become correlated with any time trends that are present almost every day due to weather or other factors, and this could heavily bias the results.

The data was combined across the two tests. A variety of statistical tools were applied to appropriately analyze the data generated by the runs and ensure that the results could be projected to real world contexts. For more information, see the full report[4].

Figure 9 shows the overall fuel savings due to the wheel flange lubrication sticks is estimated to be 3.2%. This represents a statistically adjusted estimate of the percent savings difference between the lubrication and Base runs of the combined TTCI tests. The results are statistically adjusted in the sense described in the methodology section. Analysis of Covariance (ANCOVA)[5] methods quantify potential other causal factors, such as speed, curvature, and elevation changes, to balance the comparison and isolate the effect due solely to the lubricant. The raw mean difference between the groups was 3.3%. The fact that this was a very modest adjustment indicates that the tests were well-executed to minimize any differences that might mistakenly be attributed to the lubricant.

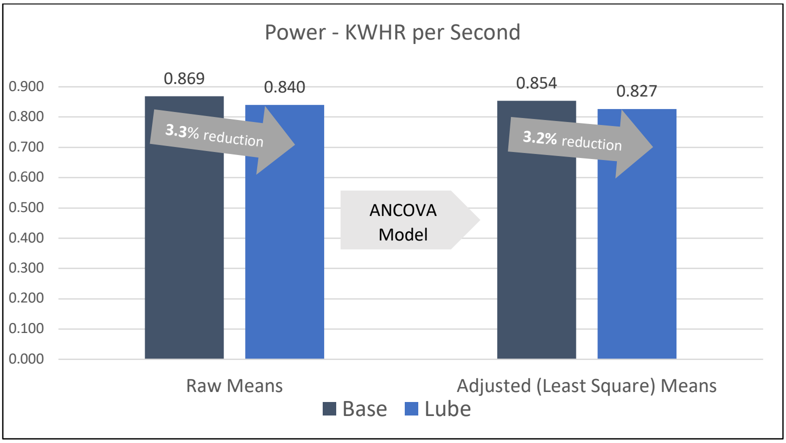
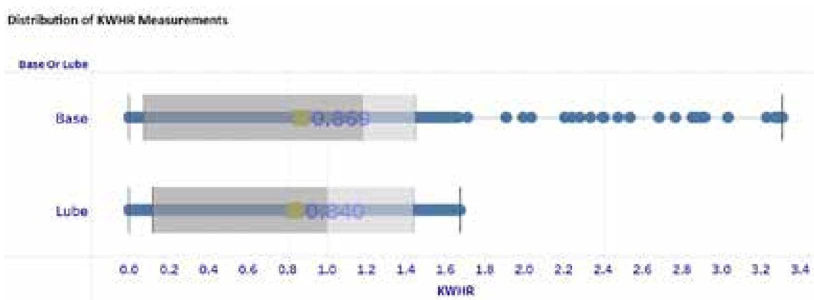


Figure 9 – Comparison of Means, Base versus Lubricated

Because of the very small adjustments to the means, we can, in fact, look at the dispersion of the raw, unadjusted data, to get some insight into the differences. Figure 10 is a box plot showing the spread of the measurements for the Base versus Lube conditions. In the case of this visualization, the green box represents the mean, with the mean KWHR for Base being slightly higher than that for Lube.

We also see that for the Base condition there are several measurements of high energy expenditure (the points above 2.0). Although one may label these as outliers and conjecture that these alone are driving the difference in means, in reality, these are a small number of observations among 8681 total observations for the Base runs. Furthermore, the ANCOVA approach allows us to study this variation as a whole in a way that accounts for these kinds of events.

Base skews slightly higher than Lube with higher measurements



Condition	Number of Observations	Mean	Standard Deviation
Base	8,681	0.869	0.659
Lube	11955	0.840	0.636

Standard Deviation is a measure of spread. Base has a greater range of energy measurements values.

Figure 10 – Distribution of KWHR Measurements

An output of the ANCOVA model is a statistical estimate of the hypothesis that the effect of the lubricant is different from zero[6]. In statistics parlance, this is the so-called "null hypothesis" – that of no difference between two measured phenomena[7].

Our formal statistical test indicates that we can reject the null hypothesis of no effect and can do so at the greater than 99% confidence level (t-value of 3.56). That is to say, there is a very small chance that there is no effect of the lubricant.

A second, but less generalized test of differences is the so-called two-sample t-Test[8]. It is less powerful and accurate than ANCOVA with covariates in that it is a univariate approach comparing the simple means and variances, without accounting for other factors, such as those described previously, that could influence those means and variances. It is only presented here to give the reader an understanding of the raw data. Again, the null hypothesis of no difference between the means was rejected at the greater than 99% confidence level (t-value of 3.14 using the Satterthwaite test of unequal variances).

In addition to these tests, we can use the same model to provide an estimate of the range of possible effects, versus a single point estimate such as the mean. This "histogram"[9] provides an extra dimension to our understanding of the effect.

Figure 11 shows how the ANCOVA model simulates the spread of the possible effect, where the height of the bars indicate the relative probability of the effect being in the range shown in the horizontal axis. In other words, if we were to conduct the tests many thousands of times, the effects would fall into these "buckets."

The 90% confidence interval for fuel savings is between 1.8% and 4.3%, the 90% confidence interval will capture the true parameter value 90% of the time when a statistical test is run.

It is worth noting that the histogram does not cross zero. That is to say, it is very improbable that the lubricant has no effect absent some unknown bias in the testing.

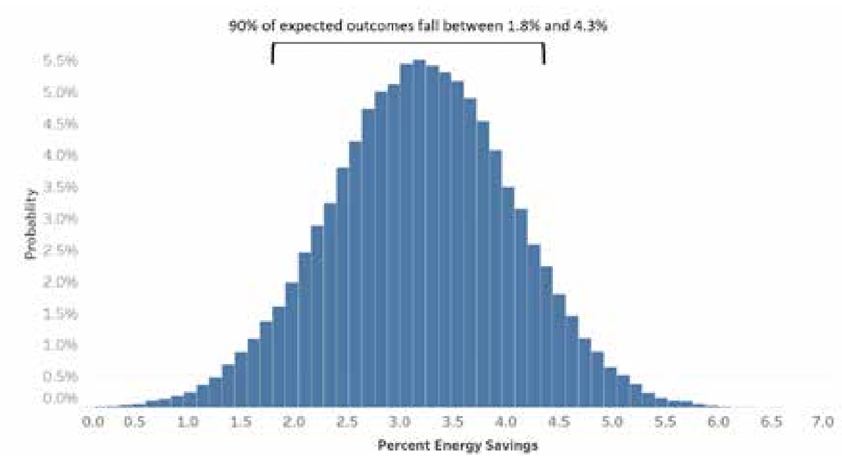


Figure 11 – Range of Estimated Savings

Other analysis, not included in this paper, were also performed. You can download the full report for details.[10]

To provide confidence in the test results the analysis approached the test data from a number of angles. A battery of statistical tools, including models and formal statistical tests, were applied. The following table provides a summary of those analyses.

Analysis Metric	Test or Methodology	Result
Energy Savings	ANCOVA - Estimation	Savings estimated to be 3.2%
Energy Savings	ANCOVA– Hypothesis Test (t-test)	“No effect” hypothesis rejected at 99% confidence level
Energy Savings	Simple two-sample t-test	“No effect” hypothesis rejected at 99% confidence level
Energy Savings	Confidence Intervals	90% of expected outcomes are within 1.8% and 4.3%
Throttle Position	Simple statistics and visualization	7.1% less time spent in T8 (not statistically adjusted) More time spent in T4 and T5
Throttle Position	M-H Chi-Square test	Time spent in each throttle position, taken as a whole, is statistically different at the 90.1% confidence level
Throttle Position	Simple two-sample t-test	Average throttle position is statistically different at the 90.0% confidence level
Throttle Position	Logistic Regression - Estimation	Odds of being in T8 reduced by 4.8%
Throttle Position	Logistic Regression – Hypothesis Test (Wald Chi-Square)	“No effect” hypothesis on T8 reduction rejected at 87.1% confidence level.
Throttle Position	Visualizations	Visible gap between Lube and Base along the track mileage

Table 5 – Summary of Various Methodologies Applied

Leveraging the data from the two TTCI tests (2012 and 2014), a third study produced a model to project the results from the tests to real-world field contexts[11]. This allows a railroad to input the attributes of their network and operations, such as grade profile, tangent versus curve percentage, typical locomotive counts, train length, and the application protocol for the lubricant. Figure 12 shows the output of the end-user tool for a typical Western US railroad.

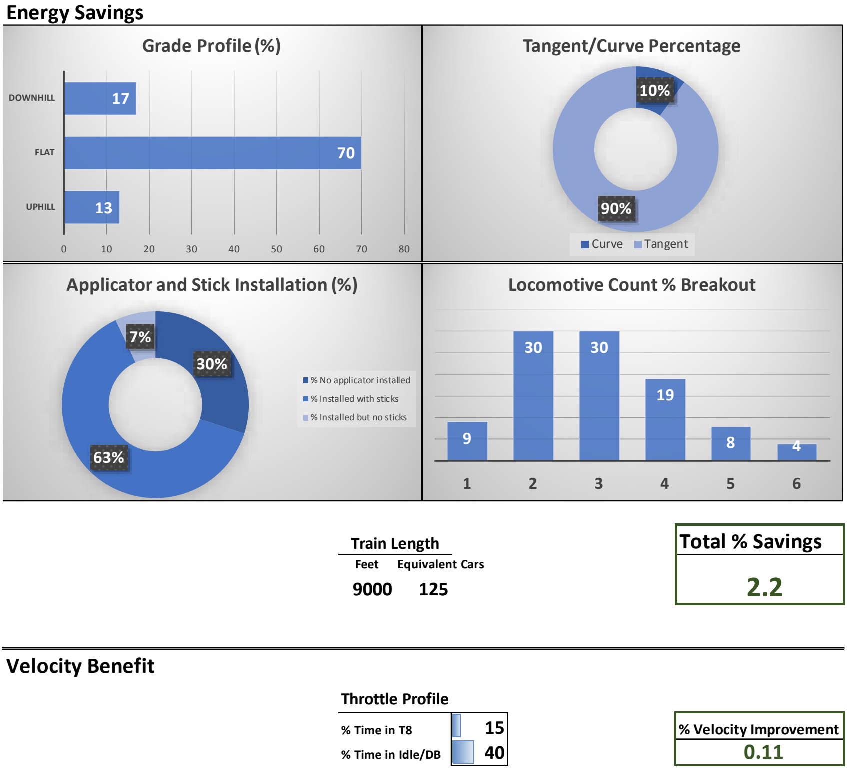


Figure 12 – Projection of Energy Savings Based on Various Operating and Track Parameters

Revenue Field Testing at a Class I Railroad

Revenue testing was performed using these products on a class I railroad from 2014 through 2015 with data including over 500,000 individual crew trips. Both log(FE) and trip velocity in MPH were modeled using the mixed effects regression method described above. Separate models were developed for Intermodal, Manifest and Coal train categories and combined using Meta-analysis. Meta-analysis is commonly used to combine several medical studies to calculate a single overall average treatment effect. This analysis found an average savings from flange sticks of 1.4% with a 95% confidence interval between 0.7% and 2.2% when one locomotive had stick brackets equipped at the front of the train during the study period. When multiple locomotives had brackets equipped the savings increased to 1.8% with a 95% confidence interval of between 0.6% and 2.9%. Brackets also increased speeds by 0.09 MPH but this impact was not statistically significant. A differences-in-differences study design utilizing both bracket presence and study start date as commonly seen in Econometrics was used to identify causal impacts from flange stick usage.

Conclusions

Accurately measuring the fuel savings of many different locomotive technologies and rail operational changes (lowering HPTT as an example), as well as various locomotive engineer training initiatives is challenging. Given the vast variability of day-to-day operations for any given Class I railroad and somewhat unreliable on-board locomotive fuel gauges, the problem becomes compounded quickly.

A rigorous statistical approach to this problem can yield results, usually with a good degree of precision and a high level of confidence.

When investigating new technologies in particular, available test facilities such as TTC and MxV Rail are excellent resources to perform energy testing. If Class I's decide to pool resources and agree on a structured test regimen, the cost considerations can be very reasonable while providing controlled results that all railroads can use as a baseline.

For railroads that may lack the expertise to design, build and perform the statistical tests outlined in this paper, there are statistical companies and consultants who have a specialty and rich history of performing this type of work for railroads. Use them in conjunction with testing performed at TTCI or MxV Rail and revenue field testing also.

Revenue field testing is the logical next step as there likely will be variations on actual savings from one railroad to the next, driven by differences in HPTT, commodity mix, track topography and other factors. When designing a statistical test, keep in mind the following factors:

1. Allow enough time to test the technology completely, this is usually measured in months
2. Test through a broad range of scenarios across the network and across seasons as well
3. Compare baseline to test measurements concurrently so as to avoid seasonal issues
4. Design a balanced model which can be analyzed several different ways with various statistical comparison tools

Avoid the mentality trap of "we couldn't prove anything within a matter of weeks, so the technology must not be saving any fuel". Generally, most technologies do provide some level of fuel savings; the goal is to accurately determine the appropriate range of savings in order to calculate a reasonable return on investment or ROI.

Another concern is succumbing to a "groupthink" where a certain technology falls out of favor for no good reason at one railroad and others follow suit, not driven by any firm data analysis.

The number of fuel-saving technologies is varied and plentiful – many of them are in low levels of adoption due to an inability to effectively measure fuel savings. The tools and techniques outlined in this paper can help railroads as they work to reduce their GHG emissions to meet their short term SBTi goals.

REFERENCES

1. https://sciencebasedtargets.org/news/sbti-raises-the-bar-to-1-5-c
2. https://ttc-ensco.com/
3. https://www.mxvrail.com/
4. https://firstanalytics.com/wp-content/uploads/NatureBlend-TTCI-tests-analysis.pdf
5. https://en.wikipedia.org/wiki/Analysis_of_variance
6. https://en.wikipedia.org/wiki/Statistical_hypothesis_testing
7. https://en.wikipedia.org/wiki/Null_hypothesis
8. https://en.wikipedia.org/wiki/Student%27s_t-test
9. https://en.wikipedia.org/wiki/Histogram
10. https://firstanalytics.com/wp-content/uploads/NatureBlend-TTCI-tests-analysis.pdf
11. https://firstanalytics.com/wp-content/uploads/NatureBlend-TTCI-projection-model.pdf

Zero GHG-Emissions on Rail … Dream or Reality

By:
Graciela Trillanes
Pedro Santos
John C. Hedrick

Introduction:

The objective of this paper is to expand on the 2023 LMOA Joint paper titled "Future Fuels Review". This paper will examine some information that is new to the rail industry on the topic of zero Green House Gas (GHG) emissions and some of the challenges of implementing emissions efficient technologies needed to achieve the industry's GHG reduction goals.

Background:

Currently, the locomotive market in North America stands largely under the sway of diesel-fueled locomotives as shown in Figure 1., with over 37,000 units registered in the Unified Locomotive Emissions Registry (ULER) [1], commanding a staggering 94.03% of the market share. By comparison, electric locomotives (mainly passenger) hold a notable presence at 5.4%, steam locomotives trail behind at 0.4%. The remainder of the market is fractionally divided among dual-fuel (0.11%), battery-powered (0.05%), and fuel cell (0.01%) locomotives.

The railroad industry interchanges an estimated 500 locomotives daily as implied by the combination of railroads represented in Figure 2. [2.] The industries rely on the interchange of locomotives to improve operational efficiency and reduce the need for frequent locomotive changes. However, this need for seamless interchangeability poses a complex and unique challenge in establishing a standardized system that meets the diverse operational needs and infrastructures of all different railroads in America. Recognizing this, the Association of American Railroads (AAR) has established comprehensive standards and regulations to streamline equipment interchangeability. Any advancements in the future fuels and their associated "systems" must be designed for compatibility and interchangeability to ensure widespread adoption of the technology across the industry.

Additionally, as discussed in the Joint 2023 paper titled "Future Fuels Review" and in the 2022 paper titled "GHG Emissions Reduction for North American Railroads", the railroads have signed on to the Science Based Targets Initiative (SBTi) that will require the GHG reductions of the railroads of between

26% (absolute) and 43% (intensity) reduction in GHG-emissions[3]. These commitments by the Class I railroads will require the use of fuels and technologies that will significantly reduce or eliminate the GHG-emissions. While progress is being made, the shift towards zero emissions requires a fundamental overhaul of current practices and technologies needed to meet these targets. This demands robust commitment, sustained innovation, and collaboration from all industry stakeholders. Although progress in GHG-emission reduction is tangible, the industry must remain resolute in its pursuit of sustainable and environmentally conscious solutions to effectively achieve these GHG targets [4].

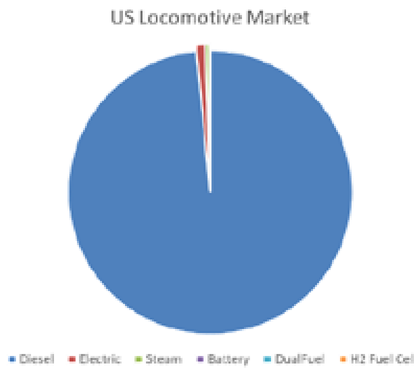


Fig. 1: Locomotive market

Fig. 2: Locomotives Interchanged

On top of the SBTi mandates, there are two additional mandates for emission reduction from both federal and state entities. The Federal Railroad Administration (FRA), aligned with the global imperative to combat climate change, issued its rail industry Climate Challenge on Earth Day 2022, [4]. This initiative urges owners, operators, and manufacturers across the national rail network to support the commitment to achieve net-zero GHG-emissions in rail transportation by 2050. Meanwhile, California Air Resources Board (CARB), in collaboration with the Department of Energy (DOE) and Environmental Protection Agency (EPA), is accelerating the adoption of zero-emission technologies across all modes of transportation within the state. California's Zero-Emissions Freight Corridor Strategy, developed with federal agencies, aims to establish charging and Hydrogen refueling infrastructure along high-volume freight highways and hubs by 2040. To complement this strategy, CARB has set stringent decarbonization targets for rail transportation. By 2030, CARB is mandating that 50% of all locomotives within the state must comply with Tier 4 emissions standards, and all new locomotives must be zero-emission (ZE), and by 2035 100% of locomotives must meet Tier 4 standards, with 50% being zero-emission. Finally, by 2047, all locomotives must be zero-emission compliant [5].

These targeted deadlines by government entities, SBTi targets, and locomotive interchangeability requirements are just some of the many hurdles or challenges in the transition to becoming a zero GHG-emissions rail system. One of these key challenges is the process of retrofitting or replacing the locomotives to accommodate the fuel of choice, especially when the expected locomotive service life is approximately 10 years between locomotive overhauls and potentially over 50 years before replacement of the locomotive. Therefore, choosing the best path to meeting the GHG reductions from locomotives is imperative, requiring analysis of both the benefits and associated challenges of each fuel before moving forward [6].

Discussion:

During the process of exploring various paths to reduce GHG-emissions in transportation shown in Figure 3, some of the options listed are deemed to be more expensive, have a higher high risk, and potentially smaller GHG reductions. Therefore, they will require government, tax and grant support to make them competitive to the existing Diesel-powered locomotive fleet and a lot of development. Each of the energy source options shown in Figure 3 has their own pros and cons that primarily revolve around energy conversion system (IC engine, battery, fuel cell, …). Additionally, when looking at the path towards hitting the GHG-emissions targets cost implications, infrastructure requirements, and technological readiness all must be considered. The choice of technology will drive the adoption rate and will depend on factors such as availability of green fuel sources, regulatory environment, and long-term sustainability goals.

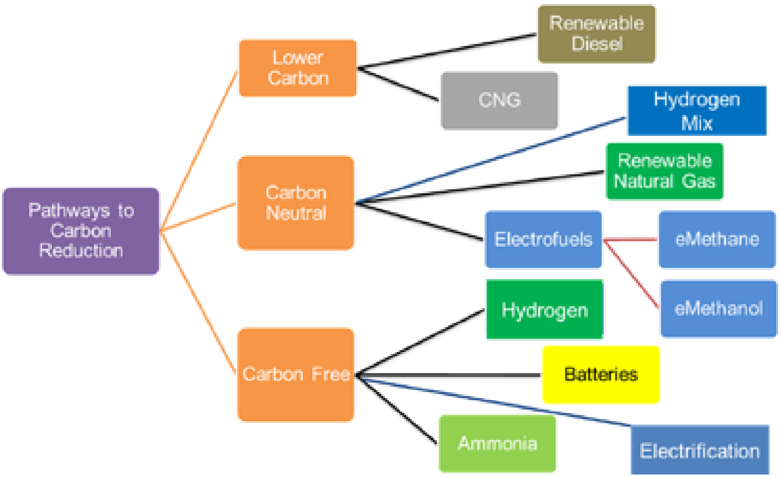


Fig. 3: Pathways to Carbon Reduction

While a majority of the pathways listed in Figure 3 will allow the rail industry to hit their GHG-emission reduction targets, it is felt that some energy sources being considered as a higher risk, limited GHG-emissions reductions, health and safety issues, and or the cost of implementation. These pathways that this paper will not cover are [7&8]:

- CNG / LNG / RNG / eMethane /NG+H2 Mix
  - Any Methane loss (boil off, fuel system venting, in exhaust emissions due to incomplete combustion, leaks occurring during the transportation of the fuel source) will have a high GHG carbon intensity.
- Methanol / Ethanol
  - Both are considered a “toxic alcohol”.
- Ammonia
  - Inhalation health/safety risks in populated areas and if we consider from wells to wheels it is not zero emissions
- Electrification
  - Very expensive to apply due to the long distances in North America

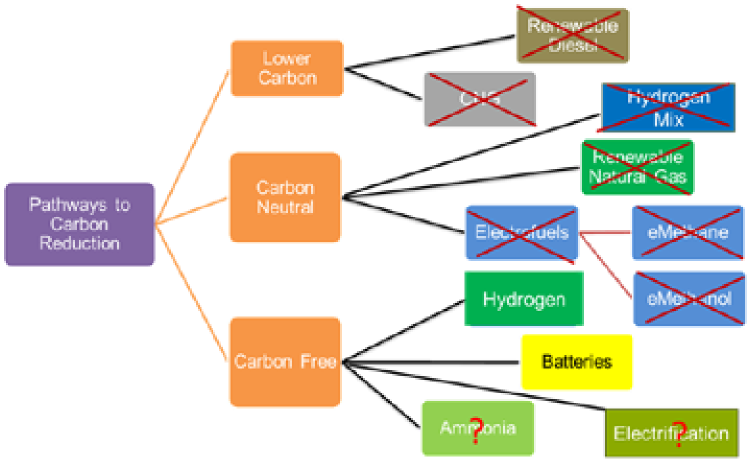


Fig. 4: Pathways to Carbon Reduction, Options for Zero Emissions

As discussed in the 2023 paper titled “Future Fuels Review”, the application of batteries has a lot of potential to reduce GHG-emissions. The application of batteries has increasingly become a vital component in the transportation sector since they offer the advantage of zero local emissions. This trend is particularly evident in the railway industry, where numerous locomotives and switches utilize battery technology both in North America and worldwide. With ongoing advancements, battery capacities are steadily increasing; current locomotives can achieve a maximum capacity of 8-15 MWh. (Wabtec announced capacities up to 8.5 MWh [9] and Progress Rail up to 14.5 MWh[10] capacities)

To put this into perspective, a typical diesel locomotive carries around 4,500 gallons of fuel, equivalent to approximately to 183 MWh without considering energy losses. This means that to match the energy capacity of a traditional diesel locomotive, a locomotive would need a considerable amount of battery-powered locomotives or battery tenders to allow for an equivalent range. However, some of this can be mitigated by using battery technology to recover energy during the dynamic or electric braking process. This allows the use of the “typically” wasted braking energy to help reduce the overall battery size or energy requirements but is highly dependent on the elevation changes along the route and other compounding factors.

If a railroad determines that green Hydrogen is the solution to hitting their GHG-emissions goal, the difference in fuel energy density will be a key driver for the development and deployment of Hydrogen fuel tenders. Figure 5 provides a graphical representation of fuel density comparisons of Hydrogen and several other fuels. This disparity in energy density between Diesel and Hydrogen presents a notable challenge when transitioning to alternative fuels [11].

Transportation Equipment Supply Company
8106 Hawthorne Drive
Erie, PA 16509
(814) 866-1952

www.tescotools.com

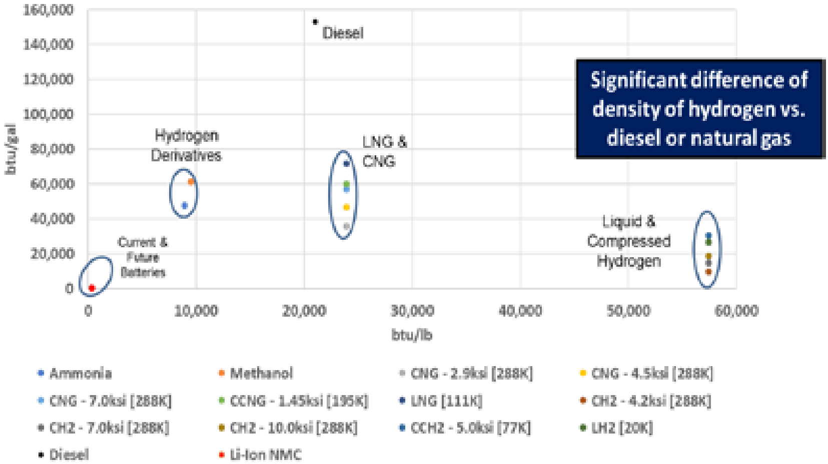


Fig. 5: Fuels Density comparations

The adoption of Hydrogen in the rail sector, known for its stringent safety standards and traditional practices, raises numerous questions regarding its implementation:

- When will the green Hydrogen supply chain sufficiently mature?
- What should locomotives use to convert Hydrogen to electrical power needed to drive the locomotive?
  - Fuel cells (FC)
  - Modification of the existing IC Diesel engines to allow operation on 100 percent Hydrogen.
  - Conversion of IC Diesel engine to a dual fuel combustion.
    - Needs to allow a large portion of the Diesel energy to be substituted with Hydrogen
- What are the challenges of using fuel cells in a rail environment?
- What is the optimal balance between new, transition, and traditional Diesel systems?
- How do economic, regulatory, and environmental factors impact these decisions?
- Are mature tender solutions available, and are there appropriate regulations governing their use?
- How Hydrogen can be transported to the remote filling stations at the railroads?

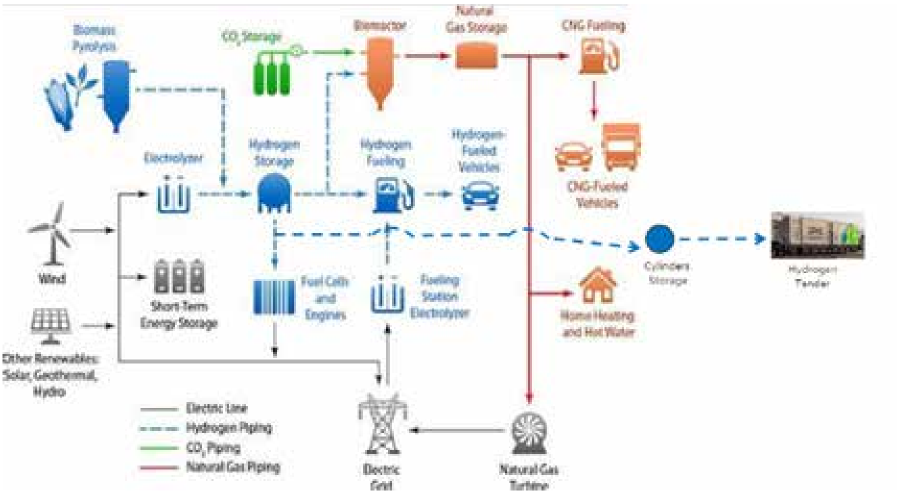


Fig. 6: Hydrogen Ecosystem

The answer to these questions is beginning to emerge through testing and validation processes. It appears that several railroads are embracing Hydrogen as a fuel source. Concurrently, several government entities are actively developing and implementing standards for these transportation systems. The DOE is leading efforts to regulate Hydrogen production, distribution, and utilization, alongside organizations like the National Renewable Energy Laboratory (NRLE). Regulatory bodies overseeing Hydrogen include the DOE, Occupational Safety and Health Administration (OSHA), United States Environmental Protection Agency (EPA), and the Pipeline and Hazardous Materials Safety Administration (PHMSA).

Additionally, industry bodies such as the AAR are spearheading the development of standards for alternative fuel tenders, which includes tenders designed for use with Hydrogen. For example, the forthcoming AAR M1004 standard, that encompasses the use of tenders with Hydrogen, has undergone industry-wide review and is anticipated to be finalized and published in late 2024. The FRA plays a critical role in ensuring the safety and compliance of Hydrogen-powered rail systems through rigorous testing and validation requirements [10].

Currently, the companies that are vying to supply FC's to the locomotive market have increased since the 2023 LMOA Joint paper on "Future Fuels Review". The current list of interested companies are:

- Cummins Inc.
- Ballard Power Systems
- GM and Wabtec (teaming together) [11]
- Hyundai Hydrogen Mobility (H2 Energy)
- Toyota

Fig. 7: Cummins Fuel Cell

Fig. 8: Ballard Fuel Cell

Additionally, both locomotive OEM's have recently announced that they will have FC powered locomotives in production by 2027 (Fig. 9 & 10). This reflects the growing interest and investment in zero GHG-emission transportation solutions in the freight sector. A couple of the Class 1 Railroads, CPKC (Fig 11) and CSX (Fig. 12) have partnered with a fuel cell from Ballard to build and demonstrate Hydrogen FC-powered switcher and line-haul locomotives.

Fig. 9: EMD Fuel cell Locomotive

Fig. 10: Wabtec Fuel Cell Locomotives

Fig, 11: CPKC long haul locomotive and tender

Fig, 12: CSX Hydrogen Switcher

If FC's are not a near-term solution, an intermediate step could be the use of Hydrogen fueled Internal Combustion Engines (H2ICE) as the development of these modified engines continues. For this concept, Hydrogen is combusted in the IC engine, producing mechanical shaft power and the shaft power drives a traditional traction alternator, powering the locomotive. It is important to note that H2ICE, fueled by green Hydrogen, would not be considered zero emissions as NOx will be produced by the combustion of Hydrogen and in some cases the co-combustion of other fuels (Diesel, CNG or combination of both) as well as the engine oil, that is needed to lubricate engine, will generate particulate matter and other Carbon-based emissions.

Both approaches have their advantages and challenges. FC locomotives will likely be more efficient and produce zero GHG-emissions at the point of use, making them suitable for electrified rail lines and urban areas. On the other hand, H2ICE's will be like existing Diesel engine technology, potentially allowing for easier integration and infrastructure reuse. Each approach requires careful consideration of factors such as efficiency, infrastructure costs, refueling logistics, and overall environmental impact [12,13&14].

To carry enough Hydrogen fuel for a locomotive, either FC or H2ICE driven, a tender will be needed. A tender is a separate rail car with either cryogenic compressed hydrogen or several large high-pressure cylinders attached to the rail car; both systems would allow hydrogen to cross the locomotive knuckle at the appropriate pressure and temperature needed by the FC or H2ICE. These tenders will allow the locomotive to operate over longer distances without frequent refueling stops. However, the tenders will need to comply with the FRA and AAR regulations that are associated with AAR M1004 Specifications.

Conclusion:

During the latter part of the 21st century, Diesel fuel locomotives have been the standard in the railroad transportation industry. Unfortunately, Diesel engines, while very efficient, durable, and a known cost of ownership, offer a constant environmental concern due to their high GHG and other regulated emissions. To address this significant environmental impact, various state and federal agencies are collaborating to create mandates and standards to achieve zero emissions in the transportation sector.

There are multiple pathways to achieving zero emissions. Each solution has its unique advantages and challenges, and there is no single clear-cut solution that can be universally applied across North America. After careful consideration, the most promising approaches appear to be the use of batteries and or green Hydrogen.

Battery-electric locomotives offer zero-emission operation and potentially lower operating costs. However, concerns about battery range, charging infrastructure, energy density, battery shelf life, and the costs of battery replacement and management pose significant barriers to adoption.

Green Hydrogen used in fuel cells, which only emit water vapor as a byproduct, represents a truly zero GHG-emission solution. However, challenges remain in green Hydrogen production, storage, and distribution infrastructure, along with high initial investment costs,

The transition to zero GHG-emission locomotives demands a critical and detailed plan of application within the transportation field. This plan should include evaluating fuel options, and weighing environmental benefits against technological feasibility, infrastructure requirements, and economic viability. Collaborative efforts between industry stakeholders, government agencies, and research institutions are crucial for overcoming these challenges and realizing a sustainable future for rail transportation.

Notes:

1 2024 North America locomotive review, Railinc.

2 Railroad blogspot.com JP2012

3 pdf_up_2022_bar.pdf, CSX Leads North American Rail Industry with Most Ambitious GHG , Environment - CSX.com, BNSFEmissions Intensity Reductions Goal, Commitments | Norfolk Southern, CPKC 2023 Climate Statement_FINAL.pdf (cpkcr.com), https://www.cn.ca/en/delivering-responsibly/

4 FRA's Rail Industry Climate Challenge | FRA (dot.gov)

5 Reducing Rail Emissions in California | California Air Resources Board

6 www.eia.gov

7 Lean-Burn Natural Gas Engines: Challenges and Concepts for an Efficient Exhaust Gas Aftertreatment System | Emission Control Science and Technology (springer.com)

8 Cummins Unveils a Combustion Engine That Could Run on Any Fuel, It's the End - autoevolution

9 https://www.wabteccorp.com/FLXdrive-Battery-Electric-Locomotive?inline

10 https://s7d2.scene7.com/is/content/Caterpillar/CM20230808-02625-8000c

11 https://orbitaltoday.com/2022/04/07/making-space-greener-from-hydrazine-rocket-fuel-to-green-propellants/

12 battery technology and HYDROTEC hydrogen fuel cell systems for Wabtec locomotives.

13 Up today Hydrogen production in North America emission based on energy supply https://steps.ucdavis.edu/wp-content/uploads/2016/10/09-17-2015-Table-for-UCDavis_LCFS-Illustrative-CIs_FINAL.pdf

14 https://www.bing.com/search?q=%E2%80%A2+Alstom+Coradia+iLint&cvid=53417b648e0e47be8be1c8224dbe2747&gs_lcrp=EgZjaHJvbWUyBggAEEUYOdIBCDIxMTNqMGo0qAIIsAIB&FORM=ANAB01&PC=HCTS

Fuels		Carbon Intensity			
		Direct CI, $gCO2_e$ /MJ	ILUC, $gCO2_e$ /MJ	Total CI, $gCO2_e$ /MJ	EER-Adjusted CI, $gCO2_e$ $/MJ_{baseline\ fuel}$
Baseline Fuels	CARBOB	99.78		99.78	99.78
	ULSD	102.01		102.01	102.01
	CaRFG	98.47		98.47	98.47

Report on the Committee on Facilities, Material & Support

THURSDAY, OCTOBER 10, 2024

11:00 AM

Chair

Brandon Teal

Director-Railway Machine Systems

NSH USA Corporation, Albany, NY

Vice *Chair*

Tim Bernat

Director of Business Development

Powerhouse Rail, Dallas, TX

Commitee Members

Derek Barber	Railroad Services Director	Nabholz Corporation	North Little Rock, AR
Timothy Chung	Senior Manager Locomotive Reliability	Canadian National Rwy	Homewood, IL
Josh Figurski	Purchasing Manager	Wheeling & Lake Erie RR	Brewster, OH
Bob Harvilla	Outside Sales Support *Reg Exec & Past President*	PowerRail, Incorporated	Exeter, PA
Damir Hasagic	VP-Stretegy and Growth	Varidapt	Chatewood, Australia
Jeremy Hazelett	Senior Procurement Manager	CSX	Jackson, FL
Robert Hodge	RR Division Manager	Industrial Maintenance & Engineering	Nashville, TN
Rhiannon Knezevich	Executive Account Manager	Clark Industrial Power	Gilman, IL
Jason Mann	Business Development Mgr-Rail	Enerpac	Sugar Grove, IL
Craig Opacic	Sales & Business Development	R&W Machine	Bedford Park, IL
Ronald Schaer	Material Director-Strategic Sourcing	BNSF	Fort Worth, TX
Mike Sells	National Sales Manager-Rail Divn	Railhead Corp	Burr Ridge, IL
Andrew Waltz	Asst Director of Material	Mid America Car	Kansas City, MO

PERSONAL HISTORY

Brandon Teal

Director-Railway Machine Systems

NSH USA Corporation

Albany, NY

Brandon Teal is the Director, Railway Machine Systems at NSH USA Corporation in Albany, New York. Brandon started at NSH USA in 2006 as a Field Service Technician, installing and commissioning underfloor wheel lathes and other Hegenscheidt and Simmons products around the world. This hands-on knowledge proved valuable when he transitioned to Machine Sales Associate and later Sales Engineer. In his current role as a Director, Brandon continues to lead sales efforts for the Simmons and Hegenscheidt wheel set maintenance product lines. He is involved with coordinating product specifications with Engineering, Sales, and Marketing, as well as developing strategies for next generation machines and continuous improvement of current systems.

Brandon is a native resident of Upstate New York. Brandon has been married for 12 years to wife Farrah. Brandon enjoys travelling, German Sports Cars, motorcycles, physical fitness and home renovations.

THE FACILITIES, MATERIAL AND SUPPORT COMMITTEE HAD THEIR WINTER MEETING DURING THE AMERICAN SHORTLINE RAILROAD ASSOCIATION REGIONAL MEETING IN KANSAS CITY, MO ON MARCH 25, 2024.

THE COMMITTEE WOULD LIKE TO EXPRESS THEIR SINCERE APPRECIATION TO OUR COMMITTEE MEMBER MIKE SELLS OF RAILHEAD CORPORATION FOR HOSTING THE SUMMER MEETING ON JULY 31, 2024 IN CHICAGO, IL. THE COMMITTEE WAS ALSO ABLE TO TOUR WOODCREST SHOPS IN HOMEWOOD, IL COURTESY OF OUR COMMITTEE MEMBER, TIM CHUNG. THANK YOU, TIM, FOR GIVING US THE OPPORTUNITY TO TOUR THE SHOP.

Quality Assurance of Received Goods

By:
Andrew E Waltz
Mid-America Car, Inc- Kansas City, MO

Table of Contents

Abstract

The LMOA Facilities, Materials, and Support Committee recognizes that having a process of purchasing, receiving, and inspecting goods that is uniformly applied to every order is important to ensure the quality of goods used in production of final products.

Quality Assurance of Received Goods

The process of ensuring the quality of a final product being produced for customers starts well ahead of the final product being released. The individuals responsible for procuring materials, receiving materials, and inspecting materials all play a vital role in the quality of the completed product. Several important steps can be taken to ensure consistent, high quality of received goods:

- Have an established procurement policy
- Ensure employees are aware of the specific procurement policy
- Maintain a professional working relationship with suppliers
- Periodically renew supplier qualifications and capabilities
- Clearly identify requirements when procuring materials
- Thoroughly inspect material compliance to supplied requirements or certifications
- Maintain clear, non-objective notes and photos
- Retain paperwork as long as necessary

The Procurement Policy

One critical step to ensuring quality of received goods is to have a clear direction for employees who primarily deal with purchasing, receiving and inspecting goods. The purchasing policy should address all aspects of material acquisition including:

- Determine what suppliers are authorized to supply materials
- How those processes are updated
- When processes are updated
- How pricing requests are generated and evaluated
- How materials are shipped
- Specific inspections that must occur once the material is received before being released into production

As with most policies, this may start out as a basic document with very little details and should be adapted over time as issues and situations arise. The procurement policy should be reviewed or updated on a consistent basis to ensure that it is still operating to the organization's requirements and should be expanded based upon actual situations the organization faces in their previous operations. Even if reviewing the policy doesn't warrant any significant changes, it will ensure appropriate care has been taken to ensure the policy is up to date and compliant with regulations and needs of the organization.

It is important that companies review their policies related to inspection of received goods to ensure they are compliant with industry organizations, government regulations and supplier policies. In most cases, a company that fails to carefully craft procurement policies will find that they have little to no success in documenting issues they run into as well as filing claims with carriers and suppliers.

Maintaining a Professional Working Relationship with Suppliers

Suppliers are critical to the flow of materials into and out of a company's production process. Oftentimes suppliers will provide information regarding enhancements to products, production issues on their end and critical information needed when using their materials. Maintaining a fair and professional relationship with suppliers ensures when an issue does arise, they will be more apt to find a solution to the problem or may already be working on a fix for the issue.

When a material concern is identified by the receiver, communicating with the supplier as soon as possible is essential and oftentimes required by a supplier's terms of sale. The longer a company waits to report issues to a supplier, they increase the risk of the supplier not being able to rectify their problems. In addition, the longer the material is not under control of the seller, the more likely the article is subjected to other sources of failure such as weather conditions, aging of rubber seals, or damage from outside sources.

In some cases, when installing larger components, it is necessary to document steps taken for installing the component, including measurements that are critical to proper operation of the component. It is very important that these requirements are identified and accounted for during the procurement process as there are typically additional costs or time required to meet these requirements.

Reviewing Supplier Qualifications, Capabilities, and Past Performance

Organizations should ensure their suppliers are an appropriate fit for the project being performed. It is important for the organization to have a list of qualifications for submitting a quotation for materials that is provided when sending the request for quotation. For example, if the receiver of the material requires the material to be manufactured in a facility with certain industry qualifications, those requirements should be communicated when requesting the quotation so the supplier can plan for additional costs and production lead times or when deciding if the quotation is a project the organization can accept.

Organizations are constantly adding or removing capabilities from their business models to streamline or enhance the services and products that they offer. In some cases, those organizations will communicate to their clients the additional services, or discontinuation of those services. However, there are some situations where this is not communicated due to oversight or in some cases due to temporary issues within the facility or organization such as mechanical issues with necessary tooling and labor issues, etc. If a company who is requesting a quote for an item knows they will need the supplier to have certain capabilities, they can plan to research or request of the supplier a list of capabilities prior to requesting a quotation to narrow down the number of organizations receiving the request for quotation.

Additionally, the company requesting a quotation should include previous performance of the supplier in their decision whether to utilize the supplier for the project. If a supplier fails multiple times to produce an acceptable product, it isn't likely they will be successful in future projects of similar nature. However, if a supplier has implemented processes or checks into their processes and procedure to eliminate past shortcomings and issues, it may be worthwhile for a company to look at using the organization for a project.

Changes in market conditions may also affect the likelihood of using a particular supplier for a component. The endless number of acquisitions, closings, and splitting of companies may necessitate changes with a list of approved suppliers. Failure to maintain a current list of approved suppliers that is inclusive can lead to pricing, lead time and quality shortcomings that are tougher to overcome during the procurement process.

Clearly Identify Material Requirements

Material Makeup

Companies have spent years enhancing materials used within the rail industry to improve overhaul intervals, reduce waste, increase performance of materials and reduce environmental impacts. Because of these enhancements, it is more important than ever for companies to clearly identify the requirements of their materials used in projects. While enhanced products may be a good choice, there may be significant enough changes that may not work in conjunction with the requirements of the project. Enhancements or alternate products may also create an incompatibility or regulatory issue that changes the performance of a system. This could potentially cause failures and longer laid-up intervals and troubleshooting time or fines from regulatory agencies if not correctly managed.

Organizations purchasing materials should make it a practice to review the products available, requirements of their projects, and regulatory requirements at regular intervals to establish what should be requested when ordering the products. These specifications should be maintained and identified on all subsequent documents related to the material including purchase orders, order acceptance, shipping documents and invoices to ensure the specifications are clearly provided. Maintaining these requirements will greatly reduce the research time needed when procuring materials for a project.

If a substitution is made for a product for any purpose, it is important that all documentation references the change in specification so that the material can be tracked for performance and usage. The project requirements may require approval from the end user prior to usage of non-specified or out-of-specification components.

Material Condition

It is important to indicate the condition of the materials being procured from the beginning of the procurement process. Typically, unit exchange, remanufactured and running take out products can save an incredible amount of money in the short term; however, they may be quicker to break down over a period or may not meet the same specifications when compared to a new component. A remanufactured component may have been rebuilt using a non-specification part that may operate but not accomplish all requirements related to performance or emissions. Prior to using any unit exchange, running take out, and remanufactured items, written permission from the end user may be required to maintain compliance with contractual obligations.

Over time, the definitions related to the components used in rebuilds have expanded beyond running take out, remanufactured and new. With companies attempting to get a better value for their dollar, new terms have been introduced, such as New Unit Exchange, non-OEM rebuilds, and qualification only inspections. It is necessary to have a full understanding of the condition materials are being sold in. If there is any doubt regarding the condition, it may be necessary to get clarification from the supplier prior to issuing a purchase order for the material.

Clearly Document Packaging & Material Conditions

Clearly documenting conditions of materials and packaging is important and should be completed while the carrier is present and available to process material rejections. It is important that the individuals responsible for shipping and receiving material from carrier's trucks are fully aware of the terms related to what they are signing and agreeing to when accepting materials. Carriers will typically require a signature at delivery indicating that the packaging or materials have been received in-tact. If a person responsible for unloading a carrier believes damage is present or notices broken securements, packaging, pallets or other signs of damage, it must be clearly noted on the delivery receipt or rejected with the carrier altogether. Failure to understand this important information may result in a loss of rights when attempting to generate a claim for the materials. Care should be taken when signing digital delivery receipts from carriers as they are typically backed by a statement indicating the goods were received in good condition.

If the carrier allows the receiver to document and take photos of the shipment while still on or near the carrier's truck, this can provide critical evidence that the material was damaged prior to being turned over to the receiver at the point of delivery. Photos should include overall condition of packaging, identifying decals such as tracking numbers, shipping labels, suspected damage, potential sources of damage (if other materials were stacked on top of a pallet, and it was clearly identified as non-stackable) and any additional photos that may be a source of evidence in a claim.

If any damage is suspected, the carrier must be notified that the shipment is rejected or partially rejected subject to inspection while the carrier is still present and in control of the shipment. Rejections should be made in writing if possible or verified as reported by the carrier with customer service as soon as possible. Carriers each have specific steps they require but, in most cases, they require specific information related to the shipment, shipper, receiver, shipment being claimed, and proof of condition the shipment was sent in through a form or claims portal.

Once materials have passed the initial inspection with the carrier present, packages should be opened to verify appropriate packaging was utilized to prevent the materials from moving around, causing damage to other articles in the shipment. In most cases, boxes that are authorized for shipping purposes will provide a seal of conformity and maximum weight per square inch or square foot. Overloading a box may be a contributing factor to damage of the contents.

Receivers should make note of packaging inside the box, securements used on pallets, whether small items were packaged in such a way they would fall out of the box or off the pallet and whether any additional damage is found to packaging. If any issue is found, the receiver should include additional photos of the packaging that show exactly what concerns are present. These photos should show the exact problem observed and should be fact based.

After documenting the condition of packaging, receivers should document each item's condition, any visual defects, counts of each item received, any identifying plate or marking, visual non-conforming conditions and possible concerns related to the material. Receivers should take care to review technical specifications such as material makeup, thread count, dimensions and applicable markings to ensure material received is the same as what was ordered. Typical defects that can be found in received goods include defects in manufacturing, damage caused from improper storage of materials, and missing quantities of materials. Defects should be listed on paperwork that is kept within the official procurement File. This paperwork may include packing slips, bills of lading, inspection documentation and purchase orders. Depending on the procedures of the company receiving the material, it may be necessary to complete additional paperwork related to inspection or non-acceptance of materials.

Specific Procurement and Receiving Notes are Important

The process of filing a claim or issue with suppliers or carriers can be a lengthy and technical process. Over the period, it is possible that many significant events can occur, and it may be possible that many communications are made, some through email and other less documented communications such as in-person communication, conference calls, or through one-on-one telephone calls. This can cause confusion with dates or times, inaccurate notes, and notes that are opinion based. Companies should include a standard for documenting the applicable communications, tasks and actions taken for each purchase or material received. These notes should be detailed, complete and filed in a standardized easy to access file. The contents of notes should be determined by the company and should be kept confidential unless requested by a party to the quality process, legal authority, or possibly an industry group where required.

When a failure occurs after being assembled or installed, additional notes are typically required to ensure the installer or assembler acted in accordance with industry or manufacturer standards. Adherence to manufacturer and industry standards is extremely important as non-adherence could create a condition that would cause a failure to occur prematurely. In most cases, suppliers will advise if specific processes are required to be utilized in installation or if there are critical measurements that must be collected to ensure a failure is truly related to the component and not of another component or installation mistake.

Retention of Packaging & Rejected Materials

Packaging and rejected materials should be retained in-tact until the manufacturer or carrier authorizes the material to be disposed of in writing. There is typically a standard requirement provided in purchasing agreements or carrier agreements where the recipient agrees to hold packaging and damaged material for a set number of days until an inspection window closes. The possibility also exists that a party may waive this requirement and authorize the receiver to dispose of the material prior to the end of the agreement terms. If a receiver is in possession of the material, they must have written authorization by a competent representative of the offending party prior to disposing of the material.

Retention of Documentation

It is important to retain the data you've collected on shipments until the possibility no longer exists that the data is relevant. This may be set by an organization, industry group, government, industry or by preference of the individual that collected the data. Data should be stored in a format that is accessible whenever needed and easily located. This data may be utilized for supplier performance or as a resource for updating policies. In most cases, notes, photos and data should not be shared with outside parties unless prior authorization has been received.

In conclusion, organizations should take steps to ensure policies are in place for the process of purchasing, receiving, and documenting received goods. Receivers of goods must ensure they maintain a relationship with suppliers, inspect packaging, materials and paperwork for accuracy, and retain paperwork, packaging and materials until such time as it is no longer necessary for their organization or the supplier to utilize. Organizations should review their policies periodically to determine whether any updates are necessary.

SAMPLE RECEIVING REPORT

SHIPMENT TRACKING NUMBER	CLAIM / CASE NUMBER	PURCHASE ORDER	REPORT DATE/TIME	

RECEIVER INFORMATION	
COMPANY	
REPRESENTATIVE	
ADDRESS (1)	
ADDRESS (2)	
CITY, STATE, ZIP	
PHONE NUMBER	
E-MAIL ADDRESS	

SUPPLIER INFORMATION		CARRIER INFORMATION	
NAME		NAME	
CONTACT		TERMINAL NAME	
ADDRESS (1)		TERMINAL ADDRESS	
ADDRESS (2)		TERMINAL ADDRESS (2)	
CITY, STATE, ZIP		CITY, STATE, ZIP	
PHONE		TERMINAL PHONE	
E-MAIL ADDRESS		TERMINAL E-MAIL	

DELIVERY PACKAGING INSPECTION

EMPLOYEE UNLOADING FROM TRUCK	EMPLOYEE COMPLETING REPORT	SUPERVISOR APPROVING	DATE	TIME

WAS SHIPMENT FOUND TO BE DAMAGED WHILE ON THE CARRIER'S TRUCK? (Y/N)	
WAS CARRIER NOTIFIED OF DAMAGE PRIOR TO ACCEPTING SHIPMENT? (Y/N)	
WERE ALL COPYS OF DELIVERY RECEIPT OR BILL OF LADING MARKED AS HAVING DAMAGE, INCLUDING BUT NOT LIMITED TO DAMAGED BOXES, BROKEN SHRINK WRAPPING. PAPERWORK MUST INCLUDE THE TERMS "PENDING SECONDARY INSPECTION" (Y/N)	
WAS SHIPMENT DENIED AT TIME OF DELIVERY (Y/N)	
CLARIFYING REMARKS	

CORNER SHOT	CORNER SHOT
DAMAGE	LABELS / TRACKING STICKER

SECONDARY PACKAGING INSPECTION

EMPLOYEE FORWARDING SHIPMENT	EMPLOYEE PERFORMING SECONDARDY PACKAGING INSPECTION	SUPERVISOR APPROVING	DATE	TIME

IS THERE ANY DAMAGE NOT PREVIOUSLY IDENTIFIED ON THE EXTERNAL OF THE PACKAGE? (Y/N)	
IF PACKAGE CONTAINED TAMPER RESISTANT PACKAGING, WAS IT IN-TACT? (Y/N)	
WERE SUFFICIENT SECUREMENTS IN PLACE TO SECURE PACKAGE AS NECESSARY? (Y/N) I.E. PALLET WRAP, PALLET STRAPPING, BOXES, TAPE	
WAS SUFFICIENT PACKAGING PRESENT INSIDE BOX TO PROTECT MATERIALS FROM DAMAGE? (Y/N)	
CLARIFYING REMARKS	

PACKAGING SECUREMENT	PACKING MATERIALS
ADDITIONAL PHOTOS	LABELS / TRACKING STICKER

NOTE: USE AS MANY COPIES OF THIS FORM AS NECESSARY FOR EACH PACKAGE RECEIVED.

SECONDARY MATERIAL INSPECTION

QUANTITY EXPECTED	PART NUMBER	DESCRIPTION	QUANTITY RECEIVED	REQUIRES Q/A INSPECTION	DEFECTS FOUND

PHOTO OF MATERIAL	PHOTO OF MATERIAL
PHOTO OF MATERIAL	PHOTO OF MATERIAL
CLARIFYING REMARKS	

NOTE: USE AS MANY COPIES OF THIS FORM AS NECESSARY FOR EACH ITEM RECEIVED.

NOTIFICATIONS LOG

DATE	TIME	PERSON MAKING NOTIFICATION		

EVENT, CALL, COMMUNICATION LOG

DATE	TIME	EVENT

Shipping Practices, Trends and Documentation Creation

By:
Craig Opacic – R&W Machine
Josh Figurski – Wheeling & Lake Erie Railway

It takes a large number of parts and commodities to operate a railroad. These items range from small to large. Mechanical and electrical components, and fuel are examples. Some are hazardous in nature. Establishment of and adherence to documentation and safe shipping practices is essential to ensure that these products arrive in good condition, on time, and as economically as possible. For the purposes of this paper, the focus will be on the process as it relates to the maintenance of locomotives.

Shipping is a two-way street. Obviously, the supplier sends new or remanufactured parts and commodities to the railroad. Getting the items to the destination on time in good condition and, equally important, ensuring the safety of those involved in the process is crucial. Choosing the correct type of transportation and method of packaging and/or securing the load assures that this will be accomplished. This also applies to material being sent from the railroad to the supplier for UTEX or repair & return transactions.

Packaging

No matter the type of product or commodity and the method of transportation being utilized, packaging is important as proper methods lessens the risk of damage during transit and the safety of the employees involved in the handling process. Depending on what is being transported, palletizing, shrink wrapping, metal banding, and tarping can be utilized. Also important is the utilization of signage or placards when hazardous material and/or those that might have an environmental impact are involved.

Material Classification

The National Motor Freight Traffic Association (NMFTA) defines a class as a way "to establish a commodity's transportability." The National Motor Freight Classification (NMFC) is the standard which enforces this system, grouping commodities into one of 18 classes – ranging from 50 to 500. The NMFC determines this class using four characteristics: Density, Stowability, Handling and Liability.

Density: An item's density is determined by its weight and dimensions. Check out our freight density calculator to determine your item's density in pounds per cubic foot. The higher the density, the lower the class and ultimately, the lower the cost. This may seem backward at first glance, but consider this: carriers love shipping freight that is heavy and doesn't take up much space compared to its weight.

Stowability: Means how the shipment can be arranged with other freight in the transport vehicle. This takes into account hazardous shipments (which cannot be moved with non-hazardous shipments) or items with strange dimensions that make it difficult to load freight around them. Classification helps carriers optimize the loading and unloading processes. By categorizing freight based on characteristics like size and weight, carriers can efficiently stack and organize shipments within trailers, maximizing the use of available space.

Handling: Handling concerns the item's ability to be handled as the freight is loaded and unloaded from LTL terminal to LTL terminal. Dimensions, fragility and packaging play a role in how difficult an item is to handle.

Liability: Liability takes into account the probability of the shipment being damaged or stolen, or damaging other adjacent freight – as well as the perishability or possibility of freight theft of the item.

How Freight Class Affects Quote Prices

This part is simple — the lower your class, the lower the price. An item that is a class 50 will be cheaper to ship than an item that is class 500.

Maximum average value Per pound	Class
1.25	50
2.5	55
3.75	60
6.25	65
9.4	70
12.55	77.5
18.85	85
25.1	92.5
31.35	100
34.5	110
39.2	125
47.1	150
54.95	175
62.8	200
78.45	250
94.15	300
125.55	400
156.95	500

Fuente/Source: 2018 National Motor Freight Traffic Association, Inc

Freight type

UPS, FedEx, USPS: For small quantities of smaller items, generally 50 LBS or less. Offers cost effective and relatively fast delivery.

LTL: Less-than-truckload, also known as or less-than-load (LTL), is a shipping service for relatively small loads or quantities of freight. Less-than-truckload services are offered by many large, national parcel services as well as by specialized logistics providers.

These services can accommodate the shipping needs of countless businesses that need to move smaller batches of goods frequently. Less-than-truckload shippers offer economies of scale so that freight costs of individual shipments are minimized.

The big advantage of LTL is that it saves money and is more efficient for smaller shippers.

FTL: (full truckload) is a type of shipping mode where a truck carries one dedicated shipment. In other words, the entire journey is reserved for a single shipment. FTL has several advantages over the alternative trucking mode, Less Than Truckload (LTL):

- Cost-effectiveness: For shipments large enough to fill or nearly fill an entire container, FTL is cheaper.
- Faster delivery: FTL shipments reach their destination sooner because the truck makes no other pickups or drop-offs along the way.
- Less handling: There's no transferring between trucks mid-transit, reducing the risk of loss or damage to the shipment.

Flatbed: Flatbed shipping involves transporting cargo on a flat, open-deck trailer without the constraints of enclosed walls or roofs. Unlike traditional dry van trailers, flatbeds allow for cranes and forklifts to load goods from all angles. These versatile trailers are ideal for oversized, heavy, or irregularly shaped freight, such as engines, generators, wheels, wheelsets, combos.

Tanker: Bulk liquid transport involves moving large volumes of liquid cargo in tanks on trailer trucks. When it comes to road transportation, tank trailers (also known as bulk tankers) play a crucial role. These cylindrical tanks are pulled by freight trucks and carry various types of bulk liquids, including fuel, oil, gas, and hazardous materials. The cylindrical shape of the tanks facilitates loading and unloading, and many tank trailers have baffles inside to prevent liquid agitation during transit. These tankers are essential for safe and secure transport of bulk liquids.

Air Freight: Airfreight offers several advantages over other transportation modes. It is also, by far, the costliest and is generally used in instances where the cost of having a locomotive out of service outweighs the freight cost.

- Speed: Air transport is the fastest mode, ideal for urgent shipments. Goods can reach their destination within hours or a few days, depending on the distance.

- Global Reach: Airfreight connects cities and countries worldwide, even to remote locations. It's especially useful for international trade.
- Reliability: Airlines adhere to strict schedules, minimizing delays. This reliability is crucial for time-sensitive cargo.
- Security: Air cargo undergoes rigorous security checks, reducing the risk of theft or damage.
- Reduced Inventory Costs: Faster transit times mean lower inventory holding costs.

Documentation

Shipping and receiving documents play a crucial role in commerce, ensuring smooth transactions and efficient cargo transportation. Here are ten essential shipping documents:

- Purchase Order: An official declaration of receiving an order, containing details about the transaction, parties involved, product types, and transaction date.
- Commercial Invoice: The complete details of the sales transaction between the vendor and buyer, including shipping terms. It serves as the official proof of sale.
- Bill of Lading: A contract of carriage document that outlines the terms and conditions of shipping goods. It acts as a receipt for cargo and evidence of the contract between the shipper and carrier.
- Air Waybill: Similar to a bill of lading but used for air shipments. It provides details about the shipment, parties involved, and the route.
- Letter of Credit: A payment guarantee document issued by a bank, ensuring payment to the seller upon meeting specified conditions.
- Certificate of Origin (C/O): A document declaring the country of origin for manufactured goods, often certified by the consulate or chamber of commerce.
- Import License: A government permission document required for importing goods into a country.
- Export Packing List: A cargo description document specifying the contents of the shipment, including quantities, weights, and packaging details.
- Dock/Warehouse Receipt: A shipment receipt document issued by the warehouse or dock when goods are received.
- Insurance Certificate: Provides liability coverage for the shipment.

Remember that accuracy, completeness, and compliance with regulations are essential when creating and managing these documents. Proper documentation ensures successful shipping and minimizes delays.

Payment Terms & Liability

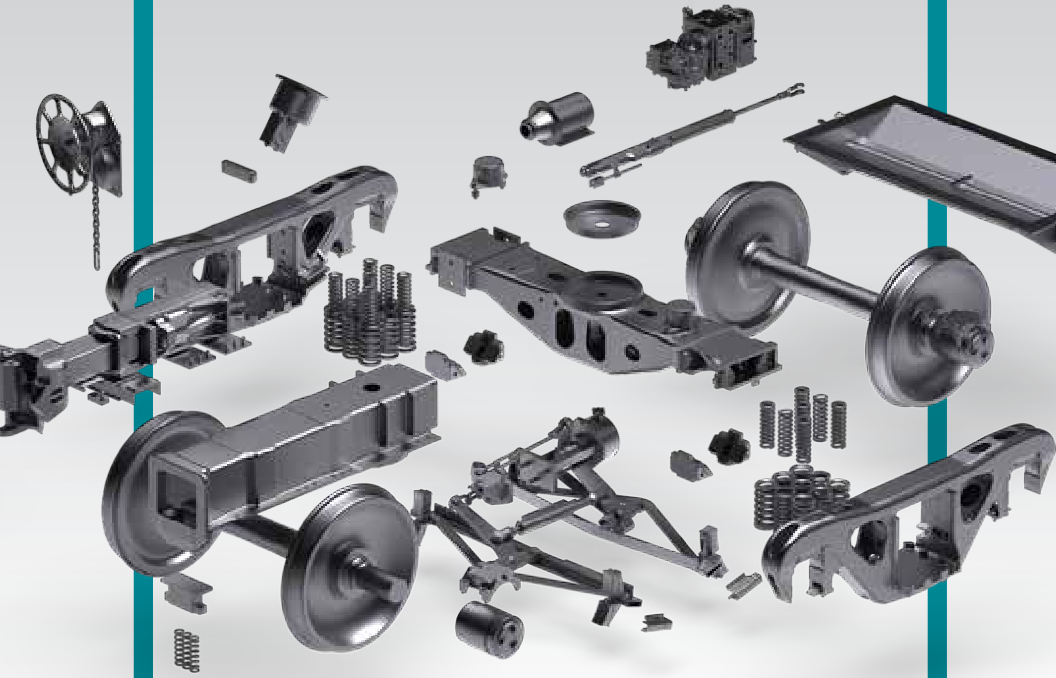
A need has been identified and a requisition has been initiated. This leads to a Request for Quote to a supplier. Included within the RFQ should be the shipping terms. Whether this is a spot buy or part of a contract, terms and conditions are included on the supplier quotation. Once a supplier is selected, this leads to the creation of a purchase order. The railroad will generally have their own standard terms and conditions, which are usually part of the formal purchase order. Acceptance of the purchase order by the supplier is acknowledgement that these terms are accepted. Shipping terms are very important for two reasons:

1. Definition of which party is responsible for shipping costs.
2. Definition of which party is responsible for the goods at specified points during the transportation process.

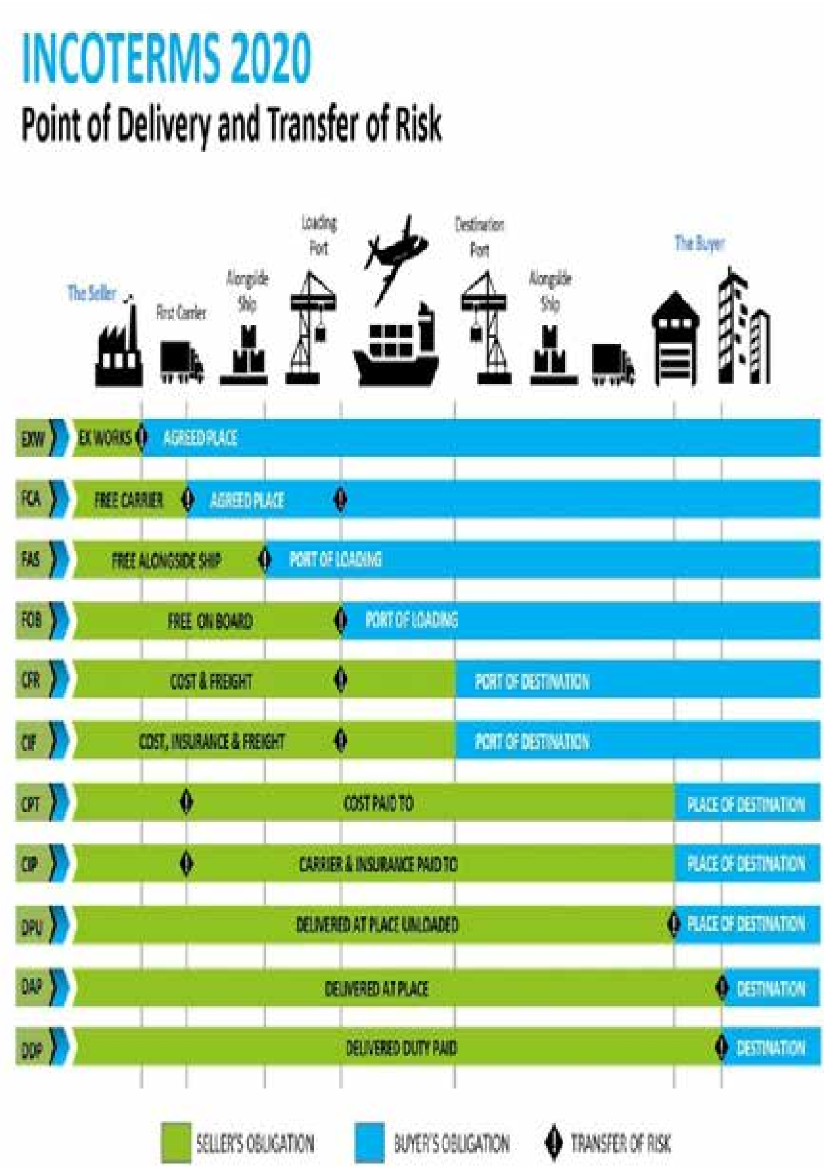
Responsibility for payment is defined in the following chart:

SPECIFICATIONS	Departure from ware-house	Main transportation not paid by the seller			Main trasportation by the seller				Shipping charges paid by the seller until reaching destination point		
Incotern / Cost	EXW	FCA	FAS	FOB	CFR	CIF	CPT	CIP	DAT	DAP	DDP
Packaging	S	S	S	S	S	S	S	S	S	S	S
Loading from warehouse	B	S	S	S	S	S	S	S	S	S	S
Pre-carriage	B	S	S	S	S	S	S	S	S	S	S
Export customs clearance	B	S	S	S	S	S	S	S	S	S	S
Handling at departure	B	B	B	S	S	S	S	S	S	S	S
Main transportation	B	B	B	B	S	S	S	S	S	S	S
Transportation insurance	B	B	B	B	B	S	B	S	S*	S	S
Handling at arrival	B	B	B	B	B	B	B	B	S	S	S
Import customs clearance	B	B	B	B	B	B	B	B	B	B	S
Post-carriage	B	B	B	B	B	B	B	B	B	B	S
Unloading into warehouse	B	B	B	B	B	B	B	B	B	B	S

S: Cost paid by the seller
B: Cost paid by the buyer
* Non-mandatory



The transfer of risk used in establishing these responsibilities is defined in the chart below.



Shipping cost

Of course, all of the above needs to be done with a focus on minimizing delays and controlling cost. As an example, the Wheeling & Lake Erie Railway reviewed their freight costs and implemented some changes by the way of moving away from a single preferred carrier.

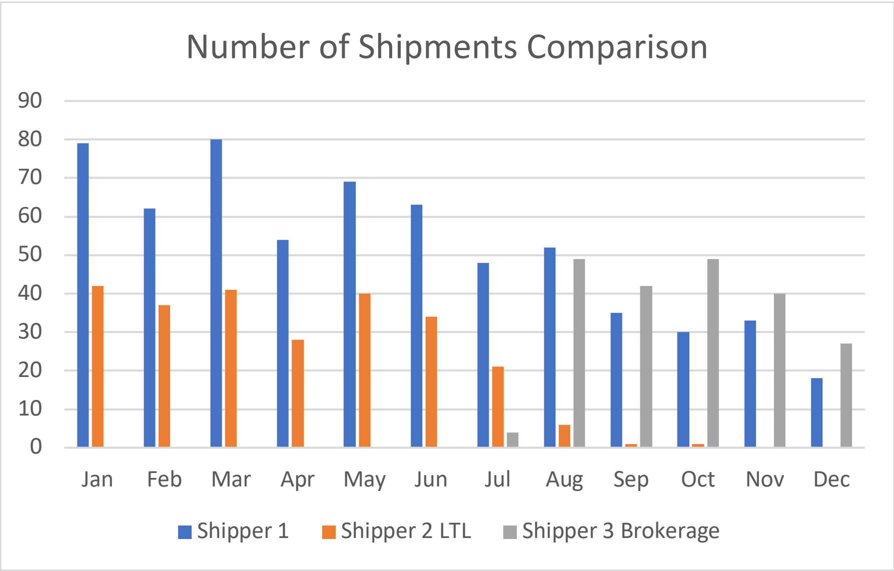
The Wheeling and Lake Erie Railway team has made countless efforts to eliminate issues with tracking shipments of time sensitive package delivery critical to the organization to make sure that the fleet keeps moving. One way in which the W&LE is able to do this is through the use of a third-party broker. A third-party broker is an engineered shipping system that allows customers to track and manage shipments across multiple shipment carriers. Through the use of this third-party broker system, the railroad is able to access preferred carriers against other carriers to find out when packages were shipped, when the packaged is delivered, and when the package could be picked up to be returned. The W&LE can also track delayed or damaged shipments.

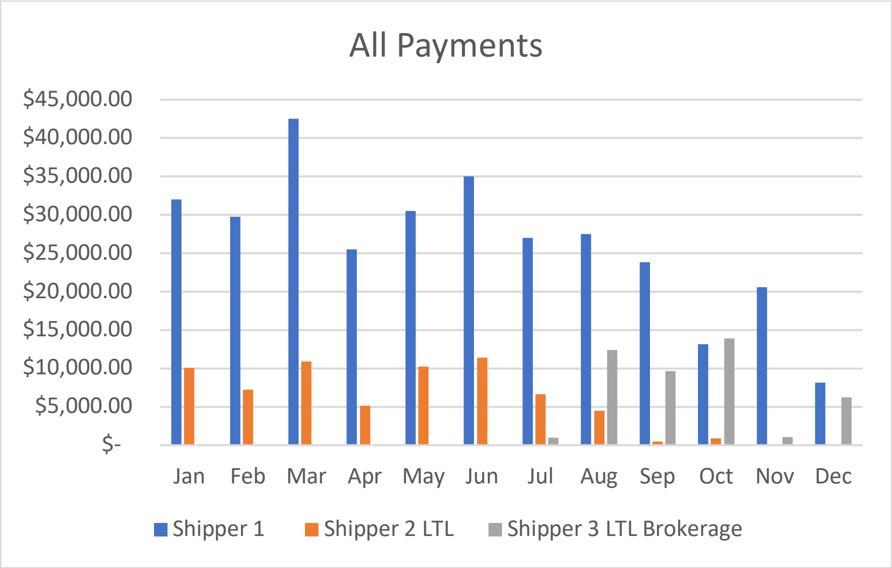
Wheeling and Lake Erie Railway uses the brokerage system to track pricing discrepancies and trends to make best financial shipment decision. Previous quotes from all carriers can reviewed to determine whether prices have fluctuated since the last shipment. Competitive pricing from other outside sources aides in the shipment decision. These prices usually come from smaller carriers trying to establish business with your company. This helps the W&LE see the ultimate best price to have products shipped out

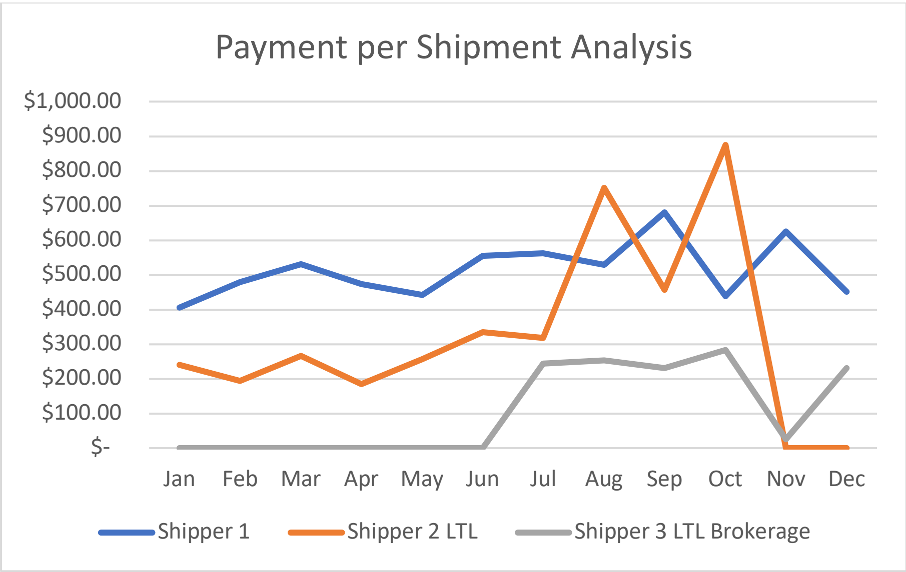
In addition, from a timing perspective, the brokerage system also gives the railroad the opportunity to combine shipments via one carrier, to reduce the number of non-full shipments. This has offered another method to help control and reduce overall shipment costs. It has also reduced labor costs and reduced wear and tear on forklifts, as staff is not utilized to unload less than full shipments over a period

This brokerage system also helps eliminate the use of multiple websites to track shipments. This helps eliminate wasted time in switching back and forth across multiple carrier websites to track shipments.

With using this type of system, a dramatic cost savings in freight shipping has been realized. The Wheeling and Lake Erie Railway's brokerage system introduction has resulted in an almost thirty-three percent reduction in shipment expenses. These savings are evident in the following graphs.


Number of Shipments Comparison
90
80
70
60
50
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Shipper 1
Shipper 2 LTL
Shipper 3 Brokerage


All Payments
$45,000.00
$40,000.00
$35,000.00
$30,000.00
$25,000.00
$20,000.00
$15,000.00
$10,000.00
$5,000.00
$-
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Shipper 1
Shipper 2 LTL
Shipper 3 LTL Brokerage



While the implementation of this approach does require time and resources, the realized cost savings has justified the W&LE's effort.

In conclusion, as with any business, the railroad is made up of many departments working together and performing responsibilities necessary to operate in an efficient and cost-effective manner. Shipping & Receiving, Maintenance, Purchasing, and Finance all have a role in executing the shipping process and, with a coordinated effort, can accomplish this task in a seamless, effective manner.

Report on the Committee on Fuel, Lubricants and Environmental

THURSDAY, OCTOBER 10, 2024

1:40 PM

Chair

Chris Miller

Senior Director of Services Product Management

Wabtec Corporation, Chicago, IL

Vice Chair

Steve Fritz, P.E.

Senior Manager-R&D

Southwest Research Institute, San Antonio, TX

Commitee Members

D. Abeywickrama	Loco Fleet Leader-Mech Reliability	Canadian National Railway	Montreal, Quebec
B. Amen	Manager-Mechanical Engineering	Union Pacific RR	Omaha, NE
J. Barnes	Chief Chemist	Norfolk Southern	Chattanooga, TN
D. Beebe	Technical Director	Temple Engineering	Liberty, MO *Past President*
M. Brinkman	Sales Manager-Engineering	Boll Filter	Novi, MI
T. Degerness	Manager Fuels	CPKC	Calgary, Alberta
R. Denton	Corp Chemical Technology Manager	Cummins, Inc	Columbus, IN
S. Fenwick	Technical Director	Clean Fuels Alliance America	Jefferson City, MO
R. Flott	Chief Fuel Chemist	BNSF Railway	Topeka, KS
P. Fontecchio	Engrg Mgr-Engine Cooling & Lube	Wabtec Corporation	Erie, PA
T. Gallagher	OEM Technical Liaison	Chevron Oronite	Allendale, MI *Past President*
R. Garver	Sr Senior Manager	Innospec Fuel Specialties	Englewood, Co
N. Gawin	Technical Sales Manager	Shell Whitmore Reliability & Sol.	Strathmore, Alberta
S. Golisz	Technical Director	Innospec	Newark, DE
D. Gray	Industry Liaison Advisor	Infineum	Brick, NJ
D. Hays	Manager Mechanical Maintenance	Terminal RR Assn of St. Louis	Venice, IL
R. Hays	Director-Sales	Red Gian Oils/HF Sinclair	Council Bluffs, IA
A. Hesse	Senior Mechanical Engr	Amtrak	Lincoln University, PA
J. Heywood	Senior Fuels and Lubricants Engineer	Wabtec Corporation	Fort Worth, TX *Regional Executive*
S. Jaworski	Application Advisor	Exxon Mobil	Williamstown, Ontario
W. Kennedy	Consultant	Kennedy Rail Consulting	Omaha, NE
C. Koglin	OEM Relations Specialist	Afton Chemical Corporation	Southfield, MI
S. Koshy	Senior Mechanical Engr	Amtrak	Bear, DE
T. Mack	President/Owner	Zero Emission Loco Technology	Blue Ash, OH
J. Meinhardt	Applications and Service Engineering	Cummins, Inc	Columbus, IN
R. Modiyani	Senior Manager Emerging Markets	Chevron Renewable Energy Group	Ames, IA
G. Natarajan	Specialist-Research & Business	The Viswa Group	Houston, TX
S. Nevin	Managing Director-Supplies & Material	CPKC	Calgary, Alberta
L. Rasmussen	Product Engineer-Engine Systems	Progress Rail-Electro Motive Diesel	LaGrange, IL
L. Rawding	RR Product Manager	American Refining Group	Beaver Falls, PA
C. Ruch	Director-Technical Research & Development	BNSF Railway	Topeka, KS *1st Vice President*
G. Smith	Project Manager	Argus Consulting, Inc	Overland Park, KS

NOTE: The following individuals will be joining the committee: Michael Blumenfeld of Exxon Mobile, Michael Cleveland of Peaker Services and Joshua Horner of Canadian National

PERSONAL HISTORY

Chris Miller

Senior Director of Services Product Management
Wabtec
Chicago, IL

Chris Miller is the Senior Director of Services Product Management at Wabtec where he is developing the roadmap and strategy for the energy systems powering the world's existing freight locomotives. His products push the existing diesel-burning locomotive fleet to be more reliable and fuel-efficient while growing to include energy sources such as alternative fuels, batteries, and hydrogen that are needed to support the industry's transition to carbon neutrality. Much of that push is around understanding the impact of biodiesel and renewable diesel when used in Wabtec locomotives, but also includes alternative fuels such as hydrogen.

Chris started his railroad career with Norfolk Southern as a Mechanical Supervisor supporting operations in Atlanta, GA, Chattanooga, TN, and Macon, GA. He then spent eight years with Union Pacific in the Locomotive Engineering and Quality group managing the reliability of UP's fleet of ~7,000 locomotives. His last railroad stop was at Canadian National Railway as the Senior Manager of Mechanical Engineering where he functioned as an internal consultant guiding CN's locomotive decarbonization and other locomotive projects.

This railroad experience combined with his time as the General Manager of a Steak 'n' Shake restaurant makes Chris a versatile professional with experience in product management, employee development, problem solving, strategic planning, carbon reduction, sustainability, and customer service. He also enjoys learning about new concepts and technologies, especially in the energy systems space to be a resource for others. Chris works cross-functionally to develop innovative and pragmatic solutions for customers that create win/win solutions.

Chris has three children aged 12, 9, and 5 with his wife, Liz. They moved to Chicago in 2021 and love the city and suburbs. He enjoys running when there's free time from all the kid's fun activities (soccer, dance, swimming, and basketball).

THE FUEL, LUBRICANTS AND ENVIRONMENTAL COMMITTEE WOULD LIKE TO EXPRESS OUR SINCERE APPRECIATION TO SUZANNE GOLISZ AND RANDY GARVER FROM INNOSPEC FUEL SPECIALTIES FOR HOSTING OUR JANUARY 24, 2024 WINTER MEETING IN NEWARK, DE. WE HAD A GREAT TOUR AND LEARNED QUITE A BIT FROM THE WHOLE TEAM AT INNOSPEC WHILE ALSO ENJOYING SOME DELICIOUS FOOD AT THE LOCAL EATERIES.

THE COMMITTEE WOULD ALSO LIKE TO THANK LUKE RAWDING FROM AMERICAN REFINING GROUP FOR ORGANIZING AND HOSTING OUR AUGUST 14, 2024 SUMMER MEETING IN BRADFORD, PA. IT WAS NICE TO HAVE ONE LAST IN-PERSON MEETING BEFORE THE 2024 RSI EXPO AND CONFERENCE. THE R&D/QC AREAS AND REFINERY TOURS WERE VERY INFORMATIVE FOR THE WHOLE GROUP, AND WE APPRECIATE THE OPPORTUNITY TO USE THE ARG R&D AUDITORIUM FOR THE MEETING.

CARB In-Use Locomotive Regulation

By:
Steven Fritz - Southwest Research Institute (SwRI)
Brett Amen – Union Pacific Railroad

Abstract

The California Air Resources Board (CARB) approved an "In-Use Locomotive Regulation" on April 27, 2023. This regulation is subject to authorization from the U.S. Environmental Protection Agency (EPA), and separately is the subject of a lawsuit by the Association of American Railroads (AAR) and the American Short Line and Regional Railroad Association (ASLRRA). This regulation will have major impact on the California locomotive fleet (as intended by CARB). This paper gives an overview of major aspects of the regulation, identifies selected "technical loose ends" that will need clarification, and sets the stage for what could be significant locomotive fleet changes for LMOA members.

Background

CARB and EPA have recognized that the replacement of legacy locomotive with Tier 4 locomotives has not progressed as expected, resulting in a stagnation of emissions reductions in the railroad sector. CARB highlighted this situation in their 2021 Line-Haul Locomotive Emission Inventory [Ref. 1]. This updated emissions inventory was developed using line haul activity and population data supplied by both Union Pacific (UP) and BNSF railroads. The previous emissions inventory model, developed in 2011 based on 2007/2008 data, was later updated in 2016. Given that these inventories were created prior to the availability of Tier 4 locomotives, CARB had to estimate the rate at which railroads would purchase Tier 4 locomotives.

Both earlier inventory releases predicted a relatively rapid penetration of Tier 4 locomotives in the fleet, at a rate of up to 7 percent per year after 2015. In retrospect, the predicted penetration rate turned out to be very optimistic and has not been realized. According to the most recent data, Tier 4 locomotive engine penetration rates sit at under 1 percent per year on average due in part to the fact that railroads have been purchasing fewer than expected Tier 4 locomotives for the past few years, instead choosing to modernize Tier 1+ locomotives.

Figure 1 shows CARB's 2016 locomotive NOx emissions projection (black line with red dots) for the South Coast Air Basin (SC) State Implementation Plan (SIP) inventory, and the 2020 updated inventory projection through 2050 based on Business As Usual (BAU), along with the Tier distribution making up the inventories. This graph clearly shows that not only are locomotive emissions in California not dropping as projected in 2016, but rather locomotive emissions are increasing in the 2020 to 2030 timeframe.

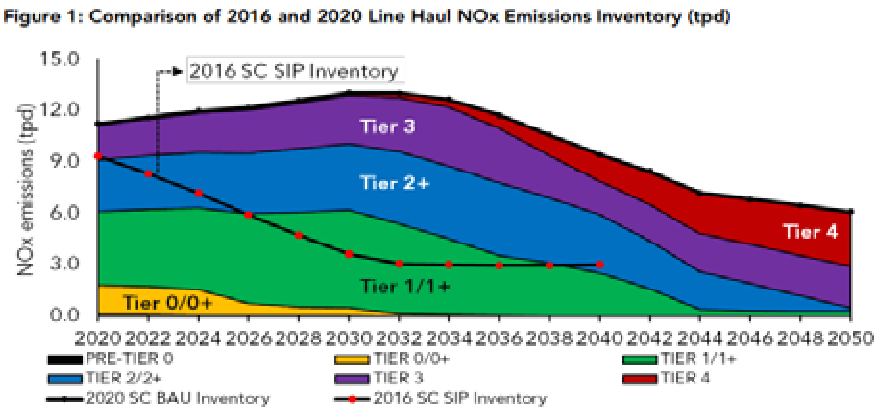


Figure 1. Comparison of 2016 and 2020 Line-Haul NOx Emissions Inventory for the South Coast Air Basin

CARB In-Use Locomotive Regulation

Mobile sources, including locomotives, contribute a significant amount of criteria pollutants including smog-forming oxides of nitrogen (NOx) and PM 2.5, as well as the largest portion of greenhouse gas (GHG) emissions in California. In 2020, California's locomotive sector was responsible for 10 percent of statewide NOx emissions from mobile sources and is projected to grow to over 15 percent in 2035 without regulation. [Ref 2]. As cleaner technologies are adopted most other mobile sectors are expected to significantly reduce emissions by 2035, however, the locomotive sector's relative contribution is expected to increase without further regulations. In response, CARB developed an In-Use Locomotive Regulation intended to help achieve California's criteria pollutant and GHG reduction goals by increasing the use of Tier 4 or cleaner diesel locomotives, zero emission locomotives (ZE Locomotives), and reducing use of and emissions from older locomotives.

CARB reports that the primary benefits of the regulation are reductions in PM2.5, NOx, and GHG emissions from locomotives that operate in California. Staff estimates that cumulatively for the period 2024 to 2050, the regulation will reduce statewide emissions by approximately 7,300 tons of PM2.5, 386,000 tons of NOx, and 21.6 million metric tonnes (MMT) of GHGs, relative to the baseline. This is shown in Figure 2 for NOx emissions and Figure 3 for PM2.5 emissions, which CARB adapted from its In-Use Statement of Reasons (ISOR) for the proposed in-use locomotive regulations [Ref 3].

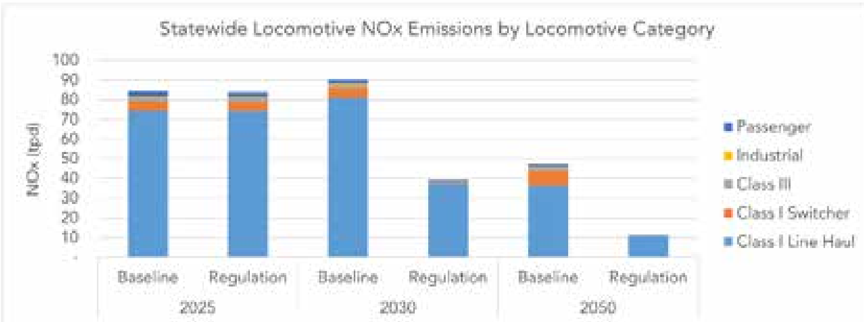


Figure 2. CARB Estimates of Locomotive NOx reductions

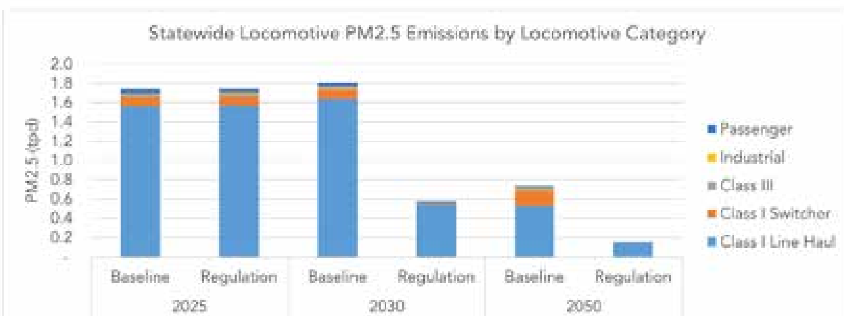


Figure 3. CARB Estimates of Locomotive PM2.5 reductions

Table 1 gives the timeline for the regulation. An initial hearing for the CARB In-Use Locomotive Regulation was held on November 18, 2022, and a second hearing on April 27, 2023, where the Board voted and approved the regulation.

Table 1. CARB In-Use Locomotive Regulation Administrative Timeline

November 18, 2022	CARB hearing on proposed regulation
April 27, 2023	2nd CARB hearing, vote => approved
June 16, 2023	AAR + ASLRRA file lawsuit against CARB
October 27, 2023	Final Regulatory Order (legal review)
November 7, 2023	CARB letter to EPA requesting authorization
January 1, 2024	Effective date of the regulation

On October 27, 2023, the California Office of Administrative Law completed its review of the regulation, and proposed the Final Regulatory Order, adopting title 13, California Code of Regulations, Chapter 9, Article 8, Sections 2478 through 2478.17.

On November 7, 2023, CARB sent a letter to EPA *"to request that the United States Environmental Protection Agency (EPA) grant California an authorization, pursuant to section 209(e)(2) of the federal Clean Air Act (CAA), for California's Non-Road Program in light of the recent addition of In-Use Locomotive Regulation (Locomotive Regulation)."*

On June 16, 2023, the Association of American Railroads (AAR) and the American Short Line and Regional Railroad Association (ASLRRA) filed a lawsuit against CARB in the Eastern District of California over the CARB In-Use Locomotive Regulation. Figure 4 provides a screenshot of details of the lawsuit that should allow the reader to find updated information on this case online.

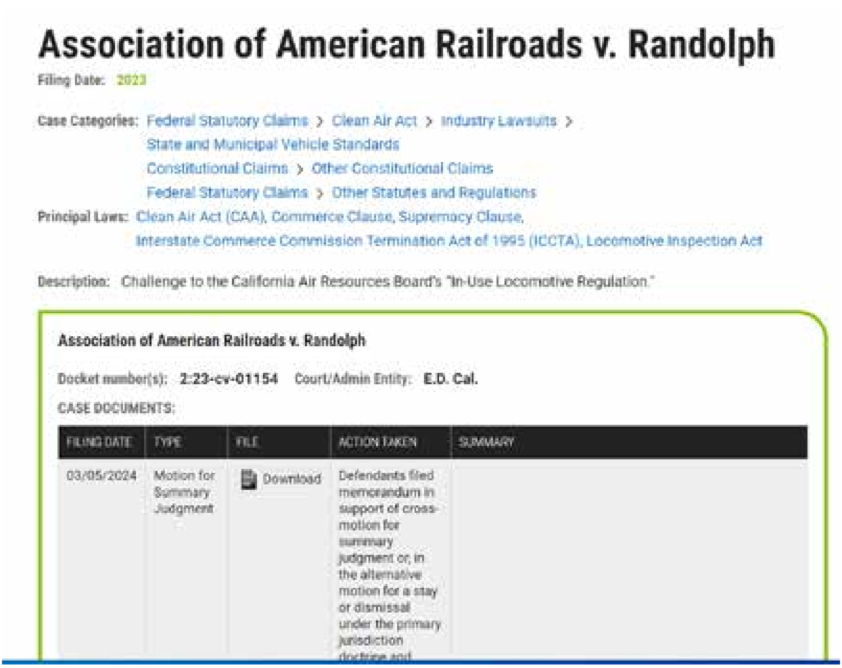


Figure 4. Details of the AAR Lawsuit against CARB

As of the time of this LMOA paper preparation (June 2024), CARB has not yet received authorization from EPA, and separately, the AAR lawsuit is progressing through the legal system.

Key aspects of the CARB In-Use Locomotive Regulation are outlined below, with details and the full regulation available online.

First and foremost, this regulation applies to *"any locomotive operator that operates a locomotive in the State of California."* So, it means the railroads operating the locomotive, not the owner of a given locomotive, nor the lessor are affected. The four major components of the regulation are described below.

Spending Account – Railroads pay a "use fee" into a railroad-held escrow based on use in California, calculated using a multiplier of use based on logged work in megawatt-hours times a factor based on the EPA Tier of the locomotive, with fees going to fund Tier 4 and "Zero Emission" (ZE) locomotives, and associated infrastructure. Locomotive operators will be required to fund their own trust account based on the emissions created by their locomotive operations in California. The dirtier the locomotive, the more funds must be set aside. BNSF and UP have estimated that for their current fleet makeup and activity in California, this will be on the order of $800M per year, for each of these railroads. Spending Account funds can be used in the following manner:

- Until 2030, to purchase, lease, or rent Tier 4 or cleaner locomotive(s), or for the remanufacture or repower to Tier 4 or cleaner locomotive(s).
- At any time, to purchase, lease, or rent ZE locomotive(s), ZE capable locomotive(s), ZE rail equipment, or to repower to ZE locomotive(s) or ZE capable locomotive(s).
- At any time, for ZE infrastructure associated with ZE locomotive(s), ZE capable locomotive(s), or ZE rail equipment.
- At any time, to pilot or demonstrate ZE locomotives or ZE rail equipment technologies.

In-Use Operational Requirements – Starting in 2030, any locomotive older than 23 years will not be permitted to operate in California, unless operated in a ZE configuration. For example, this means that T1+ SD70M or AC4400 locomotives originally built in 2003 would be banned, unless operated in a ZE configuration or remanufactured to Tier 4.

Switch, industrial, and passenger locomotive operators with an original engine build date of 2030 and beyond will be required to operate in a ZE configuration to operate in California.

Freight line-haul locomotives with an original engine build date of 2035 and beyond will be required to operate in a ZE configuration to operate in California.

Idling Requirements: Annually, for locomotives equipped with Automatic Engine Stop/Start (AESS), any Idling event of more than 30-minutes with the locomotive stationary needs to be reported to CARB by July 1 of 2026 (where, when, why, for how long).

All locomotives with AESS will not be permitted to idle longer than 30 minutes, unless for an exempt reason. Exemptions align with those described by U.S. EPA and will be granted for reasons like maintaining air brake pressure or keeping the driver cabin heated or air conditioned.

A locomotive operator with an AESS equipped locomotive shall ensure the AESS is always functional during the locomotive's operation. A locomotive operator shall replace or repair a malfunctioning or broken AESS no later than 30 days after discovering the initial malfunction or break.

Locomotive Registration and Reporting Requirements: Any locomotive operated in California needs to be registered with CARB. The locomotive operator shall register the Locomotive within 30 calendar days of the first day when the locomotive operates in California.

Locomotive activity, emission levels and idling data will be required to be reported annually. Calendar year 2025 is the start of this activity logging and reporting, with 2025 data and spending account deposits to be made by July 1, 2026. Reporting includes an annual administrative payment of $175 per locomotive per year, except for ZE locomotives and historic locomotives.

Non-Compliance: Section 2478.16 covers non-compliance, penalties, and right of entry. Although monetary penalties are not specified, each individual violation of each section of the regulation, for each locomotive, for each day, is a separate offense. In other words, not being ready to start monitoring all locomotives your railroad operates in California starting on January 1, 2025, could add up quickly.

CARB In-Use Locomotive Regulation Points of Discussion: Presented below are a few examples of details that need to be sorted between CARB and the railroads operating locomotives in California.

Registration of locomotives:

Submittals to CARB are covered in §2478.15, which indicates that there is "a CARB reporting system implemented to assist with document submittals of this locomotive regulation. CARB is working on an online reporting system that will be live prior to the registration and reporting deadline. CARB has a payment portal, https://ww2.arb.ca.gov/carb-payment-options, and accepts credit cards (w/ fee), but can also take wire transfers, checks, money orders, and cashier's checks. CARB should expect on the order of 1000-5000 locomotive registrations by the end of July 1, 2026.

Assuming that on any given day, roughly 10 percent of locomotives operating on BNSF and UP are "foreign" locomotives (CN, CPKC, NS, CSX), this could likely mean BNSF and UP's locomotive registration requirements would include

100 to 500 "foreign" locomotives, for which they will be responsible for gathering the extensive list of information required during registration, that is likely not part of the UMLER system for locomotive interchange. For example, the locomotive serial number, the EPA engine family, the engine serial number, the last remanufacture date, and the EPA engine certification data (ECD) specifically for the engine family of that locomotive. The authors are not aware that this collection of information exists in any database on any railroad today. Gathering and reporting this information for thousands of locomotives will be a significant administrative effort and is complicated by the fact that information for a given locomotive will change over time. For example, if a UTEX engine is installed as part of a planned overhaul or because of an engine failure, the CARB registration database will need to be updated within 30-days of that locomotive's next trip into California.

Tracking Usage in California

CARB defines locomotive "usage" as tracking energy (MWh) using the equipped MWh meter, or if not equipped with a MWh meter – to use fuel consumption, both tracking operation while in California. For BNSF and UP, this quickly becomes a "back office" automated function, relying on GPS plus "geo fencing." However, there are several aspects of this that are problematic. First is the unanswered question of, "What MWh are we talking about?" The In-Use Locomotive Regulation allows locomotive usage to be determined by either MWh meter or fuel consumption. When using a MWh meter to determine the usage, the MWh meter is defined consistently with Code of Federal Regulations, Title 40, sections 1033.140(d) and 1033.115(h). That is, MWh used for usage should be consistent with the MWh used to determine useful life. Unfortunately, §1033.140(d) arguably allows either BHP or (net) traction HP to be used in the useful life.

MWh can be defined three ways; net-traction MWh, or traction MWh, or gross MWh. These three are broadly defined as:

Net-Traction MWh = energy consumed for traction (traction alternator output)

Traction (MWh) = energy input into the traction alternator (equals Traction MWh divided by the alternator efficiency)

Gross MWh = also known as brake power, is the power output of the engine at the flywheel, which for the locomotive is traction MWh plus all the various electrical and mechanically-driven auxiliary loads such as air compressor, cooling fans, etc.

Why does this matter? The difference between traction power and gross power over a typical duty-cycle is on the order of 8 percent, which for the estimated $800M annual total usage fees for BNSF or UP, could mean a +/- $64M difference.

Another challenge with usage tracking via MWh is that existing on-board MWh meters are notoriously incorrect. Not so much in their ability to track MWh's, but rather they are often reset with software updates or control system electronic board changes resulting in MWh (and distance traveled) readings that seem to "defy the time-space continuum." SwRI's 20-years of performing in-use emissions testing suggests that roughly 2/3 of locomotives tested have MWh totals that do not make sense.

Fuel consumption is given by CARB as an alternative method of calculating usage, along with conversion factors to calculate MWh from gallons used. Tracking fuel consumption for a given locomotive, overlaid with only the consumption in California, may be a significant challenge for interstate locomotives, with most existing locomotive fuel level gauges and monitoring systems likely being inadequate for meaningful and accurate reporting to CARB.

Note the key point that the CARB regulations require the operator to track this information for any locomotive operated in California, starting January 1, 2025. The question becomes how are BNSF and UP going to track MWh for "foreign" locomotives operating on their trains in California?

Idle Reporting

The CARB In-Use Locomotive Regulation require reporting of any AESS equipped locomotive Idling event longer than 30-minutes when the locomotive is stationary, including where, when, for how long, and why. Conceptually, most AESS-equipped locomotives will have the individual components necessary to track this information (GPS, AESS system status, etc.) but will require software updates and remote downloads and database tracking of this information. Again, locomotive operators will be responsible for tracking and reporting this information for not only their own locomotives operating in California, but also "foreign" locomotives they operate within the State.

Conclusions

The CARB In-Use Locomotive Regulation is intended to accelerate the reduction of locomotive emissions in California. If EPA grants CARB's request for authorization of the regulation, and if CARB is successful in defending against the lawsuit by the AAR and the ASLRRA, the regulation will have a major impact on the locomotives operating in California.

Because locomotive operators in California are responsible for registering locomotives entering the state, and have obligations to track usage and Idling, this regulation could also impact the other Class 1 railroads in North America (CN, CPKC, CSX, and NS), in that those locomotives may need to be equipped to provide the operator the reporting data required by CARB.

Usage tracking (MWh or fuel consumption) is going to be a challenge, and it is not clear that the locomotive operators in California are or will be ready to track this information as required starting January 1, 2025. Railroad locomotive maintenance personnel should follow developments on these regulations closely.

Idle monitoring and reporting systems will need to work reliably to comply with the regulations. This also means that any AESS system maintenance issues will need to be addressed in a timely manner.

LMOA members should also expect an influx of new Tier 4 and "zero emission" locomotives, and need to plan on training, tooling, and maintenance support for these new locomotives.

Recommendations

"Know the law" and plan accordingly.

References

[1] "2012 Line-Haul Locomotive Emissions Inventory," Report published by the California Air Resources Board, Air Quality Planning and Science Division, Mobile Source Analysis Branch, February 2021 (July 2022 update

[2] CARB, Appendix G, CARB's 2022 In-Use Locomotive Emission Inventory: Regulation Proposal and Scenarios.

[3] Staff Report: Initial Statement of Reasons, Public Hearing to Consider Proposed In-Use Locomotive Regulation, November 17, 2022, Page 183.

T4 Locomotive Incentive Grant Funding

By:
Steven Fritz - Southwest Research Institute
Tom Mack – ZELTECH
Mark Duve, Higher Power Industries
Michael Cleveland - Peaker Services

Abstract

Several incentive grant funding programs currently support the transition from legacy locomotive fleets to T4 or "Zero Emission Locomotives." The recently implemented California Air Resources Board (CARB) In-Use Locomotive Regulation is expected to expedite this transition. This paper outlines various Federal and State incentive grant programs available as of mid-2024, focusing on typical grant requirements such as cost-share limitations, "Buy America" requirements, potential scrappage of legacy locomotives or at least their diesel engines, and administrative and cash-flow considerations. The aim is to equip LMOA members with insights into the considerations and risks associated with leveraging public incentive grant funding for locomotive replacements.

Background

The United States Environmental Protection Agency's (EPA) locomotive exhaust emission regulations were last updated in 2008, mandating Tier 4 emission standards for new locomotives beginning in 2015. Both the EPA and CARB expected a significant turnover from older locomotives to Tier 4 models. However, the adoption rate of Tier 4 locomotives has been lower than anticipated. This discrepancy is partly attributed to the success of locomotive modernization programs, such as the DC-to-AC conversion, which upgrades Tier 0 and Tier 1 locomotives while maintaining emission levels at Tier 1+.

Recognizing the slower-than-expected turnover to Tier 4 locomotives, both the EPA and CARB are actively addressing this issue. CARB, in particular, introduced the In-Use Locomotive Regulation (IULR) aimed at accelerating the replacement and cleanup of legacy locomotives. Figure 1 illustrates CARB's 2021 locomotive emissions inventory estimates, alongside their 2016 State Implementation Plan (SIP) locomotive inventory for the South Coast Air Basin. This graph highlights the initial projections of Tier 4 fleet replacement at 7 percent annually versus the actual replacement rate of less than 1 percent per year from 2016 to 2021.

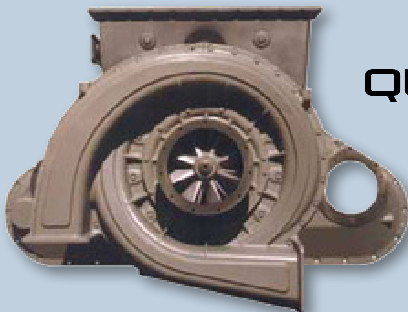
PRICE SERVICE DELIVERY QUALITY

PowerRail
570-883-7005
Sales@ePowerRail.com

POWERRAIL ENGINE SYSTEMS

CREATIVE INNOVATIONS...CONTINUING TRADITION

PowerRail, in partnership with Quality Turbocharger, proudly offers a complete line of New and UX, EMD and GE Turbochargers, as well as EPA emission equivalent replacements.



QUALITY TURBO

- Class I Approved
- Certified EPA Equivalent Compliant
- AAR Quality Parts
- Experienced Staff
- Technical Support
- Competitive Pricing
- Full Line of Support Products

AAR M-1003 CERTIFIED

www.ePowerRail.Com

This paper focuses on the "carrot" approach—various incentive opportunities aimed at promoting locomotive replacement to Tier 4. Conversely, the "stick" approach, represented by CARB's IULR, was previously detailed in a 2022 LMOA briefing and further discussed in a 2024 LMOA paper update.

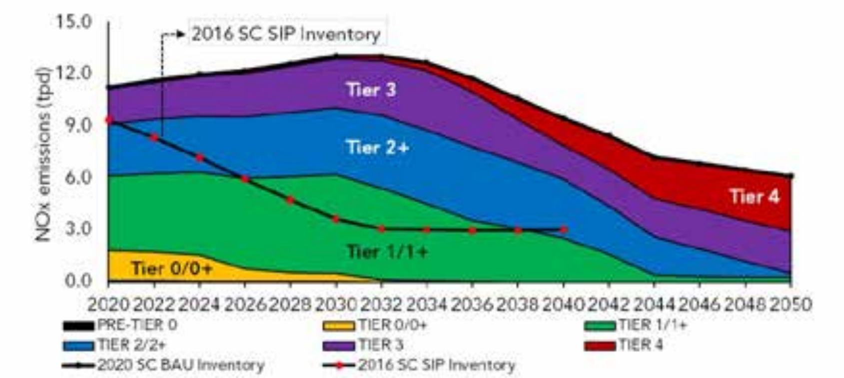


Figure 1. Comparison of CARB 2016 and 2020 Line Haul Locomotive NOx Emissions Inventory (tpd – tons per day) for the South Coast Air Basin

Factors Affecting Availability of Incentive Grants for Locomotive Upgrades

Legacy locomotives represent a substantial and cost-effective target for reducing NOx emissions, making locomotive emission reduction projects highly valuable within air quality programs. Compared to efforts targeting trucks, off-road equipment, or lighter vehicles, replacing a few locomotives can deliver significantly greater environmental benefits.

Federal, State, and NOx Mitigation Grant Programs

Numerous grant programs at the Federal, State, and regional levels incentivize the replacement of legacy locomotives with Tier 4 or Zero Emission (ZE) models. These programs aim to accelerate the adoption of cleaner technologies in the rail sector. However, accessing these grants entails navigating through complex administrative procedures, stringent reporting requirements, and often involves coordination among multiple stakeholders. Additionally, these grants may only be available at limited times during the calendar year and may not align to a railroad's purchasing calendar. These factors can contribute to extended project timelines and necessitate thorough preparation and strategic planning.

Examples of Grant Programs

1. **Federal Programs:**
    - **CRISI (Consolidated Rail Infrastructure and Safety Improvements)** by the Federal Railroad Administration (FRA): Supports capital projects that enhance safety, efficiency, and reliability of rail infrastructure.
    - **DERA (Diesel Emissions Reduction Act)** by the Environmental Protection Agency (EPA): Provides grants and rebates to reduce diesel emissions by upgrading or replacing older diesel engines.
    - **PIDP (Port Infrastructure Development Program)** by the U.S. Department of Transportation (DOT): Funds infrastructure projects that improve freight mobility and reduce congestion at U.S. ports.
    - **CMAQ (Congestion Mitigation and Air Quality Improvement Program**) by the U.S Department of Transportation to reduce emissions in areas that do not meet the National Ambient Air Quality standards.
2. **State Programs:**
    - **CARB (California Air Resources Board)**: Administers various programs including the Carl Moyer Program and Proposition 1B Goods Movement Emission Reduction Program, aimed at reducing emissions from goods movement activities.
    - **Texas – TCEQ/TERP (Texas Commission on Environmental Quality/ Texas Emissions Reduction Plan)**: Provides grants for projects that reduce emissions from eligible vehicles and equipment.
    - **VW Mitigation Funds**: Each state administers funds allocated under the Volkswagen Environmental Mitigation Trust, targeting emissions reductions from various sources including locomotives.

Selected Examples of Locomotive Replacement or Repowering Incentive Funding

Presented below are examples to illustrate the diversity and scope of incentive grants available for locomotive upgrades across different jurisdictions. Each program has specific eligibility criteria, funding limits, original equipment scrapping (scrappage requirements), and reporting requirements that must be carefully navigated to successfully secure and implement grant-funded projects.

- **CRISI**: Funds projects that improve safety, efficiency, and environmental performance of rail infrastructure, including locomotive upgrades.
- **DERA**: Supports projects that reduce diesel emissions through the replacement or repowering of older locomotives with cleaner technologies.
- **PIPD:** Supports projects in Ports, including electrification, replacements and retrofits, and infrastructure.

- **VW Mitigation Funds**: State-specific programs under the Volkswagen settlement aimed at mitigating excess NOx emissions, including funding for locomotive upgrades. Figure 5 gives an example for California.
- **Cummins-EPA Settlement:** Federal mitigation projects will focus on upgrading outdated locomotive engines with newer, cleaner technologies and implementing idle reduction measures.

These examples illustrate the diversity and scope of incentive grants available for locomotive upgrades across different jurisdictions. Each program has specific eligibility criteria, funding limits, original equipment scrapping (scrappage requirements), and reporting requirements that must be carefully navigated to successfully secure and implement grant-funded projects.

CRISI Program Overview*

- Department Goals
  - Safety.
  - Equitable economic strength and improving core assets.
  - Equity and barriers to opportunity.
  - Climate change and sustainability.
  - Transformation of our nation's transportation infrastructure.

- FY22 CRISI Grant
  - The total funding available for awards under 2022 NOFO was $1.4B.
  - Future NOFOs may vary between $1-2B.
  - 50% minimum up to 80% federal match.

- Eligible Applicants
  - Amtrak or other intercity rail carrier.
  - Class II or III railroads and associations that represent a Class II or III railroad.
  - Any rail carrier or equipment manufacturer in partnership with at least one state entity, public agency, and/or local government.

- Eligible Project Criteria
  - Rehab or procurement of locomotives provided that such activities result in a significant reduction of emissions.
  - A Non-Tiered, Tier 0, or Tier 1 locomotive to at least the Tier 2 level.
  - A Tier 2 locomotive to at least a Tier 4 level.
  - Or any locomotive to an all-electric, renewable diesel, battery-powered, or other renewable energy locomotive.

DERA Program Overview*

- *FY23-24 DERA Grant*
    - $22.2M per 10 EPA regions.
    - Share ranges from 25-40% on average.
    - Prioritizes projects in non-attainment zones.

- *Eligible Applicants*
    - Regional, State, Tribal agencies, or port authorities with jurisdiction over air quality.
    - Nonprofit organizations or institutions that provide pollution reduction or education.
    - School districts, municipalities, MPOs, cities, counties.

- *Eligible Project Criteria*
    - Vehicle replacements.
    - Engine replacements.
    - Verified exhaust retrofits (e.g. DPFs).
    - Verified idle reduction technologies (e.g. fuel heaters).

- *Eligible Segments*
    - School buses.
    - Class 5-8 heavy duty highway vehicles.
    - Locomotive engines.
    - Marine engines.
    - Nonroad engines, equipment or vehicles used in construction, handling of cargo (including at ports or airports), agriculture, mining or energy production (including stationary generators and pumps).

PIPD Program Overview*

- *FY '24 PIDP Grant*
    - $450M in FY 24.
    - Minimum grant award is $1M.
    - Small ports projects <$11.25M.
    - Up to 80% Match.

- *Eligible Applicants*
    - Port authority.
    - State or political subdivision.
    - Industry with lead entity from above.

- *Eligible Project Criteria*
    - Loading and unloading of goods at the port.
    - Movement of goods into, out of, around, or within (includes highway, rail, intermodal, freight transportation systems and digital infrastructure systems.)
    - Operational improvements:
        - Environmental and emissions mitigation measures
        - Electrification
        - Replacements & Retrofits
        - Purchase of new equipment
        - Training
        - Infrastructure

*Information provided courtesy of Cummins' business development

CMAQ Program Overview

FY 2024 Funding $2.639B
Grant Award: Varies per project.
Share of Funding: 50% to 80%

The Congestion Mitigation and Air Quality Improvement Program (CMAQ) provides funding to State and local governments for transportation projects and programs to help meet the requirements of the Clean Air Act. Funding is available to reduce congestion and improve air quality for areas that do not meet the National Ambient Air Quality Standards for ozone, carbon monoxide, or particulate matter (nonattainment areas) and for former nonattainment areas that are now in compliance (maintenance areas).

The states, local governments, or Metropolitan Planning Organization (MPO) determine how the funding is used to reduce air emissions in their regions and then use the CMAQ funding to create a local funding program to award the funds for emissions reduction programs that will meet their emissions reduction goals. Generally, CMAQ funded programs are found in most major densely populated metropolitan areas or areas where air pollution standards are not being met. Each program has its own rules and terms for using the funding.

The emissions reduction projects funded through the CMAQ program must comply with the terms of the CMAQ program as well as the terms provided by the state or local government that awards the funds.

Mitigation - VW

In 2016, the US Environmental Protection Agency (EPA) settled a civil enforcement case against Volkswagen AG (VW) and its affiliates. The case alleged that VW violated the Clean Air Act by equipping approximately 590,000 model year 2009 to 2016 diesel motor vehicles with "defeat devices."

As part of the settlement, VW was required to establish a $2.7 billion mitigation trust fund. The purpose of this fund is to mitigate the excess NOx emissions caused by the affected VW vehicles. Specifically, the VW Environmental Mitigation Trust for California allocates approximately $55 million to support statewide combustion freight and marine projects. Figure 2 highlights these projects aim to replace or repower equipment using the cleanest commercially available internal combustion, hybrid, or zero emission technologies.

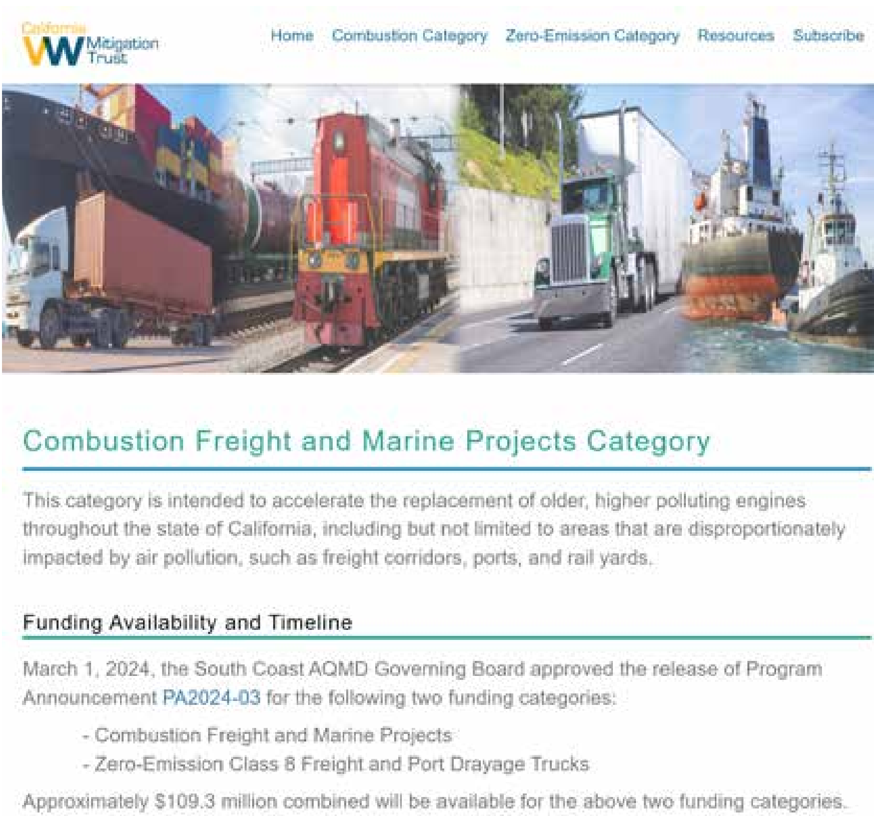


Figure 2. VW Mitigation Trust in California

Figure 3 illustrates the distribution of VW Mitigation Trust funding totaling $109.3 million allocated for freight projects across California. The top portion of Figure 3 specifically details funding allocation between government-owned and non-government-owned equipment.

An example of government-owned locomotives includes passenger locomotives operated by the Southern California Regional Rail Authority (SCRRA), known as Metrolink. For non-governmental freight and switcher locomotives, which currently operate under Tier 3 emission standards or lower, the funding allows for repowering or replacement with Tier 4 (T4) or Zero Emission (ZE) technologies, with a maximum grant amount of $1.62 million per locomotive.

It's important to note that these grants typically do not cover the entire project cost. With a maximum grant of $1.62 million per locomotive, this represents a substantial cost share, potentially around 50% of the total cost for a Tier 4 repower project. The question arises whether this level of funding is sufficient to incentivize and accelerate these projects forward.

Government Owned Project Eligibility and Funding

Baseline Equipment Category	Baseline Technology	Replacement Technology	Project Type	Maximum Funding Up To
Class 7 and Class 8 Freight Trucks, Dump Trucks, Waste Haulers, and Concrete Mixers	Engine Model Years 1992-2012	Low NOx (certified 0.02 g/bhp-hr)	Replacement	$102,000
			Repower	$60,000
Freight Switcher Locomotives	Uncontrolled and Tiers 0-3	Tier 4 and Zero-Emission	Replacement	$1,620,000
			Repower	
Ferries, tugboats, & towboats	Uncontrolled and Tiers 0-2	Tier 4, or Hybrid w/ Tier 4 equivalent NOx emissions	Repower Only	$1,200,000

Non-Government Owned Project Eligibility and Funding

Baseline Equipment Category	Baseline Technology	Replacement Technology	Project Type	Maximum Percentage (%) of Funding (of cost)	Maximum Funding Up To
Class 7 and Class 8 Freight Trucks, Dump Trucks, Waste Haulers, and Concrete Mixers	Engine Model Years 1992-2012	Low NOx (certified 0.02 g/bhp-hr)	Replacement	25%	$102,000
			Repower	40%	$60,000
Freight Switcher Locomotives	Uncontrolled and Tiers 0-3	Tier 4	Replacement	25%	$1,620,000
			Repower	40%	
		Zero-Emission	Replacement and Repower	75%	
Ferries, tugboats, & towboats	Uncontrolled and Tiers 0-2	Tier 4, or Hybrid w/ Tier 4 equivalent NOx emissions	Repower Only	40%	$1,200,000

Figure 3. Details of the VW Mitigation Trust in California for Locomotive Repower or Replacement

Mitigation – Cummins-EPA Settlement

On January 10, 2024, the US EPA, US Department of Justice, and the State of California announced a landmark settlement agreement with Cummins Inc. for violations of vehicle emissions control regulations under the Clean Air Act. As part of the agreement, Cummins will pay a record $1.675 billion civil penalty, the largest in Clean Air Act history and the second largest environmental penalty ever imposed. Additionally, Cummins will fund federal and California emission mitigation projects and a recall program for affected vehicles, totaling over $326 million.

The federal mitigation projects will focus on upgrading outdated locomotive engines with newer, cleaner technologies and implementing idle reduction measures. Cummins will target locomotive engines nationwide that predate EPA emissions regulations or comply with earlier standards, replacing them with engines certified to current emission standards. Additionally, idle reduction technology will be installed on selected yard switch engines.

Specifically, the project includes:

- Repowering 14 “road switch” locomotive engines
- Repowering 13 “yard switch” locomotive engines
- Installing idle reduction technology on 50 “yard switch” engines These initiatives are estimated to cost nearly $70 million.

All repowered locomotives must use prime movers certified to Tier 4 emission standards or stricter and must not incorporate any emission-defeating or altering devices. Cummins has the flexibility to use its own diesel engines or engines from other manufacturers, provided they meet the consent decree requirements. For road locomotives, Cummins may utilize its 2024 QSK50 Tier 4 certified engine or any 2025 Cummins engine meeting Tier 4 standards. For yard locomotives, the options include the 2024 QST30 Tier 4 certified engine or equivalent 2025 Cummins engines. Cummins’ repower strategy is initially focused on yard switchers and will begin to include road switchers in 2025.

Old prime movers removed from the selected locomotives must be rendered inoperable and incapable of future use.

In addition to locomotive repowers, Cummins is mandated to install idle reduction equipment on an additional 50 switching locomotives. The consent decree specifies several acceptable types of idle reduction technology, such as automatic start/stop systems, battery-powered auxiliary units, fuel-fired or electric coolant systems, or wayside power solutions (shore power) to substitute engine operation.

Furthermore, the settlement requires Cummins to assess the feasibility of converting one or more locomotives from diesel to full electric power. While specific implementation details are not outlined, a likely approach would involve a diesel-to-battery-powered conversion project.

Grant Structure

Understanding the contractual relationships in a grant program is crucial for all parties involved to comprehend their respective roles and responsibilities:

1. **Funding Agency**: This entity (such as DOT, EPA, FRA, CARB, etc.) provides the funds. They establish program requirements, outline the application process, determine eligibility criteria, select awardees, and contract with the awardee to administer the funds.
2. **Awarding Agency:** Some grants are awarded at the local level such as by a Metropolitan Planning Organization (MPO) or a state EPA but funded through a federal government agency such as the EPA or DOT. In this case the awarding agency defines the application process, determines the award criteria, and selects the awardees. The Awarding agency may not administer the funds. Typically, a state agency that is aligned with a federal agency will administer the funds.
3. **Applicant/Awardee**: Often not the railroad or locomotive operator, this is typically a public agency, air quality district, or other eligible non-profit organization. The awardee collaborates with railroads, suppliers, and other stakeholders to develop the grant application and manage the program. They serve as the primary liaison with the funding agency during program administration.
4. **Railroad/Operator**: The recipient of the funds who operates the locomotive. They are responsible for meeting grant requirements, including compliance and reporting.
5. **Supplier**: This entity provides the technology or locomotive equipment specified in the program. They are contracted by the awardee or railroad/operator.
6. **Infrastructure Contractors**: If infrastructure (e.g., electrical, construction) is necessary for the program, the railroad/operator may engage construction firms to provide these services.
7. **Consultants**: The railroad/operator may hire consultants to oversee grant administration, coordinate between grant partners, and ensure compliance with grant requirements.

Given the complexity and number of parties involved in these programs, contract management is critical. The contracting process is often lengthy and multi-layered due to the involvement of multiple stakeholders. Typically, the funding agency contracts directly with the awardee, who then contracts with the railroad/operator. The railroad/operator, in turn, engages with suppliers, contractors, and consultants to execute the project.

It's essential to ensure that grant requirements are clearly communicated and consistently implemented throughout all layers of these agreements.

Grant Considerations: There are "Strings Attached"

Federal incentive grant programs are typically tied to fiscal year funding cycles, with specific announcements and application timeline windows. It is essential for a designated person within the railroad to actively seek out and identify these grant funding opportunities. This responsibility often falls to government relations staff within the railroad or third-party consulting firms specializing in grant applications. Despite grant application periods lasting one or more months, significant time and coordination are required to assemble a project team and submit all required application elements. Therefore, advanced preparation with a pre-planned project aligned to a specific grant program is advisable, rather than scrambling to fit a project to a funding announcement.

Grant Application Process

Federal, State and local grant applications can be extensive, often spanning hundreds of pages, which can be daunting for first-time applicants. From the opening of a grant application to the final award, contract negotiation, and receipt of a Notice to Proceed, the process can easily span over a year. For locomotive grant applications, reporting annual fuel consumption of candidate locomotives slated for replacement is typically required. The Fuel Consumption Calculator provided by the Federal Railroad Administration (FRA) is commonly used for this purpose. Compared to the EPA Diesel Emissions Quantifier (DEQ), which was found unsatisfactory for single locomotive emission estimation in a 2023 Locomotive Maintenance Officers Association (LMOA) paper, the FRA calculator's annual fuel consumption-based approach is deemed more effective for estimating emissions. Grant applications often prioritize emissions reduction cost-effectiveness, necessitating the use of a standardized emissions estimation method across competing applications.

All of the grants are reimbursement grants where the awardee must spend the money on the project and then either a milestone is met, or the project is complete the awardee will be reimbursed. Detailed budget breakdowns are mandatory in grant applications, outlining project milestones and associated reporting requirements. Milestones typically correspond to invoicing triggers for reimbursement requests, necessitating meticulous documentation including receipts and invoices from suppliers. Payment processing following reimbursement requests can take weeks to months, sometimes only upon completion and acceptance of the locomotive by the railroad. Cost overruns and unused funds are generally non-reimbursable, highlighting the critical need for accuracy during the application stage.

Following the closure of the grant application window, the funding agency requires several months to evaluate applications and notify awardees. Subsequent contract negotiations between the funding entity and the railroad can extend over several additional months. Work on the project cannot commence until contract negotiations are finalized and the railroad receives a Notice to Proceed. Typically, grants cannot be awarded for projects already underway or for materials already purchased.

Reporting Requirements and Other Considerations

Grant applications outline reporting requirements extending beyond the commissioning of new locomotives, often including mandates for documenting the disposal of replaced locomotives (scrappage requirements) and reporting annual fuel consumption or Megawatt-hours over multiple years.

Additional Funding Considerations

- Buy America Requirements: Grant programs often enforce Buy America provisions, restricting the use of foreign materials in project components to a minimal percentage. Note there are different variations of Buy America requirements depending on the funding agency (i.e. FRA, FTA, DOT etc.). As such, compliance with these requirements can be quite involved down to the level of the source of the steel, component vs assembly location, and more. It is recommended to keep a good log of the source of materials as much as possible to aid in responding to these requirements. As most engine manufacturers globally source components, there are very few engines that can comply with the Buy America regulations. In this case, there is a waiver program if the Buy America requirements cannot be met. However, the waiver program still requires stating the amount of American made components and the process can take a year or more.
- Cost Share Requirements: Grants may require a percentage cost share from the recipient (railroad/operator), which can include both cash contributions and in-kind contributions such as services or equipment. There are often limits on the portion of in-kind contributions to ensure that all parties have a financial stake in the project. These cost share requirements are often stated as a percentage of funding agency contribution (50%, 75%, or 80% typically) up to a per project or per locomotive cap.
- Geographic Limitations: Most grants restrict the use of funded locomotives to specific geographic locations or areas for a defined period (e.g., 10 years).
- In-Use Reporting: Some government agencies require in use reporting of the MW hours accumulated yearly on the converted locomotives or annual fuel usage during the expected lifetime of the converted locomotives. The locomotive owner will have some annual administration work.

Risks

- Supplier Reliability: Concerns may arise regarding the long-term reliability of locomotive builders or retrofit/repower providers outside the typical Class 1 supply chain.
- Service Network and Technology Support: Evaluating the existing service network and ongoing support for new technologies, especially those lacking Reliability Growth Testing (RGT) in North American Class 1 railroad applications.
- Maintenance and Training: Anticipating increased maintenance costs, training requirements, part replacement frequency, and specialized tooling needs for new technologies.
- Infrastructure Compatibility: Considerations for non-locomotive engine lubricating oil requirements and infrastructure adjustments.

Conclusions

The CARB IULR represents a critical initiative aimed at accelerating the reduction of locomotive emissions across California. These regulations, alongside incentive grant programs, play a pivotal role in achieving substantial environmental improvements in the state. While awaiting final EPA authorization, if the IULR is supported by EPA, several other states will no doubt look to adopt the California IULR as well.

Awareness of grant opportunities is crucial for stakeholders involved in locomotive operations and emissions reduction initiatives. Understanding application timelines, the duration from application to award, and the comprehensive reporting requirements post-award are essential considerations. Successful implementation of these grants requires proactive planning and coordination among stakeholders, including government agencies, railroads, suppliers, and consultants.

Efforts to transition to cleaner locomotive technologies are not only driven by regulatory mandates but also by financial incentives provided through grant programs. These incentives aim to mitigate the costs associated with upgrading or replacing locomotives to meet stringent emission standards.

In conclusion, while the CARB IULR sets ambitious targets for emission reductions, effective utilization of incentive grants is imperative to realize these goals efficiently. Stakeholders must remain vigilant in navigating grant processes, ensuring compliance with requirements, and optimizing environmental benefits through strategic project planning and execution.

Recommendations

1. **Maintain Awareness of Incentive Grant Opportunities**: Original Equipment Manufacturers (OEMs) and railroad operators should stay proactive in monitoring and pursuing available incentive grant programs. This involves consistently tracking funding announcements, application timelines, and updates on regulatory requirements. Establishing a dedicated team or engaging third-party consultants with expertise in grant application processes can enhance responsiveness and maximize the likelihood of securing funding.
2. **Understand Grant Requirements and Conditions**: It is crucial for organizations to thoroughly comprehend the stipulations and obligations associated with incentive grants. These grants often come with specific terms regarding project timelines, emission reduction targets, reporting responsibilities, and financial contributions (cost-sharing). By fully understanding these "strings attached," OEMs and railroads can align project planning and implementation to meet grant criteria effectively.
3. **Strategic Project Planning and Alignment**: Prioritize pre-planning and alignment of desirable projects with available grant programs. Rather than reacting to funding announcements, proactively identify projects that align with both operational goals and grant eligibility criteria. This approach not only enhances the competitiveness of grant applications but also streamlines project execution by anticipating and mitigating potential challenges.
4. **Build Collaborative Partnerships**: Foster collaborative partnerships with stakeholders across the industry, including suppliers, consultants, and regulatory bodies. Effective partnerships can facilitate knowledge-sharing, leverage expertise, and strengthen project proposals. Engaging in industry networks and associations can provide valuable insights into emerging grant opportunities and best practices in emissions reduction technologies.
5. **Continuous Improvement and Adaptation**: Given the evolving nature of regulatory frameworks and technological advancements, OEMs and railroads should prioritize continuous improvement and adaptation. Stay informed about updates in emission standards, technological innovations, and best practices in emissions mitigation. This proactive approach not only ensures compliance with current regulations but also positions organizations to capitalize on future grant opportunities and maintain competitive advantage.
6. **Invest in Training and Capacity Building**: Equip internal teams with the necessary skills and knowledge to navigate complex grant application processes and manage grant-funded projects effectively. Training programs focused on grant compliance, project management, and environmental stewardship can enhance organizational readiness and performance in securing and executing incentive grants.

Biofuels and Low Temperature Properties

By:
Suzanne Golisz (Innospec)
Stephanie Jaworski (Imperial Oil)
and Vu Tran (Infineum)

Overview

Biofuels are expected to become a larger portion of the diesel fuel market as railroads strive to meet GHG emission reduction targets. The availability of biofuels is expected to increase over the next few years. As this transition occurs, it is important to understand the various aspects of biofuel production and low temperature properties of the fuel. This information will help railroads minimize the possible negative effects to their operations when using higher blends of biofuels.

US production capacity

The two common biofuels that can be blended with diesel fuel for use in compression ignition engines are biodiesel and renewable diesel. Biodiesel represents an immediate opportunity due to currently available supply while renewable diesel represents a medium to long term opportunity (2-8 years). One key aspect of these fuels is that they can rely on the same feedstock; therefore, feedstock availability may limit the total amount of either biodiesel or renewable diesel available in the market. Note that sustainable aviation fuel (SAF) is also derived from these same feedstocks. Recent analysis of production capacity in the United States showed that in 2023, renewable diesel production (3 billion gallon/year) exceeded biodiesel production (2.1 billion gallon/year).[1] Where renewable diesel has seen a threefold increase in production capacity between 2021-2023, biodiesel has seen a 13% decrease in that same period. The amount of renewable diesel is expected to grow over the next decade as production facilities are built or retrofitted in the US.[2] Recent estimates from the US Energy Information Administration (EIA) indicated that renewable diesel production could more than double from 2023 to 2025 if all planned facilities come on-line. This would lead to 5.9 billion gallon/year or 384,000 barrels/day production capacity in the US, the equivalent of one medium to large petroleum refinery.[2] Assuming that biodiesel production remains constant, then there would be more than 8 billion gallon/year of biofuels available for blending into the diesel fuel market in the near future.

Biodiesel and renewable diesel explained

Biodiesel (B100, FAME, BD) is a specific class of molecules (fatty acid methyl esters, FAME) that differs from petroleum diesel, whereas renewable diesel is a paraffinic hydrocarbon that represents a subset of the molecules found in petroleum diesel. Renewable diesel is known by different names throughout the world with the following being the most common: R100, Hydrogenation-Derived Renewable Diesel (HDRD), Hydrotreated Vegetable Oil (HVO), and RD. The features of both biodiesel and renewable diesel are described in Figure 1. Both biodiesel and renewable diesel can require the same feedstock which can be combinations of vegetable oil (e.g. soybean oil, canola oil, palm oil, etc.), animal fats (e.g., poultry fat, tallow, etc.), and waste cooking oil. The process for biodiesel production is transesterification using a basic catalyst and methanol whereas the renewable diesel production process is more similar to traditional petroleum refining which includes hydrogenation and isomerization. The cost of biodiesel and renewable diesel varies across North America, influenced by provincial, state and federal policies, as well as supply and transportation. Biodiesel on average tends to be at parity or slightly less than petroleum diesel as opposed to renewable diesel which on average is significantly more expensive. The fuel efficiency of both fuels is lower compared to petroleum diesel due to the difference in volumetric energy density of the various fuels. From a constituent emissions perspective, the change in NOx, particulate matter, and tailpipe CO_2 is mixed for biodiesel. Across the board, renewable diesel provides constituent emissions reductions when compared to petroleum diesel. While both fuels can provide a benefit to the railroads with respect to GHG emission reduction targets, there are differences in the low temperature properties of biofuels as compared to petroleum diesel which need to be understood prior to using and/or blending these fuels.

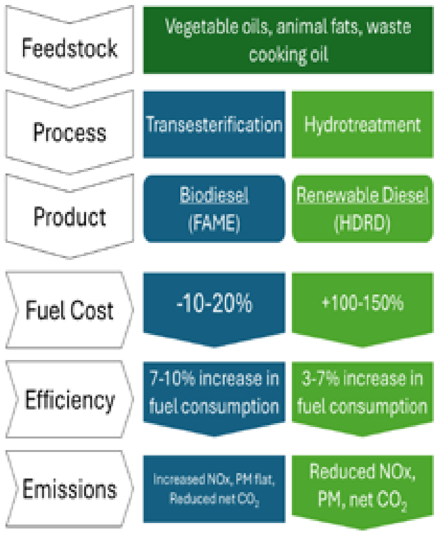


Figure 1. A visual representation of the various aspects of biodiesel and renewable diesel. Figure courtesy of Terry Degerness, CPKC Railroad.

Low temperature properties

Low temperature operability of diesel fuels can be determined in several ways using industry standard tests. This section will define the test methods and cover the approaches used in the United States and Canada.

Definitions

Cloud point (CP) defines the temperature at which the smallest observable cluster of crystals first appears in a fuel upon cooling under prescribed test conditions. It directionally relates to the temperature at which these crystals begin to precipitate and can plug fuel filters. Fuels are generally expected to operate at temperatures as low as their cloud point. Cloud Point is the most common measure of low-temperature operability. It is also the most conservative. Test methods used include ASTM D2500, D5771, D5772, D5573, D7683 or D7689.

Pour point (PP) is the temperature at which a fuel contains so many clusters of crystals that it becomes gel-like and will no longer flow. Pour point is not used to define low-temperature operability. Pour point may be used by fuel distributors as an indicator of the pumpability of the fuel through distribution systems. Pour point test methods are ASTM D97, D5949 or D5950.

The cold filter plugging point (CFPP) is the temperature, under conditions as defined in ASTM D6371, at which a specific fuel filter plugs. This test employs rapid cooling conditions and is intended to represent the performance of a typical light duty vehicle. It is recommended that CFPP results more than 10 °C below the cloud point be viewed with suspicion because field tests have shown those results do not necessarily reflect the true vehicle low temperature operability.

The low-temperature flow test (LTFT), as described in ASTM D4539, also defines a temperature at which a specific fuel filter plugs; however, this test employs slow cooling process and is considered more representative of the more severe fuel systems found in North American heavy-duty trucks. LTFT was developed to predict the low-temperature operability of fuels to which a cold flow improver (CFI) additive has been added. It is important to note that a cloud point test on CFI additized fuels might not accurately predict the operability limit of the fuel due to the use of these additives.

Low-temperature operability approaches

United States

The Standard Specification for Diesel Fuel for the United States is ASTM D975. This specification covers seven grades of diesel fuel, however for the purposes of this paper we will limit the discussion to the grade commonly used in locomotives in the United States: Grade No. 2-D S15, commonly referred to as Number 2 Diesel, and to a lesser degree Grade 1-D S15, commonly referred to as Number 1 Diesel or "Kerosene". These grades can contain up to 5% biodiesel, denoted as B5.

The specification for petroleum diesel containing biodiesel blends from 6% to 20% is ASTM D7467.

Renewable diesel may be present in any concentration in ASTM D975 or D7467.

D975 does not require a specific low-temperature operability requirement. In fact, D975 contains commentary that it is "unrealistic to specify low temperature properties that will ensure satisfactory operation at all ambient conditions." ASTM D975 only requires that the maximum Cloud Point or LTFT or CFPP value be reported.

Rather, D975 suggests that specific properties and values be agreed upon between the fuel supplier and purchaser. D975 suggests that Cloud Point (ASTM D2500), Low Temperature Flow Test (LTFT) (ASTM D4539) or Cold Filter Plugging Point Test (CFPP) (ASTM D6371) be used as an estimate of operating temperature limits, with D4539 and D6371 recommended on fuels where flow improvers are used.

Appendix X5 in D975 includes tenth (10th) percentile minimum monthly air temperatures for U.S. locations that can be used for estimating required temperatures based on expected ambient temperatures.

The tenth percentile minimum ambient air temperature is defined as the lowest ambient air temperature which will not go lower on average more than 10% of the time.

D7467 (B6 to B20) recommends the same approach to low-temperature operability as D975.

Canada

Diesel fuel in Canada is certified against Canadian General Standards Board (CGSB) specifications. There are currently three different specifications, depending on the biodiesel content of the fuel, although discussions are on-going regarding the merger of 3.517 with 3.520:

- CAN/CGSB 3.517 (<1% FAME) - https://publications.gc.ca/pub?id=9.884942&sl=0
- CAN/CGSB 3.520 (1% to 5% FAME) - https://publications.gc.ca/pub?id=9.884945&sl=0
- CAN/CGSB 3.522 (6% to 20% FAME) - https://publications.gc.ca/pub?id=9.884952&sl=0

Renewable diesel may be present in any concentration in these specifications.

CAN/CGSB 3.517 (<1% FAME) and 3.520 (1%-5% FAME) apply to two types of diesel – Type A and Type B

- Type A is commonly referred to as ULSDL or Diesel Light or Arctic Diesel. Type A is a lower cloud point material, and the cloud point varies by region but typically remains the same all year.
- Type B is commonly referred to as ULSD or Diesel or Seasonal Diesel. Type B cloud point requirements vary by region and by time of year. Type B is similar to ASTM D975 Grade No. 2-D S15

CAN/CGSB 3.522 applies to Type B diesel only.

Per Canadian General Standards Board (CGSB) 3.517/3.520, low-temperature flow properties are designed to give satisfactory performance at the temperatures indicated by the 2.5% low-end design temperature data for the period and location of intended use.

The 2.5% low-end design temperature is the temperature at or below which 2.5% of the hourly outside air temperatures are observed to occur for an indicated half month for a specific region over a 30-year period (1991 to 2020). The weather dataset is available on the Canadian Fuels Association website (www.canadianfuels.ca)

Per CGSB, the test methods accepted to determine satisfactory performance are:

- Cloud point (ASTM D2500, D5771, D5772 or D5773). In the event of a dispute, ASTM D5773 is the referee method.
- Low-temperature flow test (LTFT) for diesel fuels (CAN/CGSB-3.0 No. 140.1 or ASTM D4539.) In the event of a dispute, CAN/CGSB-3.0 No. 140.1 is the referee method.

CGSB does not accept the Cold Filter Plugging Point (CFPP) test as, in their assessment, it does not correlate well with the operability of more demanding heavy-duty applications.

Low temperature properties of biofuels

The low temperature properties of biodiesel and renewable diesel can vary based on feedstock and/or process conditions. In general, the feedstock used for biodiesel production determines the low temperature properties whereas the process conditions for renewable diesel production have a greater impact than the feedstock for that fuel. For either fuel, there are a range of values for low temperature properties.

Biodiesel and low temperature properties

The low temperature properties for biodiesel produced with various feedstocks are reported in Table 1. The CP is the same or slightly higher than the PP for all the biodiesels tested, as expected. In general, the CFPP or LTFT should be similar to the CP for a fuel that does not contain any cold flow improver additive. The CFPP data reported in Table 1 is more similar to the PP than the CP. However, the reproducibility for the LTFT is 4 °C which can account for some of the differences. It must be noted that in the Kinast report, the data is labeled as both CFPP and LTFT where the method reported is ASTM D4539 (LTFT). For a fuel without cold flow improver additive, the CFPP and LTFT are likely very similar; however, the test methods are significantly different (see above). Overall, the low temperature properties of biodiesel are much higher than those of ULSD. This is expected considering the composition of the biodiesel where the fatty acid methyl esters behave like paraffins and olefins with respect to low temperature.

Table 1. The reported low temperature properties for biodiesel (fatty acid methyl ester) produced from various feedstocks.

Feedstock	Cloud Point (CP) ASTM D2500, °C (°F)	Pour Point (PP) ASTM D97, °C (°F)	Cold Filter Plugging Point (CFPP) ASTM D6371, °C (°F)	Low Temperature Flow Test (LTFT) ASTM D4539, °C (°F)[a]	Low Temperature Flow Test (LTFT) ASTM D4539, °C (°F)	Reference
Soybean	2 (36)	-1 (30)	-3 (27)	-2 (28)	0 (32)	3,4
Canola	-3 (27)	-4 (25)	-6 (21)	-4 (24)		3,4
Lard	14 (57)	11 (52)		11 (52)		3
Edible Tallow	20 (68)	13 (56)	10 (50)	14 (58)	19 (66)	3,4
Inedible Tallow	23 (73)	8 (46)		10 (50)		3
LFFA Yellow Grease[b]	42 (108)	12 (54)		11 (52)		3
HFFA Yellow Grease[c]	8 (46)	8 (46)	3 (37)	1 (34)		3
Palm	15 (59)	13 (55)	12 (54)			4
Mustard	4 (39)	-15 (5)				5
Peanut	2 (36)	1 (34)				5
Poultry Fat	7 (45)	1 (34)	5 (41)			6
Sunflower	5 (41)	-2 (28)	2 (36)			7
Cottonseed	6 (43)					8
Edible waste oil	13 (55)8	6 (43)				9
Chicken fat	10	3				9
Goat fat	8	2				9

a. In the text of the Kinast report, the ASTM D4539 test method is referred to as the cold filter plugging point (CFPP). The method for CFPP is ASTM D6371. The two methods are not equivalent. For a neat biodiesel with no cold flow improver additive, the LTFT or the CFPP should be very close to the CP.
b. LFFA = low free fatty acid
c. HFFA = high free fatty acid

Vegetable-based biodiesel (e.g., soybean and canola), in general, has reduced low temperature properties as compared to animal-based biodiesel. This finding is also related to the composition of the biodiesel. The fatty acid portion of the triglycerides in the feedstock for biodiesel production are different depending on the origin of the oil or fat. The data in Table 2 and Figure 2 shows the fatty acid distribution of biodiesel produced from various feedstocks. There are two clear trends: 1) vegetable-based feedstocks are primarily C18 and 2) animal-based feedstocks are more saturated. While the difference in carbon number is interesting, the difference in saturation is what accounts for the different low temperature properties. The saturated fatty acids act like n-paraffins in the fuel such that they solidify at higher temperatures than unsaturated fatty acids of the same carbon number. The higher amount of saturated fatty acids in animal-based biodiesel leads to the higher low temperature properties. Note that palm-derived biodiesel is more similar to animal-based biodiesel with respect to low temperature properties. This is a result of the high amount of saturated C16, palmitic acid, in palm oil.

Feedstock	Myristic $C_{14}H_{28}O_2$ C14:0	Palmitic $C_{16}H_{32}O_2$ C16:0	Palmitoleic $C_{16}H_{30}O_2$ C16:1	Stearic $C_{18}H_{36}O_2$ C18:0	Oleic $C_{18}H_{34}O_2$ C18:1	Linoleic $C_{18}H_{32}O_2$ C18:2	Linolenic $C_{18}H_{30}O_2$ C18:3	Arachidic $C_{20}H_{40}O_2$ C20:0	Reference
Soybean	0.09	10.54	0.13	3.75	23.18	48.92	1.16	0.24	3
Canola	0.07	5.25	0.22	2.46	58.09	21.79	0.41	1.04	3
Lard	1.86	14.49	1.80	14.39	38.32	13.44	0.33	0.45	3
Edible Tallow	2.91	24.34	3.44	19.10	40.23	2.58	0.33	0.29	3
Inedible Tallow	2.08	23.93	2.79	19.54	38.54	6.43	0.32	0.34	3
LFFA Yellow Grease	Trace	11.53	Trace	13.36	60.67	0.62	Trace	0.41	3
HFFA Yellow Grease	1.08	17.30	2.23	9.54	45.28	14.48	1.3	1.06	3
Palm	1.01	44.39	0.22	4.28	38.48	9.99	0.29	0.39	10
Poultry Fat	1.07	29.05	4.23	10.49	39.56	14.13	Trace	Trace	6
Sunflower	Trace	4.5	Trace	4.0	82.0	8.0	0.2	0.3	7
Cottonseed	4.27	32.55	4.32	5.93	24.42	25.40	n.r.	n.r.	8
Edible waste oil	0.77	31.88	n.r.	6.45	41.04	17.98	0.43	n.r.	9
Chicken fat	7.9	28.65	n.r.	6.93	43.13	12.51	0.01	n.r.	9
Goat fat	0.7	25.75	n.r.	5.58	43.16	12.98	0.71	n.r.	9

n.r. = not reported

Table 2. The fatty acid distribution of biodiesel produced from various feedstocks.

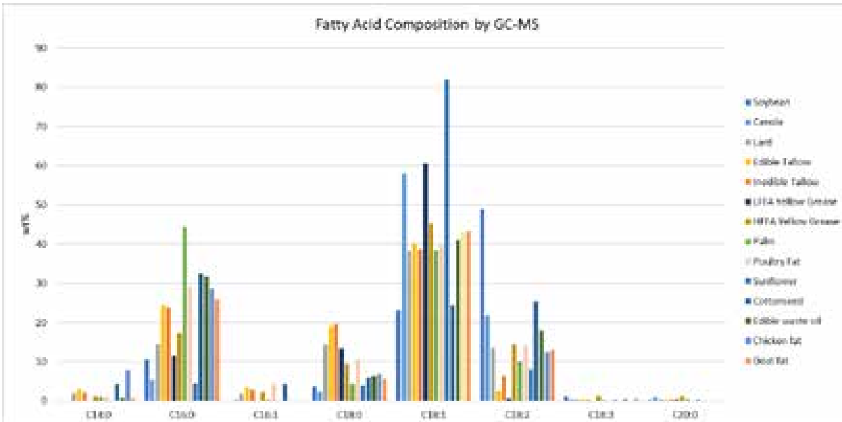


Figure 2. A graphical representation of the fatty acid distribution of biodiesel produced from various feedstocks.

While it is possible to get biodiesel from all these feedstocks, in practice, not all of these feedstocks are utilized to produce biodiesel in the US. The National Renewable Energy Laboratory (NREL) collects data from BQ9000-accredited biodiesel producers throughout the US each year.[11] The cloud point data for the year 2021 is shown in Figure 3. The distribution clearly shows that the most common cloud point is 0 °C (32 °F). This is consistent with the most common feedstock being soybean oil.

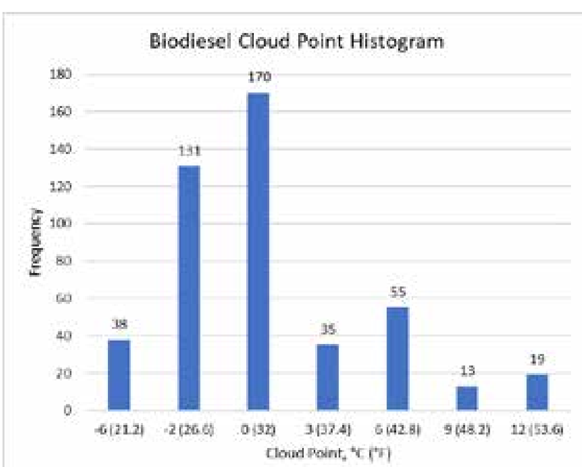


Figure 3. The histogram of CP distribution from BQ9000 producers.

Biodiesel-diesel blends and cold flow properties

Multiple studies have been completed to investigate the impact of blending biodiesel with petroleum diesel on various low temperature properties. Diesel of various sulfur levels has been used depending on the country and regulation in place at the time the experiments were completed. In limited testing, the sulfur level does not appear to impact the low temperature properties.[4]

Focusing on CP, Kinast found primarily linear behavior with vegetable-based biodiesel and non-linear behavior with lard-based biodiesel (See Figure 4).[3] Nearly linear behavior was found for poultry fat-derived biodiesel[6] and canola-derived biodiesel[13] blended with petroleum diesel when the CP of the petroleum diesel was higher than the Kinast study. For palm-based biodiesel, non-linear behavior was observed where the CP increased exponentially with small amounts of biodiesel in the blend.[8] At around 50 volume % biodiesel, the CP of the blend was the same as the CP of the biodiesel. These data clearly indicate that the CP of biodiesel-diesel blends can show near-linear or quite obviously non-linear behavior depending on the biodiesel and diesel used to make the blend. This is similar to what is observed for blends of different petroleum diesels. The starting CP of the biodiesel and the petroleum diesel can also influence the resulting CP of the blend. The variation in CP results is also related to changes in the solubility of the fuel matrix, as small changes in the overall solubility of the fuel can impact the temperature at which crystals become visible. To accurately predict CP of biodiesel and diesel blends, the sample must be tested or consistent supply of biodiesel and diesel should be used to create valid predictive models.

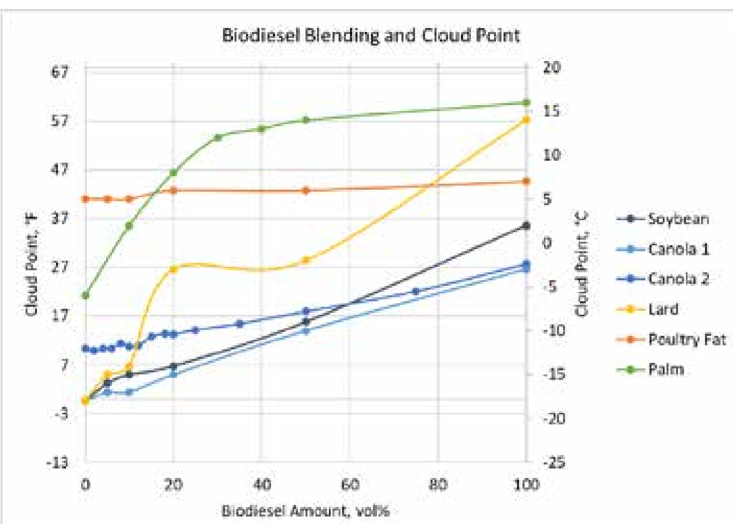


Figure 4. The measured CP for blends of various biodiesels with diesel.[3, 6, 8, 13]

Looking at the CFPP of biodiesel and diesel blends, almost none of these examples exhibited linear behavior (see Figure 5). There also did not appear to be any trend with respect to the feedstock used for the biodiesel production as both vegetable-based and animal-based biodiesels showed variable behavior. One of the more interesting results for CFPP came with a blend of rapeseed methyl ester (RME) and pork lard methyl ester (PME) in either summer diesel (high starting CP) or winter diesel (lower starting CP).[14] For the winter diesel blend, the CP increased exponentially with low amounts of biodiesel which eventually became more linear with higher amounts of biodiesel. For the blend with summer diesel, eutectic-like behavior was observed where the CP of B10 to B60 blends was lower than the initial CP of either the biodiesel or the diesel. (A eutectic is defined as a mixture of two constituents where the melting temperature of the mixture is lower than the melting temperature of the individual constituents.) This can be understood as an improvement in solubility of the fuel matrix such that the n-paraffin crystals remained in solution at higher temperatures.

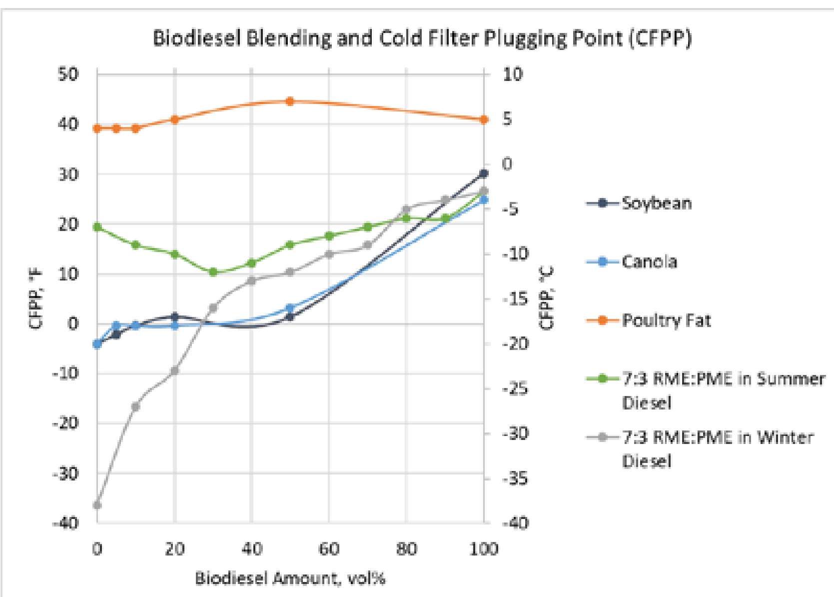


Figure 5. The measured CFPP for blends of various biodiesels with diesel.[3, 6, 14] For this graphic, RME = rapeseed methyl ester and PME = pork lard methyl ester.

For PP of biodiesel-diesel blends, the trends do not appear linear for any of the combinations (see Figure 6). Note that the PP test is reported at 3 °C intervals unlike the CP and CFPP tests which are reported at 1 °C intervals. This can influence the overall appearance of the curves. The biodiesel appears to have a larger impact on the PP of the blend at lower levels. Similar to CP and CFPP, the PP of the blend should be tested as the variation would make it hard to predict.

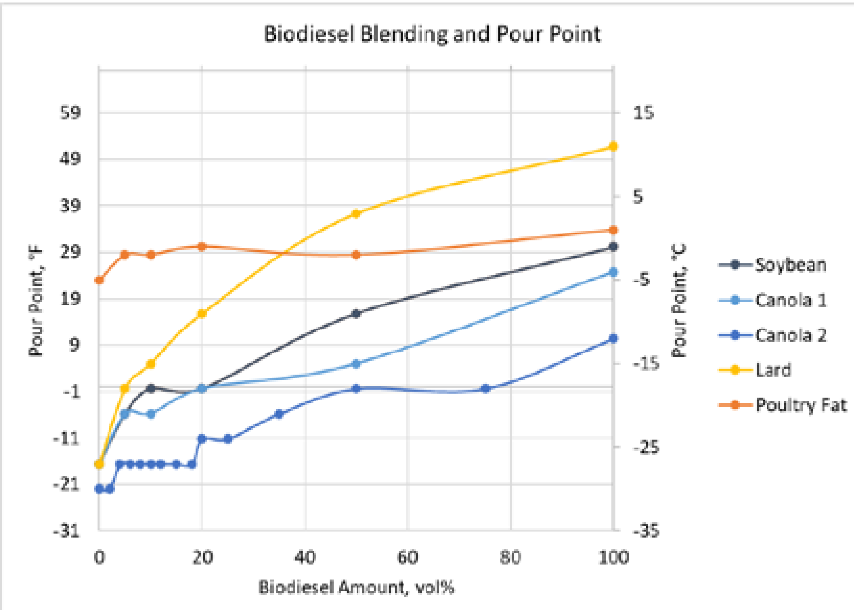


Figure 6. The measured PP for blends of various biodiesels with diesel.[3, 6, 13]

Although most of these results can be understood in the context of the solubility of the saturated fatty acid methyl esters, the n-paraffin like molecules in the biodiesel, there are other constituents in the biodiesel that can impact the cold flow properties. Tang et al. evaluated three different biodiesel types (soybean oil, cottonseed oil, and poultry fat) in ULSD to show that the CP, PP, and CFPP of the blends increase as the percentage of biodiesel increases in a non-linear fashion.[15] Further, they determined that the CFPP of the blend is more similar to the CP at low levels of biodiesel and more similar to the PP at higher levels of biodiesel. The same observation was found by Tang et al. when investigating blends of yellow grease and palm oil biodiesel also blended with ULSD.[16] Depending on the feedstock, the percentage of biodiesel required for the CFPP to converge with the PP changes. They attribute these differences to the constituents in the biodiesel other than fatty acid methyl esters that can form precipitates under low temperature conditions (see below). The cold soak filtration test (CSFT) was added to ASTM D6751, Standard Specification for Biodiesel Fuel Blend Stock (B100) for Middle Distillate Fuels, in order to address these issues.

The majority of the data presented on biodiesel relies on biodiesel produced from a single feedstock. In commerce today, most biodiesel production is no longer from a single-sourced feedstock. While it is possible to determine the feedstock using advanced analytical techniques, most purchasers will be unable to learn the blend concentrations of the different feedstocks utilized in the biodiesel.

Renewable diesel and low temperature properties

Renewable diesel has the potential for excellent low temperature properties. For example, renewable diesel produced by Neste can have a CP as low as -40 °C (-40 °F) which would be acceptable for use even in arctic climates.[17] However, in practice, the CP of renewable diesel is much higher and sometimes higher than petroleum diesel. Both CP and PP data for renewable diesel samples obtained in the US are shown in Figure 7.[18] At higher CP and PP values, these properties are almost identical to each other. This is in sharp contrast to petroleum diesel where there is typically a large difference between the CP and PP with CP being much higher than PP. For lower CP renewable diesel, there is a larger difference between the CP and PP where the PP can be up to 15 °C (30 °F) lower than the CP. These observations are important with respect to storage and handling of renewable diesel. Multiple events where renewable diesel has solidified in the storage tank have been reported. Because the PP is almost identical to the CP, the renewable diesel must be stored at temperatures above the CP to prevent gelling.

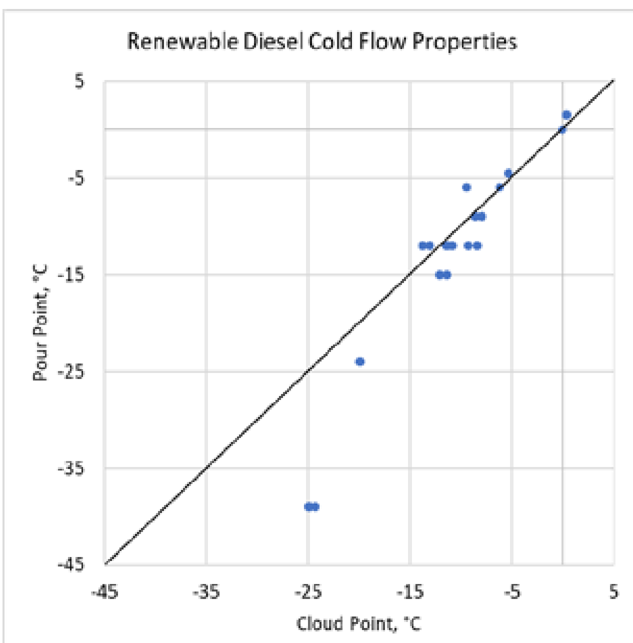


Figure 7. The CP and PP results for multiple renewable diesel samples.[18]

For biodiesel, the differences in CP and PP were related to the feedstock. For renewable diesel, the process conditions have a larger impact on the low temperature properties. In a report by Smagala et al. they performed detailed hydrocarbon analysis on renewable diesel samples to understand their composition.[19] The n-paraffin content in the samples ranged from 13 to 95 weight % (see Table 3). The CP ranged from -27 °C (-17 °F) to 24 °C (75 °F). The highest CP matched with the highest n-paraffin content. There was more variation with the n-paraffin and CP at the lower levels; however, a general trend of lower n-paraffin content and lower CP was observed. Lastly, the same CP was measured for renewable diesel made with vegetable oil or animal fat suggesting that the feedstock does not have a significant impact on the CP.

Table 3. The compositional analysis and low temperature properties of multiple renewable diesel samples prepared from different feedstocks and different process conditions.[19]

Description	CP, °C (°F) ASTM D2500	n-Paraffin, wt%	Sample
Hydroisomerized vegetable oil	-27 (-17)	14.2	A
Hydroisomerized algal oil	-19 (-2)	14.3	G
Hydroisomerized animal fat	-19 (-2)	24.2	E
Hydroisomerized camelina oil	-13 (9)	13.6	C
Hydroisomerized vegetable oil	-5 (23)	31.4	H
Hydroisomerized algal oil	-4 (25)	26.8	D
Hydrogentated animal fat, not isomerized	24 (75)	95.4	I

Building on the relationship between process conditions and low temperature properties, a group from the Czech Republic investigated how changing the reaction temperature impacted both the composition and the low temperature properties of sunflower oil-derived renewable diesel.[20] They found that increasing the reaction temperature decreased the amount of n-paraffins and the low temperature properties (see Table 4). These observations are similar to what Smagala et al. found.

Table 4. The low temperature properties of multiple renewable diesel samples prepared using different process conditions.[20]

Reaction Temperature	n-paraffins, wt%	Cloud Point (CP), °C (°F)	Pour Point (PP), °C (°F)	Cold Filter Plugging Point (CFPP), °C (°F)
360 °C	64.7	19 (66)	17 (63)	>15 (>59)
380 °C	40.0	18 (64)	11 (52)	11 (52)
400 °C	28.7	8 (46)	-7 (19)	-5 (23)
420 °C	19.8	-11 (12)	-18 (0)	-14 (7)

Renewable diesel-diesel blends and low temperature properties

Blending of renewable diesel with petroleum diesel is similar to the blends of biodiesel and petroleum diesel in that the low temperature properties are non-linear. The same study that looked at process conditions and fuel properties also investigated blends of renewable diesel with petroleum diesel.[20] In a report from a bus fleet trial in Helsinki, blends of two different renewable diesels were made with either summer grade diesel or winter grade diesel.[21] Both of the diesel samples in the bus trial were likely treated with cold flow improver (CFI) additive as suggested by the difference between the CP and CFPP results for the neat diesel. The data from these reports were combined in Figure 8 for the CP and Figure 9 for the CFPP. The CP (which is generally not impacted by CFI) shows non-linear behavior for all fuels where the blend with the winter diesel also shows eutectic formation. All fuels show non-linear behavior for the CFPP of the renewable diesel and petroleum diesel blends. In contrast to the CP where the winter diesel blends showed this phenomenon, the CFPP results for the blend with summer diesel is consistent with eutectic formation.

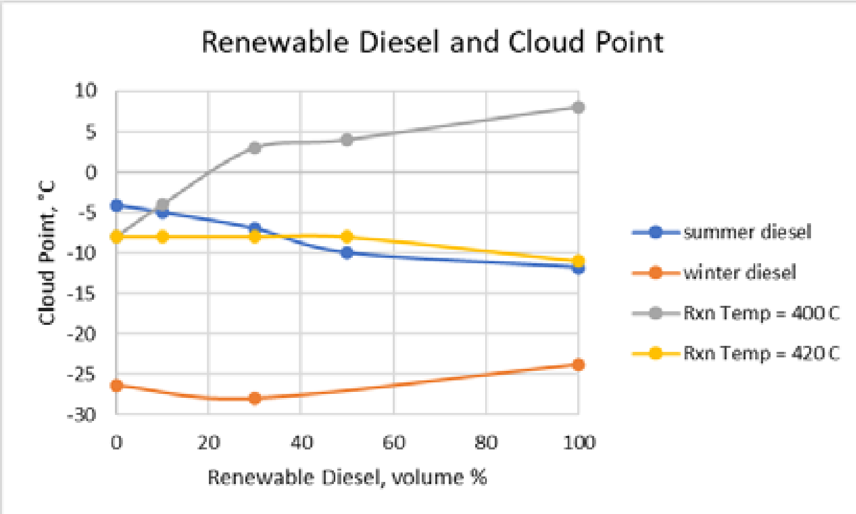


Figure 8. The CP results for blends of renewable diesel with diesel.[20, 21]

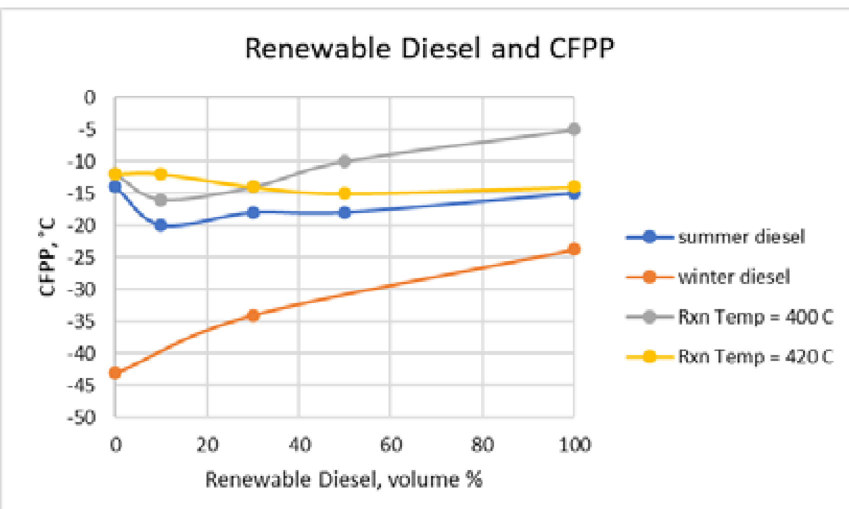


Figure 9. The CFPP results for blends of renewable diesel with diesel.[20, 21]

The formation of a eutectic when blending renewable diesel and petroleum diesel was confirmed by differential scanning calorimetry (DSC) testing.[22] Using DSC as the preferred method to determine whether a eutectic, a solution that has a melting point lower than its individual constituents, is present, blends of renewable diesel and petroleum diesel at various ratios were investigated. It was determined that the crystallization onset temperature of the blend was lower than the crystallization onset temperature of either the renewable diesel or the petroleum diesel when the renewable diesel blend percentage was between 10 and 70 volume %. These results again show the importance of testing the low temperature properties of any blends of renewable diesel with petroleum diesel.

Biodiesel and renewable diesel blends

While the blending of biodiesel and renewable diesel would exhibit the same unpredictable low temperature properties as the blends of either biodiesel or renewable diesel in petroleum diesel; there is an added concern with blends of biodiesel and renewable diesel. Due to the reduced solvency of renewable diesel (renewable diesel is primarily paraffinic which reduces the solvency compared to petroleum diesel), there exists the possibility that constituents of the biodiesel can form precipitate at temperatures above the CP.[17] This was also experienced in the early days of blending biodiesel in petroleum diesel.[23] More recently this has been reported with blends of 20 volume % biodiesel and 80 volume % renewable diesel.[24] Various additives are available to help improve the filterability of biodiesel blends that have precipitate at temperatures above the CP.

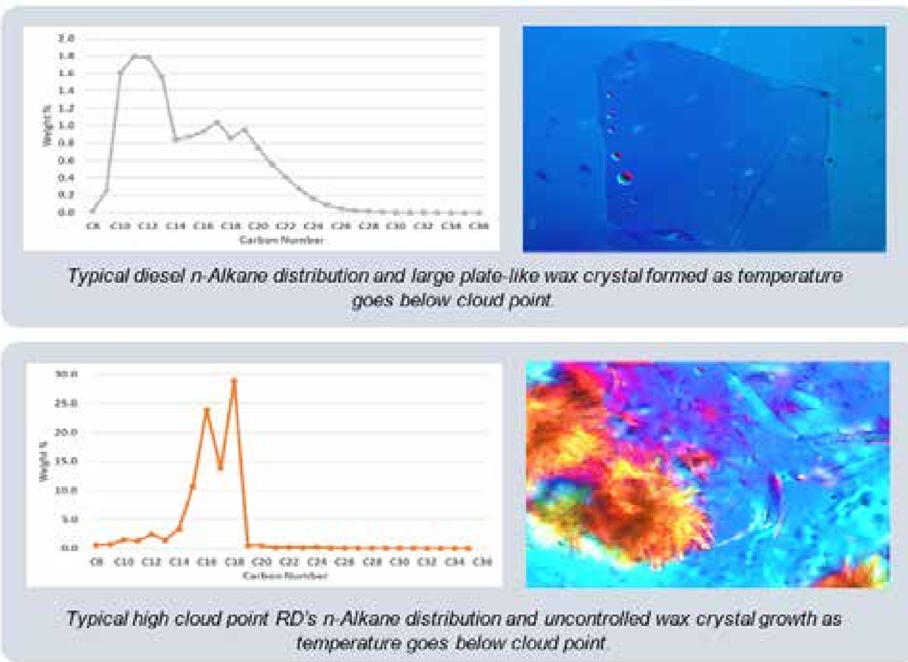
Strategies to use biofuels in low temperatures

Biodiesel (FAME) and Renewable Diesel (RD) are widely considered as alternative fuels to conventional diesel that can be used to reduce carbon intensity. Though these fuels are gaining popularity, their use in the pure form (100%) is limited. Often, they are being used as blend components with conventional diesel. The percentage at which these alternative fuels are used with conventional diesel depends on several factors such as engine design, ambient condition, cost, and fuel quality. When used in cold climate conditions, one should take into consideration the limitations of these alternative fuels. While the industry has more experience with using FAME, we will first discuss RD and then go on to discuss FAME as there are additional issues.

Considerations for using renewable diesel (RD)

Both renewable and conventional diesels contain n-paraffins. In conventional diesel, at low temperatures, these n-paraffins precipitate as thin rhombohedral plates. The point at which this starts to happen is known as the cloud point (CP). These wax crystal plates can block fuel filters very quickly leading to fuel starvation to the engine, consequently loss of power and/or stalling.

In contrast, RD contains larger numbers of n-paraffins that precipitate in a rapid and uncontrolled manner resulting in larger amounts of random shaped crystals which can also cause significant issues in terms of blocking fuel filters. In Figure 10, a broad distribution of n-paraffin found in conventional diesel is associated with slower wax crystal growth into flat plate-like structure. On the other hand, narrow n-alkane distribution of RD is associated with rapid and uncontrolled wax crystal growth into irregular-shape structures.



Typical diesel n-Alkane distribution and large plate-like wax crystal formed as temperature goes below cloud point.

Typical high cloud point RD's n-Alkane distribution and uncontrolled wax crystal growth as temperature goes below cloud point.

Figure 10. The n-paraffin distribution and wax formation of petroleum diesel (top) and renewable diesel (bottom).

The production of RD employs various feedstock oils in catalytic hydrotreating and isomerizing processes. Their final compositions, therefore, are different and highly dependent on the feedstock used and process conditions involved, which impact cold flow characteristics of final RD. Generally, higher degree of isomerization will reduce the cloud point of the fuel. Unfortunately, isomerization is an energy intensive process, and in addition, RD producers may not have the flexibility to adjust different levels of isomerization to accommodate different climate conditions. For example, North America is a vast region with extreme temperature variations from the warmth of Florida to the frigid condition of the Midwest. For a RD to handle such a wide range of temperatures, significant levels of isomerization will be required, which may drive up cost. From the perspectives of cost and production capacity, it is more practical to see RD being used as a blend component with conventional diesel rather than in pure form (100%).

Additives can be used to improve cold flow characteristic such as Pour Point (PP) and Cold Filter Plugging Point (CFPP). For 100% RD fuels, the degree of difficulty for cold flow treatment depends on the feedstock used and level of isomerization. Directionally, RD with higher degree of isomerization will be more responsive to cold flow additive. When blended with conventional diesel (RX, where conventional and X% of renewable diesel are combined), variables such as RD isomerization levels and base diesel characteristics should be understood in order to select a performance-optimal cold flow additive, if required. In most cases, compared to conventional diesel, treating a RD or RX blend requires a higher degree of understanding of the fuels and more specialized cold flow additives that may not be available to downstream consumers.

Considerations for using FAME

Up until now, FAME has been more commonly used as a blend component. However, we are now seeing an increasing use of RD. FAME is produced from natural sources via various syntheses and purifications. Although FAME can be produced from similar feedstocks to RD, the finished product is more polar, and contains a mixture of saturated and unsaturated materials. The unsaturated material can lead to oxidation issues, whereas the saturated material can lead to cold flow issues.

In similar mechanism as seen in RD and conventional diesel, in cold conditions, saturated FAME precipitates out of solution and potentially can lead to plugging of fuel filters, if not treated. The level of saturation in FAME is largely driven by the feedstocks.

When used as blend component in BX blends (BX, where conventional and X% of FAME are combined), the level of FAME and the amount of saturation drive impact on cold flow performance of the blend. Cold flow performance can be improved via the use of cold flow additives. However, careful analysis must be taken in choosing appropriate chemistry for optimal performance given the number of variables involved – FAME feedstock, amount of saturates, characteristics of conventional diesel used in BX blend, performance targets to be achieved, etc.

When FAME is used as alternative fuel or as a blending component, it not only has issues with wax precipitating below the cloud point, but its quality should be evaluated in order to assess the risk of precipitation of impurities leading to filter blocking above the cloud point. Saturated Mono-Glycerides (sMG) and Sterol Glucosides (SG) are examples of such impurities.

Saturated Mono-Glycerides (sMG)

Mono/di/tri glycerides are found in FAME because of incomplete transesterification, with the monoglyceride being the most prevalent form. Only saturated Mono-Glycerides (sMG), rather than unsaturated, have been found to cause filter blocking. The level of sMG depends on both the conversion efficiency of the biodiesel manufacturing process and the level of saturation of fatty acids within the feedstock. The leading cause of sMG filter blocking is likely to be solubility. During the biodiesel manufacturing process, it is common to perform a water wash. However, sMG is not soluble in water and therefore remains in the final fuel. With a high melting point and poor solubility in diesel fuel, sMG has the potential of building up and blocking fuel filters above the CP of the fuel. Laboratory testing of fuels spiked with sMG in an All-Weather Chassis Dynamometer showed that sMG accumulates on the filter and doesn't dissolve, therefore leading to increased pressure across the filter, and eventually operability issues.

Sterol Glucosides (SG)

Sterol Glucosides (SG) are naturally found in plants, thus likely to be found in biodiesel using such raw materials. These fine particles may also act as nucleating seeds, exacerbating the effects of other components, or over time they may themselves agglomerate into flocks and sediment. The amplifying effect of SG on other components has been observed with sMG. Due to their small particle size, SGs have no impact on a fuels CP, but have a significant negative impact on performance test such as cold soak filtration tests. Also, due to the very high melting point these materials do not simply redissolve upon heating. Therefore, like sMG, they are likely to accumulate on the filter potentially causing operability problems.

Filter blocking

When considering filter blocking above cloud point, the degree of impact on filterability performance can be estimated using test such as Cold Soak Filtration Test (ASTM 7501) or Cold Soak Filter Blocking Tendency (CAN/CGSB 3.0 No. 142.0). Additives can be used to improve the test performance, therefore, addressing the filterability issue. The required additive dosage is directly driven by the level of impurities found in FAME.

The level of unsaturation will lead to oxidation issues within FAME. This will worsen the stability and filterability of the product over time. Again, additives can be used to overcome these fuel stability problems.

These issues combined have led to well documented stability, filterability, and cold flow issues in fuels containing FAME which have led to the need to control them in fuel specifications.

Summary

The use of biodiesel and renewable diesel is expected to grow as the availability of these fuels increases and railroads work toward meeting their GHG emission reduction targets. While both fuels utilize either vegetable oil or animal fat as feedstock, the biodiesel process is transesterification while the renewable diesel process is hydrogenation and isomerization. Compared to petroleum diesel, in general, both biodiesel and renewable diesel have worse low temperature properties such as cloud point and pour point which limits the locations in which they can be used as is. Blends of these biofuels with petroleum diesel allows many more geographic locations for use, but predicting low temperature properties of BX or RX is not straightforward. Special consideration must be given to blends of biodiesel and renewable diesel due to the reduced solubility of renewable diesel. However, BX, RX, and RXBX blends can be successfully used in many locations when formulated appropriately.

Recommendations

- Low temperature properties such as cloud point, pour point, and either cold filter plugging point or the low temperature flow test are important for determining whether a fuel can be used in a cold location.
- The low temperature properties of specific biofuels and biofuel blends should be well understood prior to their use. In the absence of this information, they should be tested prior to use.
- Depending on the location of use, the low temperature properties must meet the specification (Canada) or the agreed upon target between the supplier and the purchaser (United States). In the United States, the 10th percentile temperatures can be used as a guide to determine the low temperature properties. Work with your fuel supplier to ensure that the low temperature properties of your fuel are appropriate for the region and period of intended use.
- Additives can be used to improve the low temperature properties of some biofuels or biofuel-containing blends. Work with your additive supplier to ensure that the chemistry of the additive is appropriate for biofuels.

References

1. https://www.eia.gov/todayinenergy/detail.php?id=60281
2. https://www.eia.gov/todayinenergy/detail.php?id=55399
3. Kinast, J.A. 2003. Production of biodiesel from multiple feedstocks and properties of biodiesel and biodiesel/diesel blends. Golden, CO: National Renewable Energy Laboratory. NREL/ DR-510-31460. https://www.nrel.gov/docs/fy03osti/31460.pdf
4. Dunn. R.O.; Moser, B.R. Cold Weather Properties and Performance of Biodiesel. In *The Biodiesel Handbook* 1st ed.; Knothe, G., Krahl, J., Van

Gerpen, J., Eds. AOCS Press 2010; pp 147-203. DOI: https://doi.org/10.1016/C2015-0-02453-4
5. Shrestha, D.S.; Van Gerpen, J.; Thompson, J.; Zawadzki. Cold flow properties of biodiesel and effect of commercial additives. Paper number 056121, 2005 ASAE Annual Meeting. doi: 10.13031/2013.19924
6. Ramalho, E.F.S.M.; Carvalho Filho, J.R.; Albuquerque, A.R.; de Oliveira, S.F.; Cavalcanti, E.H.S.; Stragevitch, L.; Santos, I.M.G.; Souza, A.G. Low temperature behavior of poultry fat biodiesel:diesel blends. *Fuel*, 2012, *93*, 601-605. https://doi.org/10.1016/j.fuel.2011.10.051
7. Moser, B.R. Influence of Blending Canola, Palm, Soybean, and Sunflower Oil Methyl Esters on Fuel Properties of Biodiesel. *Energy Fuels* 2008, *22* (6), 4301-4306. https://doi.org/10.1021/ef800588x
8. Rajagopal, K.; Bindu, C.; Prasad, R.B.N.; Ahmad, A. Cloud Point of Biodiesel and Blends. *J. Chem. Bio. Phys. Sci.* 2012, *2*, 1998-2003. https://www.researchgate.net/publication/342763501_Cloud_point_of_biodiesels_and_blends
9. Foroutan, R.; Esmaeili, H.; Mousavi, S.M.; Hashemi, S.A.; Yeganeh, G. Physical properties of biodiesel-diesel fuel produced vis transesterification process from different oil sources. *Phys. Chem. Res.* 2019, *7*, 415-424. https://doi.org/10.22036/pcr.2019.173224.1600
10. Kim, J.-K.; Yim, E.S.; Jeon, C.H.; Jung, C.-S.; Han, B.H. Cold Performance of various biodiesel fuel blends at low temperature. *Intl. J. of Auto. Tech.* 2012, *13*, 293-300. https://doi.org/10.1007/s12239-012-0027-2
11. Alleman, Teresa L. 2022. Assessment of BQ-9000 Biodiesel Properties for 2021. Golden, CO: National Renewable Energy Laboratory. NREL/ TP-5400-83108. https://www.nrel.gov/docs/fy22osti/83108.pdf
12. Dunn, R.O., Bagby, M.O. Low-temperature properties of triglyceride-based diesel fuels: Transesterified methyl esters and petroleum middle distillate/ester blends. *J Am Oil Chem Soc* 1995, *72*, 895-904. https://doi.org/10.1007/BF02542067
13. Hassan, U.; Al-Zubaidi, I.; Ibrahim, H. The Effect of Off-Spec Canola Biodiesel Blending on Fuel Properties for Cold Weather Applications. *ChemEngineering* 2018, *2*, 30. https://doi.org/10.3390/chemengineering2030030
14. Kazancev, K., Makareviciene, V., Paulauskas, V. and Janulis, P. Cold flow properties of fuel mixtures containing biodiesel derived from animal fatty waste. *Eur. J. Lipid Sci. Technol.* 2006, *108*, 753-758. https://doi.org/10.1002/ejlt.200600074

15. Tang, H.; Salley, S.O.; Ng, K.Y.S. Fuel properties and precipitate formation at low temperature in soy-, cottonseed-, and poultry fat-based biodiesel blends. *Fuel* 2008, *87*, 3006-3017. https://doi.org/10.1016/j.fuel.2008.04.030
16. Tang, H.; De Guzman, R.C.; Salley, S.O.; Ng, K.Y.S. Formation of insolubles in palm oil-, yellow grease-, and soybean oil-based biodiesel blends after cold soaking at 4 °C. *J. Am. Oil Chem. Soc.* 2008, *85*, 1173-1182. https://doi.org/10.1007/s11746-008-1303-1
17. *Neste Renewable Diesel Handbook*. Neste, 2016. https://www.neste.fi/sites/neste.fi/files/neste_renewable_diesel_handbook.pdf
18. Unpublished results from Innospec Fuel Specialties.
19. Smagala, T.G.; Christensen, E.; Christison, K.M.; Mohler, R.E.; Gjersing, E.; McCormick, R.L. *Hydrocarbon Renewable and Synthetic Diesel Fuel Blendstocks: Composition and Properties*. Energy & Fuels 2013, *27* (1), 237-246. DOI: 10.1021/ef3012849
20. Šimáček, P.; Kubička, D.; Kubičková, I.; Homola, F.; Pospíšil, M.; Chudoba, J. Premium quality renewable diesel fuel by hydroprocessing of sunflower oil. *Fuel*, 2011, *90* (7), 2473-2479. https://doi.org/10.1016/j.fuel.2011.03.013
21. Nylund, N.-O.; Erkkilä, K.; Ahtiainen, M.; Murtonen, T.; Saikkonen, P.; Amberla, A.; Aatola, H. *Optimized usage of NExBTL renewable diesel fuel*. VTT Research Notes 2604; VTT Technical Research Centre of Finland, Vuorimiehentie 5, P.O. Box 1000, FI-02044 VTT, Finland, 2011. https://publications.vtt.fi/pdf/tiedotteet/2011/T2604.pdf
22. Bouissey, C.A.; Cowardin, C.M.; Dickey, J.A.; Grabowski, J.N.; Lennon, J.A.; Smith, T.B.; Golisz, S.R. Evaluation of cold flow response of ultra-low sulfur diesel (ULSD) in combination with renewable diesel and biodiesel. Conference Proceedings, IASH 2022, The 17th International Symposium on Stability, Handling, and Use of Liquid Fuels; Dresden, Germany. September 11-15, 2022.
23. Selvidge, C.; Blumenshine, S.; Campbell, K.; Dowell, C.; Stolis, J. "Effect of biodiesel impurities on the filterability and phase separation from biodiesel and biodiesel blends." Conference Proceedings, IASH 2007. The 10th International Conference on Stability, Handling and Use of Liquid Fuels; Tucson, Arizona. October 7 – 11, 2007.
24. Golisz, S.R. Additives to improve the quality of R80/B20. Conference Proceedings, Biodiesel Technical Workshop; Kansas City, MO. October 24-25, 2023.

Biodiesel Handling & Blending Recommendations

By:
Rajani Modiyani – Chevron REG
Jeremy Barnes –Norfolk Southern
Glen Smith – Argus Consulting
Dwight Beebe – Temple Engineering
Randy Garver – Innospec

Introduction

Railroads are currently using more biofuels than ever driven by SBTi based GHG reduction targets and related reporting needs, set up by railroads. Policy landscape is also driving adoption of biodiesel either via incentives or other policy aspects. OEMs are in process of approving biodiesel blends up to B20 further bolstering the need for clarity on this subject. There has been increased use of biodiesel at various locations with higher percentages of biodiesel in the blend. Some locations are using pre-blended fuel directly from their supplier. Other locations are choosing to blend biodiesel with diesel at their facility. While the overall experience with handling biofuels has been positive, there are some aspects that need further information based on shared lessons learned that could provide greater confidence in handling higher blends of biodiesel.

Understanding the Current Biodiesel Delivery Mechanisms and Supply Chains

Biodiesel or biodiesel blended with petroleum diesel and/or renewable diesel can be transported and delivered by various modes, such as barge, truck, or railcar. Each mode has its own advantages and disadvantages, depending on the distance, cost, availability, and environmental impact of the transport. However, some general guidelines and best practices should be followed for handling biodiesel blends by any mode. Figure 1 shows the various biodiesel delivery and blending supply chains.

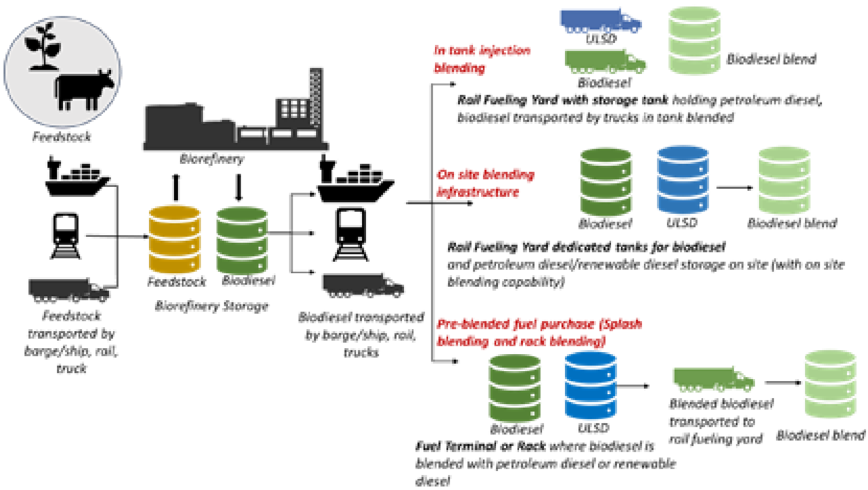


Figure 1: Biodiesel supply chain and blending value chains.

Infrastructure Considerations

Biodiesel blends can work in regular diesel tanks usually without any mechanical changes. Rail operations consistently utilize high volumes of fuel, and fuel retention times are typically limited to a few weeks. Biodiesel blends and petroleum diesel are similar in how they are stored and handled. For blends up to B20 in mild temperature conditions, there is no need for special or unique measures when transporting, loading, unloading, or handling biodiesel blended with petroleum diesel in fuel tanks.

An exception to the above could be very cold weather storage. The cloud points of biodiesel and renewable diesel can differ from petroleum diesel, and the freezing behavior of both differs significantly from petroleum diesel. For neat biodiesel and renewable diesel, it is important to keep the fuel 10 degrees Fahrenheit above the fuel's cloud point to avoid freezing challenges, whereas minority blends of both with petroleum diesel can be stored closer to their cloud points. For biodiesel blends up to B30, heated or insulated tanks are not usually required if the fuel temperature is not expected to fall below the cloud point of fuel. In cold weather conditions, the temperature of the fuel already in the storage tank and the temperature of the fuel being added to it should be considered. Depending on its supply chain, there may be situations where heating the biofuel before adding it to the blended fuel tank may be needed.

Biodiesel blended with petroleum diesel can be loaded into tanks using the same methods and equipment as regular diesel. A general best practice applicable to all fuel types (including fossil diesel) to ensure the quality and performance of the fuel is to inspect periodically for water and sediment in the tank. Any contamination in the tank can affect the stability and shelf life of fuel.

When considering the effect of biodiesel use on existing railroad infrastructure, it is important to not only consider the fueling systems, but also the associated industrial wastewater collection and treatment systems. Railroad fueling infrastructure for receipt, storage, and distribution/dispensing of fuel generally consists of piping, valves, meters, pumps, filters, storage tanks, instrumentation, loading/unloading arms and/or hoses, and fuel cranes/nozzles. All fuel infrastructure components and components of the wastewater system that could be in contact with fuel should be evaluated for the potential impact when using biodiesel.

There are no concerns with the use of biodiesel and biodiesel blends with carbon steel, which is the most commonly used material in such systems. Issues of material compatibility, however, arise with soft goods (elastomers) in valves and equipment, items such as rings, bushings, seals, and packing. Gaskets associated with equipment and piping must also be compatible with biodiesel. Finally, coatings and red metals may also interact with biodiesel and cause system issues.

In general, each of Buna-N (nitrile, NBR), neoprene and rubber have an unsatisfactory compatibility rating with neat biodiesel (B100). Materials with satisfactory ratings include fluorocarbon FKM (Viton™), Teflon, polypropylene, and nylon. There is not sufficient information available on polyethylene compatibility. Typically, however, lower blends of biodiesel present minimal concerns with fuel system component materials.

Gasket material considerations are the same as for soft goods. Rubber and nitrile gaskets should be replaced in retrofit systems and compatible materials specified in new systems. Recommended materials are Viton, Teflon, fiberglass, or metallic spiral wound gaskets. Materials should be selected for the expected ambient temperatures, especially for cold weather applications. Consideration must also be given to Fire Code requirements for gasket material selection.

Specific metals should be avoided in fuel systems. Red metals, such as brass or bronze, and any zinc bearing materials are not recommended. Brass, bronze, copper, lead, tin, and zinc may accelerate the oxidation of diesel and biodiesel fuels and create fuel insoluble (sediments) or gels and salts when reacted with some fuel components [(3)]. Lead solders and zinc linings should be avoided, as should copper pipes, brass regulators, and copper fittings. The fuel fittings tend to change color, and insoluble materials may plug fuel filters. Affected equipment should be replaced with stainless steel, carbon steel, or aluminum. [(1 & 2)] Replace any valves, pipes, or fittings made with these materials that may have crept into these systems over the years with carbon steel equivalents. Specifically, the use of these materials in new systems should be avoided. Additionally, for coatings, you should avoid the use of any zinc bearing primers or coatings for surfaces that will come in contact with biodiesel.

Hoses are used in fuel systems extensively, including truck and tank car loading and unloading, as well as at the fuel cranes. Review material compatibility with the manufacturer and replace the associated hoses if required with compatible materials.

Filtration may be affected in existing systems when biodiesel and biodiesel blends are introduced. Biodiesel has solvent properties that could disperse existing sediment and contamination in existing piping and tank systems. Consider the need for additional temporary filtration during startup. The Department of Defense design standards recommend a 30-micron and 10-micron filtration system in succession and a primary and secondary means of filtration [(4)] for fuel dispensers.

Key Biodiesel and Blending Testing Recommendations

The biodiesel specification are well covered by the ASTM D6751 standard and widely adopted by the industry. The National Biodiesel Accreditation Program takes fuel quality assurance a step further with the voluntary BQ-9000 programs. These programs combine the ASTM standards with a documented quality program, which includes biodiesel production through shipping. It is recommended that railroads source fuel from suppliers following the BQ-9000 quality program for increased quality assurance of the fuel.

Biodiesel and subsequent blends can degrade in stability when stored over an extended period in unfavorable storage conditions. You should consider initiating or adjusting a fuel quality program to allow for the storage and usage of biodiesel and/or subsequent blends.

Table no.1 shows the biodiesel properties that are commonly reported by fuel suppliers. If the railroads store B100 on site, there may be some benefit in monitoring some of the properties (*) below.

Property	Test Method	Specification
Kinematic Viscosity 40°C	ASTM D445	1.9 - 6.0 mm²/s
Flash Point (closed cup)	ASTM D93	min. 93°C
*Cloud Point °C	ASTM D2500	report
Methanol, mass %	EN14110	max 0.2%
Carbon Residue, mass %	ASTM D4530	max 0.050%
Sulfur, mass % (ppm)	ASTM D5453	max 0.0015% (15 ppm)
*Water and Sediment, % volume	ASTM D2709	0.05%
Distillation Temperature, 90% recovered	ASTM D1160	max 360°C
Sulfated Ash, % mass	ASTM D874	max, 0.020%
*Oxidation Stability	EN 15751	min, 3 hours
Glycerin Free, % by mass	ASTM D6584	max, 0.020%
Glycerin Total, % by mass	ASTM D6584	max, 0.240%
*Cold Soak Filterability	ASTM D7501	max, 240 seconds
Alkaline I Metals, Na + K	EN 14538	max, 4 ppm
Alkaline II Metals, Ca + Mg	EN 14538	max, 2 ppm
Density	ASTM D4052 or ASTM D1298C	report
*Water, total (Karl Fisher)	ASTM D6304	max, 500 ppm

Similarly, below table no.2 shows the quality parameters that could be monitored for biodiesel blends stored at rail yards.

Property	Test Method	Specification
Cloud Point °C	ASTM D2500	report
Water and Sediment, % volume	ASTM D2709	0.05%
Density	ASTM D4052 or ASTM D1298C	report
Biodiesel Content %	ASTM D7371	report
Water, total (Karl Fisher)	ASTM D6304	max, 500 ppm

Periodic sampling

Water in fuel tanks can lead to filter plugging problems in multiple ways, including the proliferation of both rust and microbes (biological contamination). Microbial growth usually leaves a "slime" on the filter, while excessive rust can be confirmed by either discolored filter media and/or the presence of dark particles in the bottom of a sample container or a water and sediment test tube. Bacteria, fungi, and mold can grow in a water layer in a storage tank and cause issues with filter clogging.

Periodic quality checks of storage tank bottoms are highly recommended as an effective way to minimize the likelihood of operational issues from water accumulation ("periodic checks" could be either quarterly or semi-annually, depending on storage tank condition and typical fuel storage duration). Tank bottoms samples should be visually inspected for the presence of water, haziness or murkiness in the water layer, and clarity of the fuel-water interface. Water with persistent murkiness or a fuel-water interface with a "rag layer" of any kind could be evidence of microbial growth. In this situation, as much free water as possible should be removed from the storage tank via a water draw outlet or a vacuum truck. Biological tests can also be run on a fuel sample from the lower portion of the storage tank to identify microbial proliferation versus baseline test results from periods without any operational issues. Minimizing water levels in storage tanks is important, and if microbial proliferation is identified, biocide treatment should be considered.

Regardless of fuel type or biodiesel content, removal of free water from the fuel is critical to maintaining fuel quality and limiting both microbial growth and corrosion. Lessons learned in other industries, such as in aviation fuel handling, can provide exemplary methods for use in removing free water before it can cause problems.

Fuel Handling Considerations for Railroad Operations

Fuel quality:

Biodiesel is generally more susceptible to oxidative degradation than petroleum diesel. Extended periods of storage can lead to peroxide formation which can contribute to gum or lacquer formation. Oxidation Stability testing can be completed at most third-party labs and should be considered at least quarterly if a fuel is likely be stored for extended periods of time (updated guidance from NREL indicates "extended storage" to be more than one year). To avoid accelerating any water-related fuel degradation mechanisms, free water that accumulates in the bottoms of fuel tanks should be drained regularly (quarterly or semi-annually, depending on rate of accumulation).

Biodiesel blends can be purchased with an Oxidation Stability Induction period (OSI) of greater than 3 hours, and fuels at higher OSI levels (>6 hours, for example) may provide additional assurance of long-term fuel stability. For biodiesel blends up to B20, the ASTM minimum requirement for OSI is 6 hours. However, some organizations have targeted an OSI greater than 20 hours for their blended fuel. Regardless of a particular railroad's OSI maintenance target, the addition of appropriate fuel stabilizers will likely increase OSI times and help avoid oxidative degradation in long-term storage, whether the additives are added at the time of production (i.e., prior to blending) or in the field after blending [(2).]

Cold weather considerations:

Filter plugging can occur at the storage and pumping equipment depending on fuel quality and the relationship between fuel cloud point and ambient temperature and storage tank hygiene. As the temperature decreases crystals begin to form in the diesel fuel to cause "gelling". The temperature that gelling could begin is indicated by the cloud point of the fuel. Biodiesel typically has a higher cloud point than #2 diesel. To verify if low temperatures are causing filter plugging, consider performing cloud point testing on the biodiesel blends. If a filter plugging issue is found with B100, a cold soak filterability test can be performed in addition to cloud point testing. In general, it is recommended to insulate/heat trace small bore piping exposed to wind in cold climates. Control valve tubing is of particular concern given the lack of flow and potential exposure to cold and hence sufficient insulation is recommended in cold weather.

Sterol Glucosides (SG) are a naturally occurring molecule in vegetable oils that are insoluble in biodiesel and diesel fuel. At low concentrations, SGs can cause filter plugging in colder temperatures. Estimation of SG content would require identification by a lab specializing in biodiesel or vegetable oil analysis, but the ASTM B100 Cold Soak Filterability test and the Canadian CGSB's Cold Soak Filter Blocking Tendency test are both useful for determining the presence of potentially problematic levels of SGs, as well as other potentially problematic minor components of biodiesel.

Water Management:

As mentioned above, storage tanks should have free water drained from the bottom on a regular basis. If water draws are performed without additional fuel recovery steps, they can cause a significant loss of fuel as well as additional loading on the industrial wastewater collection and treatment systems. To minimize the amount of lost fuel during dewatering, a device known as a sump separator should be used. Its purpose is to provide a small tank, usually 50 gallons, to collect the fuel and water drained from the bottom of the tank. Once the fuel and water have separated in the smaller tank, a small pump on the sump separator can return the fuel to the tank after the water has been drained to the industrial wastewater system or has been removed by a vacuum truck. This conserves fuel and makes it easier for the operator to perform more frequent dewatering operations.

If fuel is being received with excess amounts of water, installation of a haypack style filter is recommended to remove gross amounts of free water in the fuel while it is delivered.

Lastly, if fuel dispensing systems include long below ground piping runs, consider sloping the piping to create intermittent low points, where low point drains can be installed. Water can be removed from the pipeline at these points to further reduce water accumulation in the system.

Blending Scenarios

There are various ways for railroads to blend biodiesel with petroleum diesel and/or renewable diesel in their operations. Combining B100 (100% biodiesel) with petroleum diesel is usually done in one of the following methods.

1. **Splash Blending in Tanker Truck**:
   a. Top-loading configuration: The correct proportion of B100 is loaded on top of petroleum diesel that is already in the tanker. The B100 is added at a high enough velocity that it provides some blending. Since B100 is denser than the petroleum diesel it will flow downward in turn providing additional blending. The load is further agitated in the tanker during the trip to the destination where it arrives as a biodiesel petroleum diesel at the desired proportion.
   b. Bottom-loading configuration: the correct proportion of biodiesel is loaded first followed by petroleum diesel at a high enough velocity to provide blending. Since B100 is denser than petroleum diesel, the petroleum diesel will flow upward providing additional blending. As with the top-loading option, the trip to the destination will provide additional agitation if needed to finish the blend.
2. **In tank injection blending in Bulk Tank**:
   B100 and Petroleum Diesel are transported in separate tanker trucks and offloaded into the bulk tank sequentially. The target volume of biodiesel and diesel are calculated based on desired blend. Blending is provided from the energy of the high-speed offloading pumps and again the movement of the fuel provides for increased agitation and kinetic energy that enables further blending inside the tank. Periodic sample testing is conducted to ensure desired blend level is achieved in the tank.
3. **Inline Blending on site** – In this method blending is achieved by injecting the proper ratio of B100 into a stream of petroleum diesel as it is being transferred through a pipe. There are commercially available units that use flow meters and computer-controlled pumps or inline injectors that provide proportional control for the ratio of B100 to petroleum diesel. The injection itself provides some mixing but the majority of the mixing occurs as the fuel flows through the pipe. If additional reassurance of mixing is desired because of very short pipe runs (<30 feet, for example) combined with minimal elbows and very low flow rates (less than 30 GPM in a 2-inch pipe, for example), a static mixer can be installed downstream of the B100 injection point. However, this is not a common practice. Inline blending may be done

on the receiving side (i.e., at the end user's facility) if needed.

a. Blending during tanker offloading into a Bulk Tank.

b. Blending as the fuel is dispensed into the end use vehicle post Bulk Tank.

4. **Rack Blending** at third party terminal- Blending is done at the terminal as tankers are loaded with pre blended fuel for delivery to the customer. Blending is achieved via special blending infrastructure installed at the terminals.

Blending Method	Advantages	Disadvantages
Splash Blending in Tanker Truck	• Flexibility and ease of implementation • Typically, no need for special infrastructure • Easy integration of fuel delivery operations	• Testing may be needed to ensure desired blend levels are achieved. • Depending on contract structure may not provide full traceability of quality and other attributes needed for record-keeping
In tank injection blending in Bulk Tank	• Best economics on biodiesel values due to direct purchase from bio-refinery • Operational flexibility and ease of implementation • Usually, no need for special infrastructure and allows you to use existing infrastructure. • Easy integration of fuel delivery operations • Best control of biofuel quality and other attributes and complete traceability	• Blending requires careful management of timing of diesel and biodiesel deliveries, especially during cold weather. • Occasional testing may be needed to ensure desired blending is being achieved.
Inline Blending on site	• Best economics due to direct purchase • Flexibility to achieve desired blend rates. • Best control of quality and traceability • Allows you to manage your desired blend in real-time	• Requires additional injection equipment to achieve onsite blending along with additional biofuel tankage. • Special blending equipment could require capital investment
Rack Blending at 3rd-party terminal	• Ease of implementation • Usually no need for special infrastructure • Easiest integration of fuel delivery operations • High confidence in blend ratios	• Availability and flexibility limited dependent on terminal capability. • Little to no traceability of quality and other attributes needed for record-keeping. • Reliance on fuel terminals for quality of biofuel supplied

Additional Recommendations

- The biodiesel producer or marketer participates in the BQ-9000 certification programs or a similar quality assurance system that covers the entire biodiesel supply chain, from production to distribution to end use. For maximum quality assurance, consider sourcing fuel from companies which comply with programs like these where possible.
- Review and evaluate existing infrastructure (tanks, pumps, piping etc.) materials for compatibility with use of biodiesel.
- Conduct regular inspections of storage tanks, piping, pumps, filters, and dispensers to prevent the buildup of sediment, water, and microbial contamination that can affect biodiesel quality and performance. Remove free water and clean tanks and filter housings as indicated by the inspection results.
- Install appropriate filtration systems at the point of dispensing and replace filters as needed according to the manufacturer's specifications and/or quality test results on the dispensed fuel.
- Similar to practices with petroleum diesel, it is recommended to continue monitoring the temperature and humidity of the storage and dispensing areas to avoid water condensation and accumulation in storage tanks and fuel gelling in pipes and filter housings, especially in cold climates.
- As with any fuel incorporated in operations, it is recommended to collect and analyze representative fuel samples at the storage tank, and the dispenser, to ensure compliance with specifications and quality parameters is advised.
- Review and update the operational procedures and training programs for staff involved in biodiesel handling, blending, and dispensing, to ensure adherence to the best practices and safety guidelines.
- Evaluate the feasibility and suitability of the four blending methods described in the paper (splash blending, in-tank injection blending, in-line blending and rack injection) for different railroad operations and locations, taking into account the advantages and disadvantages of each method in terms of cost, accuracy, reliability, and flexibility.

Definitions

SBTi: The Science Based Targets initiative is a collaboration between the CDP, the United Nations Global Compact, World Resources Institute and the World Wide Fund for Nature, with a global team composed of people from these organizations, Wikipedia, https://en.wikipedia.org/wiki/Science_Based_Targets_initiative

GHG: Green House Gas, "Greenhouse gases are those gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of thermal infrared radiation emitted by the Earth's surface, the atmosphere itself, and by clouds." International Panel on Climate Change, https://www.ipcc-data.org/guidelines/pages/glossary/glossary_fg.html#:~:text=Greenhouse%20Gas%20(GHG),atmosphere%20itself%2C%20and%20by%20clouds.

Rancimat: A testing apparatus manufactured by Metrohm which measures the stability of biodiesel.

Feedstock: The biomass source (e.g. crops or waste oils, waste wood, etc.) from which Biofuels are produced

OEM: Original Equipment Manufacturer

B100 / neat biodiesel: 100% biodiesel that has not been blended with any other fuel like petroleum diesel or renewable diesel.

NREL: National Renewable Energy Laboratory

CGSB: Canada General Standards Board

References

1. National Renewable Energy Labs. Biodiesel Handling and Use Guide 6th edition September 2023 (1)
2. Re-Additization of Commercial Biodiesel Blends During Long-Term Storage (nrel.gov) (2)
3. National Biodiesel Board, Materials Compatibility white paper (3)
4. UFC 30460-01 Design: Petroleum Facilities, 16 July 2019 (4)
   Biodiesel Handling and Use Guide: Sixth Edition (energy.gov)

Railroad GHG Emissions Accounting with Biofuels

By:
Wayne A. Kennedy – Railroad Consultant
Steve Fritz – Southwest Research Institute
Veronica Bradley – Clean Fuels Alliance America
Sarah Elsokkary – Arcadis
Rajani Modiyani – Chevron REG

Abstract

The six North American Class I railroads collectively consumed 3.6 billion gallons of diesel fuel in 2023. All Class I railroads have partnered with SBTi (Science Based Targets) to aggressively reduce GHG emissions by 2030. The uptake in the use of biofuels has been increasing in recent years to help meet SBTi goals. This paper outlines various approaches, challenges, and uncertainty related to how North American Class I railroads will account for biofuel use in their GHG accounting. The authors suggest the railroad industry select a standardized approach to account for biofuels GHG emissions to improve transparency and consistency across the industry.

Word Cloud - What's the Focus for Rail?

The rail industry is relatively new to the world of setting SBTi goals and aggressive targets for GHG emissions reduction. The terminology is somewhat new and can be confusing to the uninitiated. The word cloud shown in Figure 1 is a sampling of available nomenclature. The average railroader trying to make an impact focuses on fuel conservation, burning less carbon intensive fuels, which emit less carbon into the atmosphere, and increasing the uptake of biofuels which have a much lower carbon intensity.

Figure 1 - GHG Emissions Reduction Word Cloud for the Rail Industry

Fossil Fuel Versus Biogenic Carbon - What's the Difference?

What are fossil carbon and biogenic carbon?

Fossil carbon and biogenic carbon have different origins and implications for the global carbon cycle and climate change. Fossil carbon is the carbon that is released from the combustion of fossil fuels, such as coal, oil, and natural gas, whereas biogenic carbon is the carbon that is released from the combustion of biomass, such as wood, crops, and non-petroleum waste.

How do fossil carbon and biogenic carbon affect the carbon cycle?

The carbon cycle is the process by which carbon moves between the atmosphere, land, oceans, and living organisms. Fossil carbon adds new carbon to the atmosphere that was previously stored underground for millions of years, whereas biogenic carbon recycles carbon that was more recently part of the atmosphere and the biosphere.

Fossil carbon increases the concentration of carbon dioxide (CO_2) in the atmosphere, which is the main greenhouse gas that contributes to global warming. Biogenic carbon does not increase the net amount of CO_2 in the atmosphere, as long as the biomass is regrown or replaced. Figure 2 illustrates the difference between these two sources in the carbon cycle.

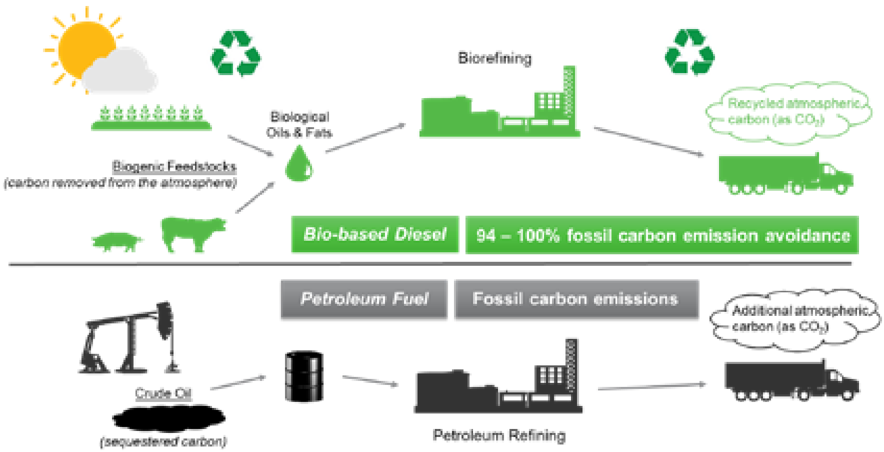


Figure 2 - Biogenic versus Fossil Fuel Carbon Cycle Diagram

SBTi Scope Emissions and Reduction Goals for the Industry

The Science Based Targets initiative (website www.sciencebasedtargets.org) was established in 2015 to help companies set emission reduction targets in line with climate science and the Paris Agreement goals. The Paris Agreement's long-term temperature goal is to keep the rise in mean global temperatures to well below 2 degrees Celsius above pre-industrial levels, and preferably limit the increase to 1.5 degrees Celsius. As of June 2024, there are almost 8,000 companies worldwide taking action. It should be noted that GHG emissions include the summation of CO2, CH4 and N2O (carbon dioxide, methane and nitrous oxide)

In order to set science-based targets (SBTs), companies first must account for their organization's emissions in a corporate inventory. Greenhouse Gas Protocol's Corporate Standard (https://ghgprotocol.org/corporate-standard) outlines which activities companies should consider when accounting for their emissions. These activities fall under 3 scopes as shown in Figure 3. Scope 1 covers direct emissions from owned or controlled sources, such as diesel fuel burned in locomotives, also called the "tank-to-wheel" emissions, which generally account for 95% of railroad companies' Scope 1 emissions. Scope 2 covers indirect emissions from the generation of purchased electricity, steam, heating, and cooling consumed by the reporting railroad company at all of their maintenance shops, crew room locations, yard/fueling facilities and headquarter locations. Scope 3 includes all other indirect emissions that occur in a company's value chain such as disposal of used railroad ties and steel rail and wheels as an example. It also includes the "well-to-tank" (the upstream portion) of fuels including extraction, production, and transportation of fuels.

For railroads, there are two main metrics used for GHG emission measures: (1) an absolute metric which is directly tied to how much diesel fuel is burned and is referenced in metric tons of CO_2 equivalent, and (2) the more common measure based on intensity using either gross ton miles or revenue ton miles, as a base measure producing an intensity value which is volume neutral. Typical units used are $MtCO_2e$/GTM (metric tons of CO_2 equivalent per gross ton mile). A ton mile is a unit of measure used in transportation and logistics which uses the weight of a shipment multiplied by the distance it is hauled. For example, one ton mile is equivalent to one ton of freight hauled over a distance of one mile. Gross ton miles include the weight of the entire train including freight, container, cars, and locomotives. Revenue ton miles include only the weight of the customer revenue generating freight.

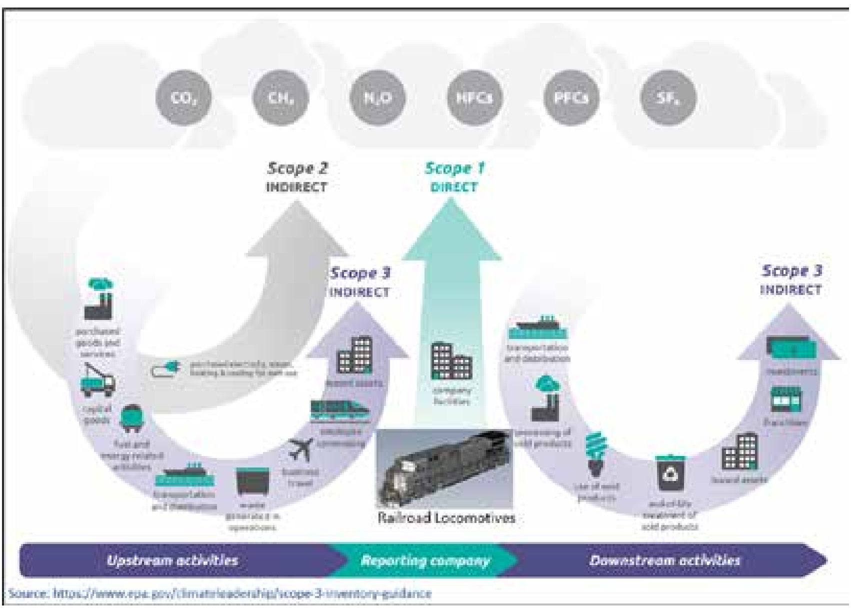


Figure 3 – Emissions Scope Definitions

Table 1 is directly from the SBTi website and shows all Class 1 goals. The goal dates vary but are mostly centered around the 2030 time frame. All participating North American railroads have chosen a "well below 2 degrees Celsius" goal for limiting long term global warming, with a 1.5 degrees Celsius goal recently approved for UP. Further, CN, CPKC and UP have committed to a Net-Zero goal by 2050.

Both BNSF and UP railroads have chosen the Absolute goal measure, where future growth and volume increases will make their GHG reduction goals more challenging to achieve, although traffic volume loss since 2018 has helped both railroads make significant progress towards achieving their SBTi goals.

Class I Railroads and Description of GHG Emissions Reduction Goals

Part of SBTi is that all railroads must reevaluate and submit more ambitious targets 5 years from the date the current target was published. In response to increasing urgency for climate action and the success of science-based targets to date, SBTi unveiled a new strategy in late 2021 to increase the minimum ambition in corporate target setting from 'well below 2 degrees Celsius' to 1.5 degrees Celsius above pre-industrial levels.[1] Union Pacific was the first railroad to have their 1.5 degree Celsius goal approved by SBTi in early 2024, moving from a 26% to a 50% absolute reduction in GHG emissions by 2030.

Company Name	Full target language	Company Temperature	Scope	Target Value	Type	Base Year	Target	Date Published
BNSF Railway	BNSF Railway commits to reduce absolute scope 1 and 2 and well-to-wheel locomotive GHG emissions 30% by 2030 from a 2018 base year*. *The target boundary includes biogenic emissions and removals from bioenergy feedstocks.	Well below 2°C	1+2	30%	Absolute	2018	2030	2023-05-25
Canadian National Railway Co	CN commits to reduce scope 1 and 2 GHG emissions 43% per gross ton miles by 2030 from a 2015 base year*. CN commits to reduce scope 3 GHG emissions from fuel and energy related activities 40% per gross ton miles by 2030 from a 2015 base year. *The target boundary includes biogenic emissions and removals from bioenergy feedstocks.	Well below 2°C	1+2	43%	Intensity	2015	2030	2021-07-21
CSX Corporation	CSX commits to reduce scope 1 and 2 GHG emissions intensity 37% per million gross ton miles by 2029 from a 2014 base year.	Well below 2°C	1+2	37%	Intensity	2014	2029	2020-01-01
Norfolk Southern Corporation	Norfolk Southern commits to reduce scope 1 and 2 GHG emissions 42% per million gross ton-miles (MGTM) by 2034 from a 2019 base year*. *The target boundary includes biogenic emissions and removals from bioenergy feedstocks.	Well below 2°C	1+2	42%	Intensity	2019	2034	2021-07-29
Union Pacific Corporation	Union Pacific commits to reduce absolute scope 1 and 2 GHG emissions 50.4% by 2030 from a 2018 base year.* Union Pacific also commits to reduce scope 3 GHG emissions from purchased goods and services, capital goods, and fuel and energy-related activities 50.4% within the same timeframe. *The target boundary includes land-related emissions and removals from bioenergy feedstocks.	1.5°C	1+2	50%	Absolute	2018	2030	2024-01-28
CPKC	CPKC commits to reduce scope 1, 2, and 3 well-to-wheel locomotive GHG emissions 38.9% per gross ton-miles by 2030 from a 2020 base year.	Well below 2°C	1+2+3	39%	Intensity	2020	2030	2023-11-21

Table 1 – SBTi Goals by Railroad

Figure 4 shows an equal weighting of the four Class I railroads that have chosen an emissions intensity goal. Note that improvement has stalled in the last three years and on average, they are now 15% above their SBTi glideslope goal. Note that the current year value is an estimate based on YTD fuel efficiency performance reported during quarterly earnings.

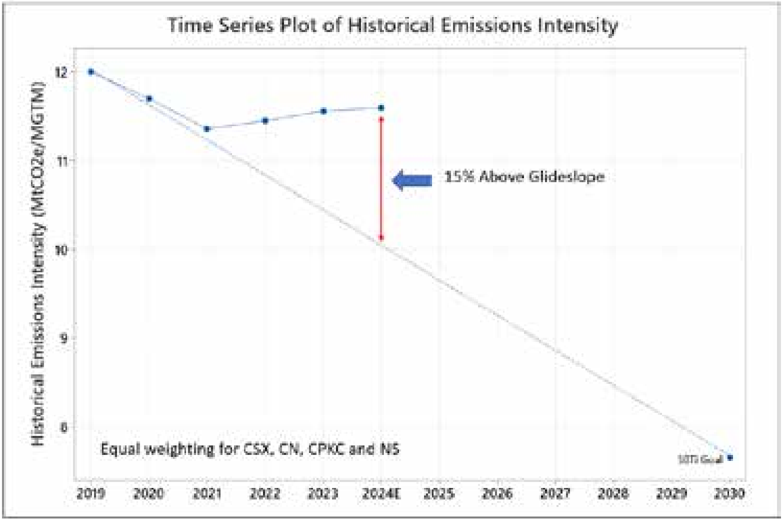


Figure 4 – Average Performance of Four Intensity Based Railroads Showing Glideslope to SBTi Goal

Figure 5 shows an equal weighting of the two Class I railroads that have chosen an absolute emissions goal with UP's new 1.5 degree Celsius goal factored in. As noted above, it is not surprising that UP is roughly on track with its SBTi glideslope goal in light of the 14% drop in gross ton miles since 2018. As in the previous figure, the current year value is an estimate based on YTD fuel efficiency performance reported during quarterly earnings.

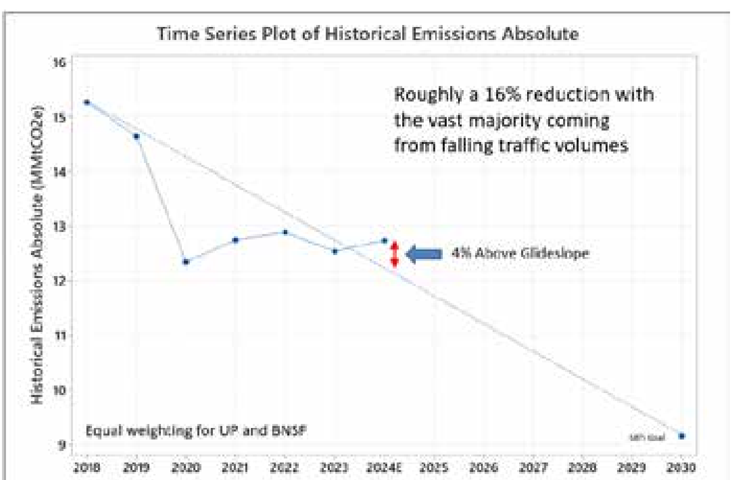


Figure 5 – Average Performance of Two Absolute Based Railroads Showing

Glideslope to SBTi Goal

Historical Fuel Efficiency Industry Performance

The rail industry commonly uses a fuel efficiency measure of Gallons per Thousand Gross-ton-Miles which has been tracked for many decades. Figure 6 shows this metric historically for each of the seven (now six) Class 1 railroads going back to 2000. Notice the Canadian railroads have generally been the best performers and starting in 2013 both distanced themselves from their US peers. It is also notable that the last three years have seen all railroads stall in progress with either flat or worsening performance due to network congestion issues brought about by the unexpected traffic rebound directly after Covid.

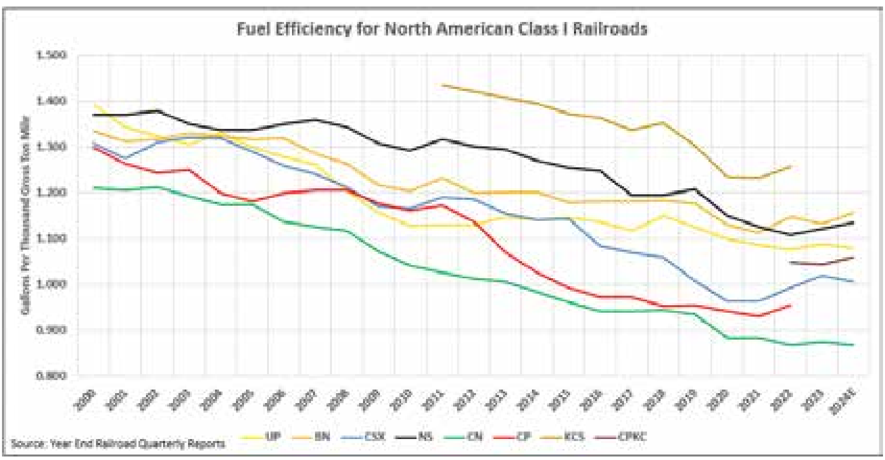


Figure 6 – Fuel Efficiency for Class 1 Railroads

Figure 7 shows the weighted average performance of the Class I railroads, indicating a 0.9% annual improvement in industry performance going back to 2011. If we look at the aggregate SBTi goals out to 2030 and the glide slope required for the industry to achieve that goal, the industry will need a 6.8% year over year improvement in fuel efficiency to meet their SBTs. This is in contrast with the current historical glide slope, which would create a 40% percent gap between where railroads need to be and where they likely will be on their current trajectory. In addition, with SBTi's urging to align SBTs to the more challenging 1.5 degree Celsius limit, this will likely mean the slope of the line shown in Figure 6 will need to become even steeper. As such, it is highly unlikely that fuel efficiency improvements alone will get the railroads to their 2030 goals. To close this large gap, railroads can and are increasingly looking to use biofuels.

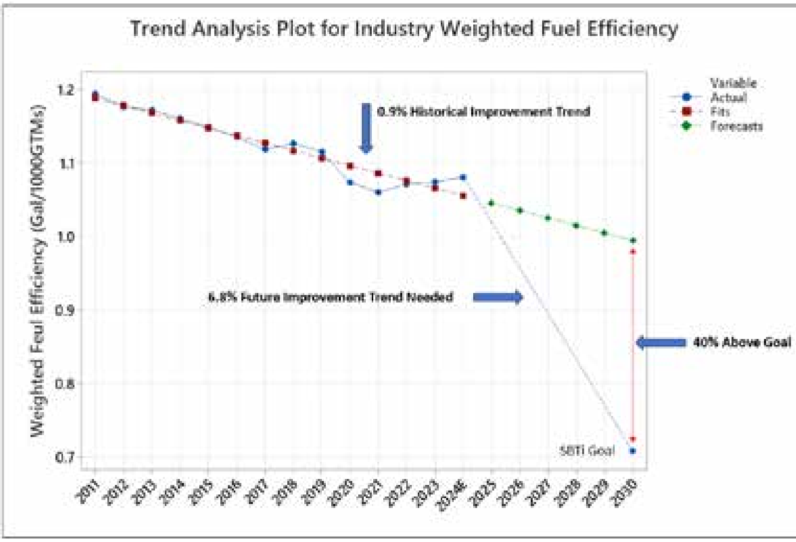


Figure 7 – Historical Rail Industry Glide Slope versus SBTi 2030 Goal

Current Biofuel Uptake for Class I Railroads

Each railroad publishes corporate sustainability reports and provides CDP, formerly the Carbon Disclosure Project with information on the approximate percentages of biodiesel (and likely some renewable diesel) being purchased for a given reporting year. Table 2 shows the current status of each Class I railroad.

Railroad	Current Percentage	Future Percentage Goal by Target Year	Comments
UP	6.1% (2023)	20% by 2030	Mid-term goal of 10% average blend by 2025
NS	0.8% (2022)	20% by 2034	Goal announced January 2024 in their Climate Transition Plan (CTP) document release
CN	4.2% (2022)	None published	Testing B100 blend in partnership with Chevron REG
CPKC	1.4% (2022)	None published	Listed as a potential future measure in Climate Strategy
CSX	0.2% (2022)	None published	Testing B20 and will increase uptake once Wabtec testing approves the use of B20/R80 by 3Q 2026
BNSF	Not Published	None published	Testing B20 and have made statements that biofuels could reduce their emissions by as much as 20%

Table 2 - Biofuel Blend Percentage by Class I Railroad [2,3,4,5,6,7]

UP and CN are leaders in their respective country in terms of having high levels of biofuel uptake. The other railroads have various lower-level blends ranging from 0.2% to 1.4% based on the most recent reporting available.

One potential reason for a slower adoption is that one of the leading locomotive OEMs is still in the process of officially approving up to a B20 blend level; that is 20% biodiesel, 80% petroleum diesel. Tentative approval is expected by the end of 2024 with final approval estimated to take an additional two years.

Different Requirements by Country

Canada has stringent fuel supplier reporting for renewable fuels, similar to the California LCFS program. These regulations require fuel producers and importers to have an average renewable fuel content of at least 2% based on the volume of diesel fuel and heating distillate oil that they produce or import into Canada. The regulation allows for the trading of compliance credits between fuel suppliers, allowing suppliers who have surpassed the regulatory percentage to sell off percentage points to suppliers who are lagging. These regulations do not affect fuel consumers' reporting of renewable fuels.

Canada also has carbon taxes including a federal minimum carbon tax in Canada which as of April 2023 was $65 CAD per tonne of CO_2e and is set to increase to $170 CAD per tonne by 2030. Provinces may also have carbon taxes, but the federal rate is set as the floor for the provincial rate. Large corporations receive exemptions to protect from foreign competitors who don't pay carbon prices. This approach to reducing GHG emissions could be an incentive beyond SBTs for Canadian railroads to use less carbon intensive fuels.

Railroad Corporate GHG Accounting Including Biofuels

Calculating the CO_2 mass emission rate from a locomotive is relatively straightforward and is part of the EPA Federal Test Procedure. Measuring emissions "out the stack" or "tank-to-wheel" is approximately 75 g CO_2e/MJ compared to the California Low Carbon Fuel Standard's baseline carbon intensity (CI) of 100.45 gCO_2e/MJ for petroleum diesel fuel. Why the difference? While the "out of stack" or use phase emissions is captured in the EPA Federal Test Procedure, carbon intensity captures the entire "life cycle" emissions of the fuel, incorporating emissions from the production of the feedstock, whether that's petroleum or of bio-based origin as well as other process and energy inputs to the fuel production phase, the transportation between all these steps, and the final distribution and use of the fuel. While the stack CO_2 emissions for a locomotive will measure roughly the same regardless of whether the fuel going into the engine is petroleum or biofuel based, the accounting methods by which traditional greenhouse gas accounting programs assess the environmental impact of the fuel-related emissions distinguish between fossil and biogenic CO_2. It is within this distinction that biofuels generate the majority of their GHG benefits to end users like the rail industry.

All carbon on Earth is stored in one of many reservoirs and flows between these different reservoirs in an exchange called the carbon cycle, wherein carbon moves from one reservoir to another at different rates. While most of the Earth's carbon is stored in rocks, it is also stored in varying amounts in the ocean, atmosphere, plants, soil, and fossil fuels. The slow carbon cycle moves carbon on geological timescales, whereas the fast carbon cycle moves carbon through biological processes on timescales more in line with animal and plant lifespans. The burning of fossil fuels has sped up the slow carbon cycle moving subterranean stores of carbon into the atmosphere widely attributed to human-induced climate change. Biofuels use carbon from the fast carbon cycle, wherein the biogenic feedstocks have recently taken up CO_2 from the atmosphere in their production that is then returned to the atmosphere upon the combustion of the fuel.

The carbon intensity of biofuels thus distinguishes between fossil and biogenic carbon and is the sum of the fossil CO_2 emissions estimated across the entire life cycle of the fuel as well as other GHGs produced in the fuels life cycle as illustrated in Figure 8.

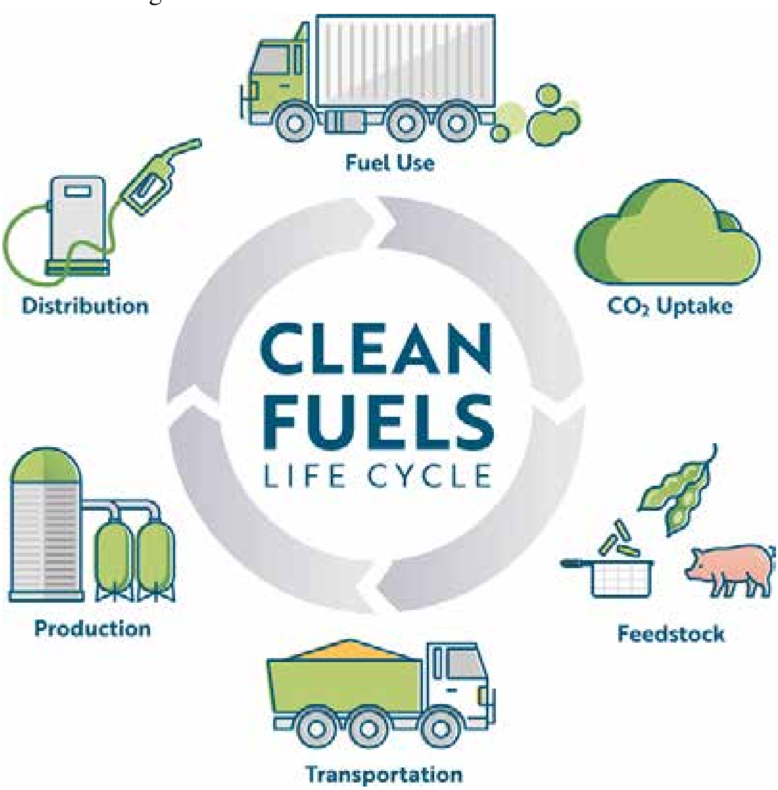


Figure 8 - Clean Fuels Life Cycle Diagram

When a company uses biofuels, it reduces their slow or fossil carbon emissions by switching to bio-based fuel. How much environmental benefit a given biofuel has in terms of carbon intensity is then compared to a petroleum baseline. For example, using the Department of Energy Argonne National Lab's Greenhouse gasses, Regulated Emissions, and Energy use in Technologies (GREET) Model, soy-based biodiesel has a CI value of 23.2 kg CO_2e/MMBTU while petroleum diesel has a CI of 95.9 kg CO_2e/MMBTU. On a life-cycle basis, therefore, soy biodiesel reduces GHG emissions by 76%.

However, because the carbon intensity of a fuel is based on the fuel's full life cycle, it cannot be used as an emissions factor to determine the associated scope 1 GHG emissions from its combustion. In addition to upstream emissions, carbon intensity scores, which are usually calculated in accordance with policy programs like California's Low Carbon Fuel Standard, may include penalties associated with indirect impacts (e.g., land use change) and credits associated with avoided impacts (e.g., methane avoidance for use of landfill gas). These additional credits and debits further justify not using a carbon intensity score as an emission factor to calculate scope 1 or scope 3 emissions.

That said, a fuel's carbon intensity score does contain the underlying data necessary to estimate scope 1 and 3 emissions from fuel combustion as they relate to scope 1 emissions for direct combustion of the fuel and scope 3 category 3 emissions from fuel activities not in other scopes (i.e., upstream emissions from feedstock extraction/production, fuel production, and transportation and distribution). Taking the GREET Model figures above, we find that the use phase or scope 1 emissions for petroleum diesel are 79.8 kg CO_2e/MMBTU while those emissions for soy biodiesel are 4.0 kg CO_2e/MMBTU, factoring in the fossil carbon from the methanol used to produce the biodiesel as well as other GHGs, including methane and nitrous oxide. This means switching from petroleum to soy-based 100% biodiesel reduces Scope 1 emissions by 95%. The balance of the carbon intensity values above, which were already corrected for indirect land use change penalties baked into the GREET model, are attributable to Scope 3 emissions. In this example, soy biodiesel increases Scope 3 emissions by roughly 19% on an energy basis.

Unfortunately, as alluded to, there is no standardization in the corporate accounting world, or under SBTi for calculating the CI of biofuels or for how to translate that CI score into scope 1 and scope 3 emissions, so the use of the GREET model in this example is for illustrative purposes. Often, biofuels producers track the CI values attributed to their fuel pathways (feedstock + fuel conversion process) for each program they participate in. As such, the same fuel may have several different CI values attributed to it depending on which program the fuel producer participates in. This is because not only are there credits and debits added to the direct life cycle emissions of the fuel, but the level of detail on the data a fuel producer can use for the direct emissions calculations varies by program. While one program may allow a fuel producer to reduce its fuel's carbon intensity by purchasing renewable electricity on the grid, other programs may require that electricity be directly connected to the fuel production facility, preventing the producer from capturing the benefits of a lower carbon intense electrical grid mix.

These nuances of carbon intensity-based policy programs make it extremely difficult for both fuel producers and consumers alike to have certainty in quantifying the emissions benefits of their fuels. Because the regulatory regimes to lower the carbon intensity of fuels were developed concurrently but separately from the development of emission factors for these fuels, both the renewable fuel industry and fuel consumers are left with an oversupply of information without concrete guidance as to best practices on reconciling carbon intensity methodologies with emission factor methodology.

GLEC Framework and the GHG Protocol

One group based in the European Union that is trying to fill that void is the Smart Freight Centre, which developed the Global Logistics Emissions Council (GLEC) Framework for logistics emissions accounting and reporting. The GLEC Framework has been approved by GHG Protocol (GHGP) as in alignment with GHGP's corporate standard. This guidance document helps walk logistics providers through emissions calculations as well as how to use those emissions results. Included in the GLEC Framework are some data sources that can be used as assumptions for emissions calculations including emission factors for various liquid fuels used in logistics, including diesel, biodiesel, and renewable diesel (called HVO in the guidance). While these emission factors may not be precise to the exact scenario a railroad is operating under, they are a good starting point where a railroad does not have more specific information about their biofuel's specific pathway to calculate a more precise emission factor. In addition, the emission factors developed for North America rely on the same GREET model mentioned above, reflecting the concerted effort for supply chain partners to align on assumptions and data used by fuel producers and consumers alike. More information on the GLEC Framework and access to the most recent version of the guidance is provided in the reference section[8].

GHG Protocol is working on updating accounting standards, with several guidance and standards documents to come out in the next year or so. However, there are currently no regulatory requirements on the consumer side for calculating greenhouse gas emissions, just these voluntary standards and some potential disclosure requirements that do not mandate any particular methodology.

In addition to biofuels' role in reducing rail's carbon footprint for the rail industry itself, downstream rail customers may also be interested in having their goods shipped on rail using biofuels to help them meet their own Scope 3 reduction goals applicable to the upstream and downstream transportation and distribution of their goods. The GLEC framework is focused on logistics, so it provides guidance on calculating emissions from the perspective of the movement of goods across several transport modes, or "transport chains" in the Framework's parlance. Once a transport chain is identified, such as rail, it is divided into transport chain elements (TCEs) representing the freight carried by that single vehicle or transiting through a single hub, so each change in vehicle or hub is a separate TCE. The TCE's emissions are calculated in three steps: (1) calculate the transport activity, (2) identify the applicable emission (or carbon) intensity, and (3) calculate the TCE emissions by multiplying the transport activity with the emission intensity value.

The transport activity of a TCE is expressed in gross ton-miles or ton-kilometers, so the mass or weight of the freight transported, and the distance transported are user defined values multiplied together to derive the transport activity value. Identifying the applicable emission intensity value for the TCE is then accomplished by identifying the transport activity, such as rail movement, the associated emissions intensity for the type and amount of energy used for that activity, and potentially a distance adjustment factor that may be necessary to convert miles to kilometers to ensure accurate accounting. These two values are then multiplied together to derive the TCE emissions.

Each TCE's emissions are summed to calculate the emissions for the entire transport chain and then aggregated across all transport chains within an organization's logistics supply chain to determine their total freight and logistics emissions. These emissions are considered on the full fuel life cycle covering well-to-wheels emissions that the biofuel industry is already familiar with; however, as noted there is no single standard recognized emission intensity value for biodiesel or renewable diesel. The GLEC Framework suggests a biofuel provider will be able to provide this value directly, yet as discussed above, fuel producers track a variety of carbon intensity values of their fuels and may not know which value is appropriate for a logistics organization to use.

An Example of Biofuel Accounting Calculating the Life Cycle Well-to-Wheel Emissions

A railroad provides either the amount of B100 purchased in gallons OR the amount of fuel purchased and the mix (example B20). The information needed for the estimation of emissions is the B100 volume therefore if we are provided gallons of B20 we determine B100 as follows:

5,000,000 gallons of B20 = 1,000,000 gallons of B100

Feedstock of the fuel is very important but as of today unless the railroad is purchasing B100 and doing onsite blending (none are doing this currently but likely will be in the next year or two) it is difficult for suppliers to provide feedstock for blended fuels. If we do not have feedstock, we use an average emissions factor for biofuels, using soy based as an example.

For reporting Scope 1 emissions of biofuels, the GHG Protocol requires biogenic CO_2 emissions to be reported separately from scope 1. CH_4 and N_2O emissions are still included in scope 1 for their Global Warming Potential (GWP) as we will see below.

Again, depending on if you get the Carbon Intensity (CI) from the supplier or if you are using the GLEC well to wheel emission factor for soy you will calculate the emissions separately.

Scope 1:

1,000,000 gallons of B100 x B100 CO_2 EF (kg CO_2/gallon) - example using the EPA EF (Emissions Factor) Hub = 9.45 kg CO_2/gallon = 9,450,000 kg CO_2 = 9,450 metric tons CO_2.

The combustion phase of biofuels is about the same as regular diesel fuel so we typically will use the diesel locomotives EF for B100 for CH_4 and N_2O.[1]

Methane: 1,000,000 gallons of B100 x Diesel Loco CH_4 EF (g CH_4/gallon) x CH_4 GWP - example using the EPA EF Hub = 0.8 g/gallon = 800,000 grams CH_4 X 28 CH_4 GWP = 22.4 metric tons CO_2 equivalent.

Nitrous Oxide: 1,000,000 gallons of B100 x Diesel Loco N_2O EF (g N_2O/gallon) x N_2O GWP - example using the EPA EF Hub = 0.26 g/gallon = 260,000 grams N_2O X 265 N_2O GWP = 68.9 metric tons CO_2 equivalent.

*Total scope 1 of biofuels = 91.3 metric tons CO2e
Scope 1 emissions excludes 9,450 metric tons of direct CO2 emissions from the use of biofuels

Scope 3 Category 3 Fuel and Energy Related Activities:
Using GLEC North American WTW (Well-to-Wheel) emission factors 22.0 g CO_2e / MJ (Biodiesel soybean)

(Source: GLEC_FRAMEWORK_v3_UPDATED_02_04_24 page 79)

1 Emission factors for methane (CH4) and nitrous oxide (N2O) for locomotives are not well documented, and default EPA emission factors may not be representative and may overstate Scope 1 emissions. Future testing is recommended to ensure accurate accounting in this regard.

To calculate just scope 3 FERA (Fuel and Energy Related Activities) we need to subtract the TTW (Tank-to-Wheel) emissions from the WTW....

22.0 - 0.8 = 21.2 g CO_2e / MJ

1,000,000 gallons of B100 x (21.2 g CO_2 e/MJ * 130.5963 MJ/gallon = 2,768.6 g CO_2e / gallon) = 2,769 metric tons CO_2e

33.3 - 35.7 MJ/liter on average (using median) = 34.5 MJ/liter (3.7854 liters / gallon) = 130.5963 MJ/gallon

LIFE CYCLE (well-to-wheel) emissions:
Scope 1 + Scope 3 Category 3 = 91.3 MT CO_2e + 2,769 MT CO_2e = **2,860 MT CO_2e for 1M gallons of B100**

Compared to 1M gallons of petroleum diesel:
Combustion EF EPA EF Hub (combined emission factor for CO_2, CH_4, N_2O) = 0.0103075 metric tons CO_2e / gallon. WTW GLEC EF = 91.4 g CO_2e/MJ x 36 MJ/liter x 3.7854 liters / gallon = 12,455.48 g CO_2e / gallon

Scope 1 = 1,000,000 gallons diesel X 0.0103075 MT CO_2e / gallon = 10,307.5 MT CO_2e
Scope 3 = 1,000,000 gallons diesel x 12,455.48 g CO_2e / gallon = 12,455 MT CO_2e

LIFE CYCLE (well-to-wheel) emissions:
Scope 1 + Scope 3 Category 3 = 10,307.5 MT CO_2e + 12,455 MT CO_2e = **22,762.5 MT CO_2e for 1M gallons of Petroleum Diesel**

Therefore, there is an approximately 87.4% reduction in life cycle emissions using B100 compared to regular petroleum diesel. Therefore, a railroad choosing an overall B20 blend would reduce their life cycle emissions by 17.5%. A blend of B30 would reduce life cycle emissions by 26.2% and using B40, the reduction would be 35%. Many of the Class I railroads have stated publicly that they plan to achieve up to half of their GHG emissions reduction goals through the use of biofuels. Table 3 shows various blends and their corresponding emissions reduction percentage along with averages for SBTi goals depending on alignment with 1.5 or well below 2.0 degrees Celsius targets.

Biodiesel Blend	Life Cycle GHG Emissions Reduction Percentage	SBTi Reduction Goal for 1.5C	Average SBTi Reduction Goal for <2.0C
B100	87.4%	50.4%	37.8%
B50	43.7%		
B40	35.0%		
B30	26.2%		
B20	17.5%		
B10	8.7%		

Table 3 - Biodiesel Blends and Associated Emissions Reductions to Average SBTi Goals

Market-based GHG Accounting Under Development to Track Environmental Attributes

There are also flexible market-based GHG accounting approaches under development to allocate and track the "environmental attribute" of biofuel usage to specific customers who may be willing to pay a premium for the use of biodiesel or renewable diesel over petroleum diesel. Normally, the methodology described above would rely on actual fuel consumption types and amounts to derive emissions estimates, but these flexible accounting approaches seek to attribute the use of lower-carbon fuels to certain freight based on customer demand rather than distributing the lower carbon fuel use across all freight in a haul. These accounting approaches, designated mainly as "book-and-claim", are currently under development. These digital systems under development are designed to ensure the proper chain-of-custody to separate the fuel from the environmental attribute, or lower emissions, and track certificates of that attribute to allow them to be issued to shippers and avoid double counting emissions benefits. Importantly, this system of allocation of bio/renewable fuels to customers does not preclude the fuel consumer from realizing the emissions savings on their own GHG accounting books. The Smart Freight Centre also has a market-based accounting measure framework where the book-and-claim concept is explored further. This framework lays out guidance on how logistics providers, like the rail industry, can reliably participate in this flexible GHG accounting system. More information is available in the reference[9].

Railroad's Role in Transporting Feedstocks and Biofuels for an Overall Lower CI

Movement of feedstocks to biorefineries and finished fuels and chemicals from biorefineries are always looking for the most efficient and fastest method of freight movement. These are key reasons why pipelines are used widely in the movement of petroleum diesel and other types of liquid fuels. However, there are limitations in using pipelines for biodiesel and feedstocks due to the lack of material compatibility and fungibility with fossil diesel and especially jet fuel. Moreover, feedstocks need to be gathered from several different locations, consolidated and then transported to crush facilities, then the oil to biorefineries. For these reasons railroads have a key role to play in partnering for the growth of the biofuels industry.

Railroads continue to be the most fuel-efficient means of transportation that can connect various regions together due to its expansive network in North America. According to the Association of American Railroads (AAR), moving freight by rail instead of truck reduces GHG emissions by up to 75%. Rail freight is also economically and operationally the most efficient method of movement for the renewable fuels industry's feedstocks and fuels due to the sheer volumes that must be transported.

Biofuels in the form of biodiesel and renewable diesel provide an effective lever to lower carbon emissions from rail as they can be integrated into operations seamlessly. Rail freight transportation being the least emitting mode of transport when using lower carbon fuels further provides an opportunity to create an even lower carbon solution. Moreover, the rail mode of transportation can be used to create an effective supply chain by having train movements structured in such a way that enables the same train to move feedstocks to biorefineries and finished fuel away from biorefineries on their return journey. All in all, rail using lower carbon fuels can provide a lower carbon, efficient, and well-connected transportation method to further enable the growth of biofuels as a lower carbon solution.

Conclusions

Biofuels represent a clear path to help railroads achieve their near term 2030 SBTs. The rail industry is struggling to stay on their respective glide slopes to attain these targets through purely fuel efficiency gains. Biofuel uptake by various railroads has begun to increase with a few leaders and a few laggards, though many of the Class I railroads have either announced or intimated biofuel blend goals of B20 or higher by 2030. Canadian railroads have more stringent reporting requirements and incentives to use less carbon intensive fuels.

Accounting methods assess the environmental impact of fossil fuels as being far greater than that from biogenic sources which produce biofuels. As an example, soy-based biodiesel reduces life cycle GHG emissions by 76% compared to regular petroleum diesel. The carbon intensity score of biofuels depends on many different factors including feedstock extraction/production, fuel production and transportation/distribution. There are various models such as the Greenhouse gases, Regulated Emissions and Energy Use in Technologies (GREET) model which strive to calculate the life-cycle carbon intensity of biofuels compared to petroleum diesel.

Unfortunately, there is no standardization in the corporate accounting world, or under SBTi for calculating a set CI score for biofuels given the various pathways and programs involved, including the potential credits and debits added to the direct life cycle emissions of the fuel. Concrete guidance is currently lacking as to best practices on reconciling CI methodologies with emission factor methodology, but it is apparent that you cannot use CI scores to directly calculate changes in Scope 1 (locomotive stack) GHG emissions.

Lastly, there are flexible market-based GHG accounting approaches also under development to track the environmental attribute of biofuel usage to specific customers who may be willing to pay a premium for the use of biofuels, based on customer demand. Book-and-claim is one such example of a digital system designed to ensure the proper chain-of-custody which would avoid double counting the emission benefits of lower carbon biofuels and may prove beneficial to railroads to socialize the cost of procuring biofuels.

Recommendations

Best practice sharing in terms of biofuels accounting methodology

As railroads continue to incorporate biofuels in their operations to make progress in line with their carbon reduction targets, there will be a need to report on their emission reductions internally and potentially externally to stakeholders and other organizations like SBTi. As discussed in this paper, biofuels accounting methodology can take different forms. For railroads that operate in multiple states and countries this creates complexity requiring management of various programs in addition to the reporting that is beyond any compliance programs.

Hence it is recommended that railroads adopt a single methodology regardless of region to account for their corporate GHG emissions to simplify internal and potentially external reporting on their voluntary targets. It is also recommended to adopt a methodology that is widely recognized and understood. As a starting point, the Smart Freight Centre's GLEC Framework can assist the rail industry in determining emission factors for the industry as GHG Protocol and others continue to develop voluntary standards around corporate accounting methodologies. In adopting a standard methodology across the industry, rail can then align this approach with their SBTi reporting to enhance the comparability and transparency of their efforts to decarbonize. It may also be beneficial for the rail industry to drive consensus around how the industry will tackle assumptions baked into that methodology, especially when certain information is unknown, e.g., fuel pathway consumed.

Another complexity in biofuels reporting emerges from how the biofuels are procured. When procuring biofuels from terminals or as a pre-blended biofuel it may be difficult to have high confidence in exact quantities and it is very difficult to trace the source of biofuels as the biofuels are procured and stored from multiple sources. Where possible it would be recommended to source biofuels directly from producers to simplify supply chains, in turn reducing carbon emissions. This would ensure better accuracy in accounting of biofuels quantity sourced and its supply chain for carbon emissions accounting.

Time will tell if in the long term, railroads will be able to expand and simplify their supply chain to include biofuel procurement and all the variables required to account for their reduced CI scores. Failing an improved and flexible system, the industry could agree to a tiered methodology by which they use different emission factors based on the transparency of the information provided by the biofuel supply chain.

References

1. https://sciencebasedtargets.org/resources/files/Business-Ambition-FAQ.pdf
2. https://www.bnsf.com/in-the-community/environment/sustainability-overview-2023/protecting-our-planet.html
3. https://www.cpkcr.com/en-ca/sustainability
4. https://s2.q4cdn.com/859568992/files/doc_downloads/sustainability/2023/2022-csx-esg-report.pdf
5. https://www.cn.ca/en/delivering-responsibly/
6. https://norfolksouthern.mediaroom.com/2024-01-04-Norfolk-Southern-inaugural-Climate-Transition-Plan-aims-for-low-carbon-future
7. https://www.up.com/cs/groups/public/@uprr/@corprel/documents/up_pdf_nativedocs/pdf_up_2022_climate_action_pln.pdf
8. https://www.smartfreightcentre.org/en/our-programs/global-logistics-emissions-council/calculate-report-glec-framework/
9. https://www.smartfreightcentre.org/en/projects/ongoing-projects/market-based-measures-accounting-framework/

Report on the Committee on Electrical Maintenance

Thursday, October 10, 2024

3:10 PM

Vice Chair

Brent Brown

Director of Locomotive and Car

Transportation Products Sales Company, O'Fallon, MO

Commitee Members

M. Ablett	Product Development Engr	Edwio Bohr Corp	Jacksonville, FL
S. Alessandrini	Manager of Locomotive Quality	Canadian National Railway	Concord, Ontario
S. Bakker	President	Transportation Products Sales Company	O'Fallon, MO
S. Bendriss	Senior Electrical Engineer	Amtrak	Miami, FL
C. Nordhues Bieber	VP-Customer Engagement	Railspire	Roanoke, TX
T. Bourbeau	President	Enerpro	Goleta, CA
D. Caron	VP-Business Development & Sales	Ekyrail Enterprises	Chateauguay, Quebec
F. Carrion	Engineering	Ferrocarril Central Andino (FCCA)	Lima, Peru
J. DeLaurentis	VP / GM	Magnetech Industrial Services	Huntington, WV
M Drylie		LMOA	Jacksonville, FL
E. Fortin	Technical Director	DLL	St. Jean Richelieu, Quebec
J. Fox	Senior Director-Locomotive Engineering	Union Pacific RR	Omaha, NE *Regional Exec*
B. Gaudet	VP-Engineering and Quality	PowerRail, Inc.	Duryea, PA
O. Goureev	Railway Product & Systems Manager	ABB Canada, Inc	Montreal, Quebec
R. Honc	Senior Research Engineer	Southwest Research Institute	San Antonio, TX
R. Huerta	Industry Segment Manager	Harting	Lemont, IL
S. Hupe	Locomotive Logistics Director	Alaska Raiilroad	Anchorage, AK
J. Jovenall	Product Manager-Rail	Cattron	Warren, OH
B. Locklear	Manager-Electrical Systems	CSX Transportation	Huntington, WV
J. Madzar	President	Smart Light Source	Brooklyn, NY
K. Mellin	Sales Manager	Peaker Services Inc	Brighton, MI *President*
C. Muir	Vice President	East Penn Manufacturing	Lyon Station, PA
D. Myers	Director-Quality Assurance	Edwin Bohr Corp	Chattanooga, TN
R. Myers	Asst Superintendent Motive Power	Wheeling & Lake Erie Rwy	Brewster, OH
J. Paxton	Owner	T&J Consulting	Springfield, MO
D. Pettengill	Account Manager	Dayton-Phoenix Group	Dayton, OH
B. Runyon		Consultant	Roanoke, VA *Past President*
H. Schafer	Superintendent-Topeka SMT	BNSF Railway	Topeka, KS
S. Sledge	Senior Manager-Loco Reliability	Norfolk Southern Corp	Atlanta, GA
A. Soora	Senior Product Manager	ZTR Control Systems	London, Ontario *3rd VP*
J. Stratman	Manager-Locomotive Reliability	Union Pacific RR	Omaha, NE
B. Wheless	Account Executive	Transportation Prod Sales Co	Fleming Island, FL
J. Whitmer	Locomotive Specialist	Dakota, Missouri Valley & Western RR (DMVW)	Bismarck, ND

Note: Following the conclusion of 2024 RSI Expo and Conference Brent Brown will assume the duties of Chair of the Committee replacing Jason Fox who is now the Regional Executive. Randell Honc will assume the Vice Chair position

PERSONAL HISTORY

Brent Brown

Director of Locomotive and Car
Transportation Products Sales Company
O'Fallon, MO

For the past five years, Brent has served as the Director of Locomotive & Freight Car for Transportation Products Sales Company. He has established business relationships with locomotive OEMs and railroads, focusing on solutions-based technology. He promotes best in class products and processes for battery maintenance, battery testing, and training within the North American rail industry. Brent is deeply involved in the business development of TPSC products used throughout the Locomotive segment.

Before joining TPSC, Brent held multiple leadership roles at a Class I railroad. He was part of the Mechanical Finance team for Kansas City Southern Railroad. His last role was managing mechanical contracts for the locomotive and freight car fleets in both the US and Mexico.

He also brings valuable experience from his tenure as the Operations Manager at Wabtec Global Services, where he was responsible for lean initiatives within the organization.

Brent began his career supporting the overhaul program at a class one for GE, where he discovered his passion and dedication to the industry—a commitment that continues to drive him today.

He has been a member of the LMOA for five years and takes pride in serving the industry, alongside respected predecessors. He currently serves as the Assistant Chair of the LMOA Electrical Committee and has authored a white paper on Battery Maintenance Practices. His enthusiasm for the field is evident in his belief that the people in the industry are its most important asset. Brent is committed to upholding and representing the traditions of the LMOA.

Brent received a Bachelor of Business Administration degree from Baker University. He resides in Liberty, Missouri with his wife Ashley, and their daughters. In his free time, Brent enjoys hunting, fishing, and kayaking.

THE ELECTRICAL MAINTENANCE COMMITTEE WOULD LIKE TO EXPRESS OUR GRATITUDE TO THOSE FACILITIES WHO SUPPORTED OUR COMMITTEE IN 2024

ORGANIZED BY ONE OF OUR NEWEST MEMBERS, MICHAEL THOMASON, THE KNOXVILLE LOCOMOTIVE WORKS IN KNOXVILLE, TENNESSEE HOSTED OUR WINTER MEETING, AND GAVE OUR MEMBERS A TOUR OF THE FACILITY ON FEBRUARY 9, 2024. A VERY SPECIAL THANKS IS EXTENDED TO ALLISON PALMER WHO ARRANGED ALL OF THE DETAILS. WE LEARNED ALL OF KNOXVILLE LOCOMOTIVE'S CURRENT CAPABILITIES AND HOW PRIDEFUL THE EMPLOYEES ARE AT KLW WHICH IS A LOCOMOTIVE MANUFACTURER THAT MODERNIZES VARIOUS SIZES OF LOCOMOTIVES.

THE SUMMER MEETING WAS HELD IN NORTH PLATTE, NEBRASKA HOSTED BY THE UNION PACIFIC RR. MR. JASON FOX, LMOA CHAIR/REGIONAL EXECUTIVE, ORGANIZED A TOUR OF THE FACILITY AND LUNCH AT THE GOLDEN SPIKE OBSERVATION TOWER IN THE BAILEY YARD ON JULY 9, 2024. NORTH PLATTE HAS A LONG HISTORY OF RAILROADING DATING BACK TO 1890 WITH TWO ROUNDHOUSES. TEN PERCENT OF PRESENT-DAY NORTH PLATTE RESIDENTS WORK FOR THE UNION PACIFIC. IT OPENED IN 1971 WITH THE PRESENT-DAY LOCOMOTIVE SHOP. TODAY'S BAILEY YARD IS THE WORLD'S LARGEST CLASSIFICATION YARD WITH TWO HUMPS AND 120 BOWL ROWS AND 400 MILES OF TRACK. THE VEW FROM THE GOLDEN SPIKE IS A SIGHT TO SEE FOR ANY RAIL PROFESSIONAL OR ENTHUSIAST.

OUR JOURNEY ENDED AT GOTHENBURG, NEBRASKA WHERE WE TOURED THE DAYTON-PHOENIX PLANT ON JULY 10, 2024 ORGANIZED BY DAVID PETTENGILL FROM OUR COMMITTEE. WHILE DAYTON PHOENIX IS HEADQUARTERED IN DAYTON, OHIO, THEIR REBUILD SHOP REMANUFACTURES 95% OF THE ROTATING EQUIPMENT AT GOTHENBURG.

THANK YOU TO THE COMMITTEE AND LMOA EXECUTIVE GROUP FOR ORGANIZING A MEANINGFUL 2024 FOR THE ELECTRICAL MAINTENANCE COMMITTEE

DEAD WON'T START? LET'S FIX THIS!

BatteryNurse™ Stations

High Performance Battery Charging and Testing

Improves battery maintenance practices within locomotive facilities.

Maximize battery starting and AESS performance.

Qualifies batteries that are ready for service and identifies batteries to be sent to repair service or scrapped.

EHI Charger for Locomotive Batteries

Provides Smart, Safe Charging for AGM and Flooded Batteries

- High Frequency IGBT Technology
- 64Volt, 125AMP and 32Volt, 200 AMP
- 480/600 3P input
- CEC compliant
- Real-time clock, calendar, computer USB interface and logging history

Factory preset specifically for your shop use; Settings can be changed in the setup menu if method of use changes.

Electrolyte's Role in Locomotive Starting Batteries

Prepared by :
Sid Bakker – Transportation Products Sales Company
Stephen Alessandrini – Canadian National Railway

List of Acronyms

SOC	State-of-Charge
FLA	Flooded Lead Acid
AESS	Automatic Engine Stop Start
SG	Specific Gravity
DI	Deionized Water
OCV	Open Circuit Voltage
EH&S	Environmental Health & Safety
DOD	Depth of Discharge
FIFO	First In First Out
MSDS	Material Safety Data Sheet

Introduction

This paper on battery electrolyte is the fourth in a series of LMOA papers on Flooded Lead Acid batteries. Each paper in the series provides results of testing, analysis, and review of lead acid locomotive starting batteries concluding with recommended practices designed to maximize performance and life of the battery.

The Flooded Lead Acid (FLA) battery is the dominant chemistry used for locomotive starting in North American rail industry. The introduction of Automatic Engine Stop Start (AESS) shifted the locomotive starting battery application from a "near float" application to a "cycle" application. Today's locomotive lead acid batteries are well suited for both float and cycle applications. However, changes for the charger and AESS settings, along with proper maintenance practices are necessary to maximize battery performance and life. The focus on electrolyte management and maintenance is critical to achieve expected reliability goals of today's locomotive.

In the distant past, most railroads performed in-house battery Specific Gravity (SG) testing, and in some cases, acid adjustments. Over the last 25 years, most railroads stopped in-house SG testing and relied on 3rd party battery service centers due to environmental, health, and safety aspects of sulfuric acid. Recently, a few railroads are exploring in-house SG testing and adjusting. This paper addresses the requirements, challenges, and considerations of working with Electrolyte. Let's start with fundamentals of the Flooded Lead Acid battery.

Flooded Lead Acid Battery Basics

Alessandro Volta was an Italian physicist and chemist credited for inventing the first battery in 1800 called the "voltaic pile" shown in Figure 1. In 1859, French physicist Gaston Planté invented the lead acid rechargeable battery as shown in Figure 2. His first model consisted of a spiral roll of two sheets of lead, separated by a linen cloth and immersed in a glass jar of sulfuric acid solution. Figure 3 shows an expanded illustration of the internal components of today's locomotive starting battery.

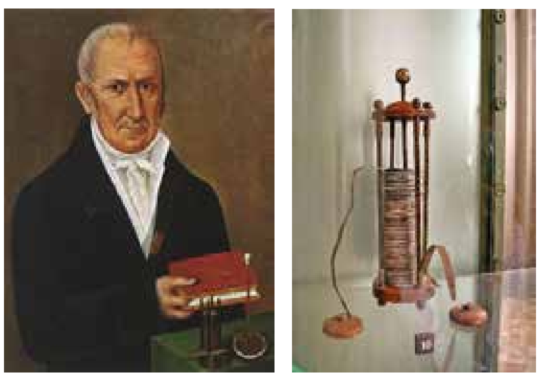


Figure 1: Alessandro Volta and the Voltaic Pile

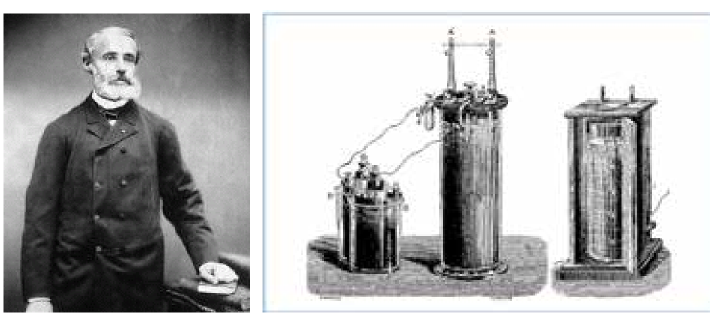


Figure 2: Gaston Plante and the first rechargeable Lead Acid Battery

Figure 3: Modern Flooded Lead Acid Battery

The modern FLA battery has evolved over the past 224 years with significant advancements in alloys, manufacturing and quality. However, the basics of Gaston Plante's battery are still present today. A fully charged FLA battery is comprised of 3 primary components as depicted in Figure 4.

1. **Two Electrodes** (plates) made from 2 dissimilar metals. Positive plate is PbO2 (Lead Dioxide), and Negative plate is Pb (Lead). A small amount of Antimony is added to both plates for strength and rigidity.
2. **Electrolyte Solution** comprised of approximately 1/3 H2SO4 (Sulfuric Acid) and 2/3 Dionized (DI) water by volume.
3. **Vented Container** to hold the above components and allow Hydrogen and Oxygen gases to vent during charging.

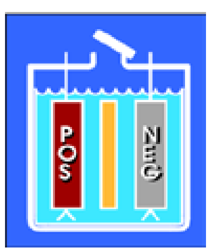


Figure 4: Battery Primary Components

Electrochemistry

A fully charged battery is illustrated in Figure 5 (left). PbO_2 (lead dioxide) positive plate, Pb (lead) negative plate, and H_2SO_4 (concentrated sulfuric acid). A fully discharged battery is illustrated in Figure 5 (right): 2 $PbSO_4$ (lead sulfate) plates and diluted H_2SO_4 (sulfuric acid).

FLA batteries are well suited for AESS equipped locomotives and daily cycling. The batteries not only support critical loads during a shutdown but must retain enough energy to reliably start the locomotive at the end of the discharge. A 2018 LMOA Proceedings paper titled "Battery Temperature Performance Study with Strategies to Optimize Charging and AESS Settings" provided results of a locomotive study of successful starts at various States-of-Charge (SOC) at near freezing temperatures. The paper included recommendations to cycle the battery between 95% down to 40% which provided ample shutdown time without threatening a Dead Won't Start. The recommendation for 100% SOC at least once every 2 weeks was also made.

During discharge, sulfuric acid reacts to the positive and negative plates producing lead sulfate which lowers the electrolyte level. During charge, the sulfuric acid is returned to the electrolyte which raises the electrolyte level. Adding water to a discharged battery followed by charging may cause overflow of electrolyte. For this reason, watering should be done after the battery is charged.

The total discharge reaction can be described as:

Lead Dioxide reacts with Lead and Sulfuric Acid to produce Lead Sulfate and Water

It can be written as:

$$PbO_2(s) + Pb(s) + 2H_2SO_4(aq) \longrightarrow 2PbSO_4(s) + 2H_2O(l)$$

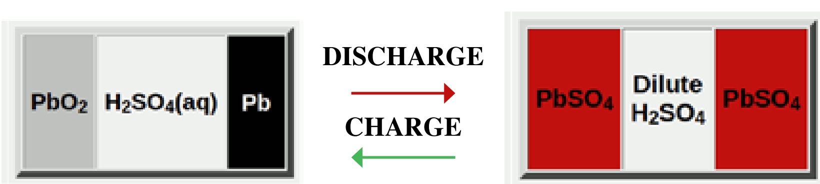


Figure 5: Chemical Reaction Charged / Discharged

Environmental, Health & Safety (EH&S)

Company EH&S policies and procedures must be adhered to by workers performing electrolyte tasks and battery tasks in general. The sulfuric acid in a lead acid battery is highly corrosive. Contact with eyes can cause permanent blindness; swallowing damages internal organs that can lead to death. First aid treatment calls for flushing the skin for 10–15 minutes with large amounts of water to cool the affected tissue and to prevent secondary damage. Immediately remove contaminated clothing and thoroughly wash the underlying skin. Refer to the battery manufacturer's Material Safety Data Sheet (MSDS).

Workers must wear specific battery maintenance PPE and use the appropriate tools and equipment for the specific electrolyte task. Examples shown in Figure 6 include PPE: aprons, goggles, face shield, rubber gloves, hard hat. Facility items include signage, eyewash station and/or eyewash bottle, shower, spill containment, neutralizer, spill cleanup materials, adequate ventilation. Consult your company's EH&S department and contact your battery manufacturer for assistance.

Figure 6: Environment, Health & Safety Items for Battery Maintenance

Electrolyte Maintenance

Water Intervals

Increased charge/discharge cycling due to AESS increases water loss due to gassing during the charge cycle. Consequently, the time between water addition must be shortened and is dependent on number of cycles, increased depth of discharge (DOD), higher float voltage, and increased temperature during the summer months. Prior to AESS implementations, 184-day water intervals were sufficient due to infrequent cycling. Today's water intervals are trending to 92 days or less, depending on the aforementioned factors of cycles, DOD, float charge setting and temperature. It is important to avoid intervals that cause electrolyte levels below the top of the plates. Consult your battery manufacturer for proper float charge and bulk charge settings.

Water Quality

Replacement water to the electrolyte must meet battery manufacturer's quality specification. The specification defines the allowable impurity limits (Parts Per Million) for specific items including solids, minerals, metals, chemicals etc. Companies should have the tap water for each watering location tested for identified impurities. If tap water does not meet requirements, water purification equipment should be added.

A Deionizer (DI), shown in Figure 7, is a cost-effective resin-based cartridge that successfully removes ions and heavy metals. When the ions in the cartridge reach maximum level, a light indicator alerts the user to dispose of the DI cartridge and replace with a new cartridge.

In a few rare cases, a Reverse Osmosis (RO) device can be added inline prior to the DI. An RO device forces impure water through a membrane trapping most impurities prior to feeding a DI. Finally, distilled water is acceptable to use in batteries, but is expensive to produce. For smaller watering locations, purchasing distilled water may be a viable option.

As part of the water replacement process discussed in the next section, the electrolyte should be inspected for water quality. As the battery ages, it is normal for clarity of the electrolyte to become cloudy or light gray. If the electrolyte becomes dark black as shown in Figure 8, it should be inspected by a battery service center to determine the cause and if corrective action is possible.

Figure 7: Water Deionizer (DI)

Figure 8: Electrolyte Sample

Water Replacement Process

With the **Water Intervals** and **Water Quality** in place, we can perform water addition. Important reminders: 1) Avoid low electrolyte levels below the top of plates, and 2) Perform water additions at or near a full State of Charge.

1. Adhere to your company policies and procedures for safe battery watering.
2. Figure 9 shows the worker rinsing the top of the battery with clean water prior to removing the caps. This keeps dirt, dust, and debris from entering the battery and contaminating the electrolyte. If a white substance is visible on the battery, it may be sulfur from the battery due to an overfill. Apply baking soda and water to the substance to neutralize and rinse thoroughly.
3. In cycling applications, the necessity to water the battery to a more precise level is imperative. Figure 10 illustrates one manufacturer's maximum fill level. Consult your manufacturer for the proper level. Underwatering poses the risk of electrolyte levels below the top of plates prior to the next watering event. Conversely, overwatering can cause electrolyte to escape the battery. The loss of water can be replaced, but the loss of sulfuric acid must be replaced by a qualified technician at a battery service facility. The resulting drop in SG will affect performance and life. There are two common watering methods used for locomotive batteries. Both methods have the capability of filling to a precise level:

a. Manual watering shown in Figure 11 uses a water gun placed directly into each cell. The water gun allows easy reach into all 16 cells in each battery. The water gun includes an automatic shutoff when the electrolyte's maximum fill level is reached.

b. Single point watering shown Figure 12 illustrates a watering method where all 16 cells in each battery are fitted with special valves connected by tubing. This enables a single point connection to the water supply to fill all cells to the maximum fill level simultaneously. This method does not require removal of caps, reduces electrolyte exposure to the technician, takes much less time, and automatically stops at the precise level for all cells to eliminate overfills and underfills.

Figure 9: Rinsing top of battery

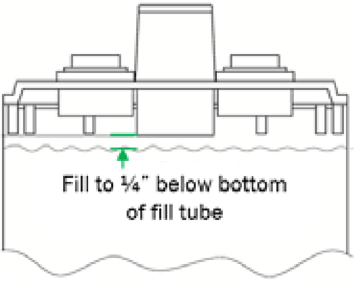


Figure 10: Maximum Fill Level

Figure 11: Water gun

Figure 12: Single Point Watering

Specific Gravity and Open Circuit Voltage

Specific Gravity (SG) of a flooded lead acid battery is the ratio of the density of electrolyte to the density of water (H_2O). Specific Gravity (SG) and Open Circuit Voltage (OCV) are measurements used to determine a lead acid battery's State-of-Charge (SOC). In fact, SG + 0.84 = OCV. An example of a 100% SOC cell @ 77˚F is $1.250_{SG} + 0.84 = 2.09_{OCV}$.

SG is measured with a hydrometer and temperature corrected to 77˚F. OCV can be calculated from SG or measured with a voltmeter. However, neither SG nor OCV measurements are accurate until the battery chemistry (and voltage) has stabilized with no load and no charging. This can take hours. SOC is not an ideal test of the battery's health. Other testing methods are more effective.

<u>SG Behavior and Measurement Tips:</u>

- Do not add water before SG measurement as this can cause an inaccurate reading.
- **Discharging**: During battery discharge, SG decreases. Since sulfuric acid is heavier than water, it is at the bottom of the cell. Wait an hour after discharge for the electrolyte to stabilize before taking the measurement.
- **Charging**: When charging begins, there is no gassing action to mix the electrolyte. Therefore, hydrometer readings taken at the top of the cell are not yet accurate. When the charging cycle reaches the gassing stage, the sulfuric acid mixes quickly for a more accurate SG value. Accurate readings can be taken at the end of the charging.
- **Low SG**: As described in the Electrochemistry section, a discharged battery is comprised of two "soft/temporary" Lead Sulfate plates and water. Prompt charging reverses this reaction back to a fully charged Lead Dioxide Positive, Lead Negative, and Sulfuric Acid. For prolonged

discharged batteries, the lead sulfate begins to harden and become more permanent. Prompt charging prevents hardening of the lead sulfate.

Electrolyte SG Adjustments

Performing SG adjustments to battery electrolyte is an advanced process requiring trained technicians, facility, and resources. Some railroads have made a commitment to perform SG adjustments at the shop, whereas most railroads choose to send batteries for SG adjustments to an outside service center. Here is a short list of basic requirements for in-house adjustments along with challenges to consider:

- Technicians must be trained in electrochemical, electrical, DC power, and hazardous chemical handling. A technician's experience over time and "the art of" SG adjustment are key to a quality program.
- Procedures and tools for sulfuric acid volumes and adjustment. Records, labeling, reporting.
- Coordination of battery services with Environmental, Health and Safety department, facilities, material department.
- Indoor workspace is preferred, ventilated, clean, temperature stable throughout the work shift, Eye wash stations, shower, spill containment, spill cleanup kits, hazardous waste disposal.
- Equipment should include chargers, load banks, racking, forklift, hand tools
- Appropriate safety PPE, digital hydrometer with temperature compensated results.
- Storage for the deionized water supply and the sulfuric acid supply, as well as the adjustment process, should have a stable temperature. Refer to temperature variation challenges in the next section.
- Large temperature variations require corrections, Such as:
    - Sulfuric acid volume increases as temperature increases. Sulfuric acid volume decreases as temperature decreases. Corrections to the volume of sulfuric acid based on change in temperature are critical to battery performance and life.
    - SG readings must be temperature corrected. Add 0.001 to SG at 77˚F for every 3˚F above 77 ˚F. Subtract 0.001 from SG at 77˚F for every 3˚F below 77 ˚F.
- Final SG adjustment should be within +/- 0.010 of target SG.

Battery Inventory Management

Battery Inventory management has a critical role in keeping batteries healthy and ready to go when called for locomotive service. Here are the critical responsibilities for locomotive starting batteries:

- Store batteries in a cool dry location if possible. Outdoor storage in summer's high temperatures will increase self-discharge rate. Outdoor storage in winter's low temperatures may freeze water in discharged batteries.
- FIFO (First In First Out) inventory management is critical. Boost charge batteries every 3 months, and every 2 months in summer's high temperatures.
- Batteries being staged for repair service should not sit for long periods of time at a discharged state, regardless of being stored inside or outside.
- Always pair 2 batteries of the same manufacturer, AH size and age within 12 months of manufacturer date, not the repair date

Conclusion

AESS equipped locomotives have increased the workload of the battery calling for extensive cycling and starting performance. Lead acid batteries are well suited for this increased demand. In turn, the battery requires best in class maintenance and a review of AESS settings to answer the call. Prioritization on the following electrolyte fundamentals will maximize battery reliability, performance and life.

1. **Watering Interval:** Identify the number of days between watering events ensuring the electrolyte level does not drop below the top of plates. Trending information suggests an interval of 92 days or less, depending on the amount of cycling. More cycles, deeper cycles, and higher battery temperatures equate to a shorter interval between watering events.
2. **Water Quality:** A high-performance vehicle needs high octane fuel. A high-performance battery needs high quality clean water free of ions, solids, minerals, or metals. Most shops will need a deionizer to remove the impurities from their water source. Do not forget to change the cartridge when dirty.
3. **Watering Process:** Water up to the maximum fill level. Avoid overfills by watering the battery at or near a full SOC. Underwatering may not provide enough electrolyte to make it to the next watering event. Use a watering gun with auto-stop for each individual cell or a single point watering system with auto-stop for all cells in a battery. Best practice is to ensure electrolyte is above top of plates, Charge, then water.
4. **Specific Gravity (SG):** SG is a ratio that indicates State-of-Charge. Open Circuit Voltage (OCV) is directly related and indicates State-of-Charge as well. Both are accurate after they stabilize, which may take hours. For this reason, SG or OCV testing should be compared against other testing methods if time is limited

5. **Electrolyte SG Adjustments:** Successful electrolyte SG adjustments at the shop requires a significant resource commitment to the program. Advanced knowledge, skill, equipment, EH&S requirements are all important aspects when considering in-house SG adjustment process vs. a third-party battery service center.
6. **Battery Inventory Management:** Material departments have responsibility for products with a shelf life, which includes batteries. Lead and acid begin their electrochemical reaction (i.e. self-discharge) the day they are manufactured. First In First Out inventory (FIFO) must be implemented. Pair 2 batteries of the same manufacturer, AH size and age within 12 months of manufacturer date, not the repair date. Batteries in storage must be boost charged every 3 months, and every 2 months for consistent temperatures >85˚F.

Recommended Reading

1. "Battery Temperature Performance Study with Strategies to Optimize Charging and AESS Settings" by Jason Fox – Union Pacific Railroad and Sid Bakker - TPSC. 2018 LMOA Proceedings.
2. "Locomotive Battery Maintenance Best Practices" by Shane Sledge – Norfolk Southern and Brent Brown - TPSC. 2021 LMOA Proceedings.

Reference List

[1] Steve Plummer, Edward Mattan, Stryten Energy
[2] Wikipedia contributors, Public Domain

FRA 92 day vs. 184 day Requirements

Prepared by :
Rodney Myers – Wheeling & Lake Erie Railway
Am Soora – ZTR Control Systems
Dave Pettengill – Dayton-Phoenix Group

This paper is being written to assist railroads in determining if they are qualified to convert from 92-day locomotive inspections to 184-day inspections, as outlined in the Code of Federal Regulations eCFR 229.23 Periodic Inspection: general. Doing this conversion will reduce the inspections from 4 times per year down to 2 times per year, which will decrease the down time of the locomotives and also the cost of filters, fluids, labor, etc. This change may not be feasible for all railroads. Several Class II and Class III railroads, for example, do not have the required equipment on their locomotives and the expense to change over to that equipment would be costly, even for a small fleet.

According to CFR 229.23 (b): for each locomotive equipped with advanced microprocessor-based on-board electronic monitoring controls:

1. the interval between periodic inspections shall not exceed 184 days; and
2. at least once every 33 days, a daily inspection required by 229.21 (CFR), shall be performed by a qualified mechanical inspector as defined by 229.5 (CFR). A record of the inspection that contains the name of the person performing the inspection and the date that it was performed shall be maintained in the locomotive cab until the next periodic inspection is performed.

It is not abundantly clear what an "advanced microprocessor-based on-board electronic conditioning monitoring" control is, however, given the maintenance tasks as outlined in "eCFR 229.25 Test: Every periodic inspection", it is safe to assume this microprocessor system must have the following (at a minimum):

- Replace all mechanical gauges used by the engineer to perform braking (air system) with digital displays and sensors that have self-diagnostics and do not require calibration
- Diagnostics automated tests for the electrical system, such as relays, contactors to verify integrity of components, wiring and connectors
- A microprocessor based self-monitoring event recorder
- Integrated alerter

Note: the way the regulation is written, Remote Control Locomotive (RCL) and Multiple Unit locomotives such as Mother-Daughter may not be covered under this waiver

PowerRail

PowerRail
570-883-7005
Sales@ePowerRail.com

CREATIVE INNOVATIONS...CONTINUING TRADITION

PowerRail Custom Inspection Kits

PowerRail proudly offers cost-efficient and time-saving custom Inspection Kits. Provide us with your maintenance schedule (92-day, 180-day, 360-day) and we'll have the Kits ready to ship when you need them.

- Assembled and tagged by customer's Road Number...easy ordering for you!
- Reduced inventory on your shelves
- No more picking and sorting to assemble kits onsite
- Reduced downtime with a more streamlined and efficient ordering process

Inspection Kits can include various consumables, such as:

- Carbon Brushes
- Filters
- Wiper Blades
- Fuses
- Light Bulbs

(just to mention a few)
Your kit...your way!

Generic Inspection Kit Examples

EMD SW1500 360-DAY INSPECTION KIT		
Qty.	PowerRail P/N	Application
4	E8345482	C-12/C-24 Lube Filter
2	E8423132	FJ-2S Spin On Fuel Filter
1	E9330535	AK-2 Air Compressor Intake Filter
3	E8470903	EG-1 Baggie Intake Filters
1	E9311037	BT-267 Air Compressor Lube Filter
1	E8343161PS1	Gasket Fuel Strainer
2	350PAR56FRADUAL	Headlight, Halogen 75V 400W
1	810WATER-BX	Water Treatment-Corrosion Inhibitor Sticks

EMD GP38 90-DAY INSPECTION KIT		
Qty.	PowerRail P/N	Application
7	E8345482	C-12/C-24 Lube Filter
3	E8470903	EG-1 Baggie Intake Filters
2	E8423132	FJ-2S Spin On Fuel Filter
1	E9330535	AK-2 Air Compressor Intake Filter
1	E9311037	BT-267 Air Compressor Lube Filter
1	E9324489	FG-3W Fuel Strainer
1	E8358905PS1	Gasket Primary Fuel
1	E8343161PS1	Gasket Fuel Strainer

Note: The above Kits are simply examples.
Let us create a customized Inspection Kit for you!

AAR M-1003 CERTIFIED

www.ePowerRail.Com

With that being said, further inquiries were made to gain clarity on the definition of “advanced on-board monitoring equipment. This resulted in learning that a locomotive equipped with a computer to monitor the engine, coupled with a computer-based air brake system (Epic, Fastbrake, or CCB [Computer Controlled Brake] or CCBII) that monitors reference/feedback voltages, qualifies for the 184-day inspections. Vendors make conversion systems for 26L brake equipment also, which qualify for this.

Air Flow Meters (AFM) are still required to be tested every 92 days but there is an FRA Waiver (FRA-2016-0086), which was started by the Class 1’s, that allows this test to be conducted at the 184 day interval if certain provisions are provided (locomotives equipped with NYAB CCB-II air brake systems and attached to this waiver).

In conclusion, there are advantages and disadvantages to make the move from 92 day to 184 day inspections. It will cost more upfront but over time there should be a savings with labor, filters, fluids, and engine down time. As stated, if the unit is equipped with an air flow meter the meter may still need to be inspected every 92 days.

Main Generator Qualification

Author:
Ken Baye
Union Pacific RR

Acronyms

ATPro 5- All Test Pro version 5
W/lb- Watts per pound

Introduction

The railroad industry relies on quality components for locomotives to be successful. One critical item to this success is the locomotive's main generator. The industry has experienced service interruptions, availability challenges, and significant disruption in railroad operations. When a main generator fails, the locomotive must be taken out of service until a new generator can be installed. This process can take up to 3 months to remove and install a new generator.

On June 8th, 2021, Dr Howard Penrose with MotorDoc LLC performed an assessment of a Main Generator overhaul facility.

This paper will highlight various tests that can be used in the qualification process for the main generator. It is important to recognize that each test is qualifying a different characteristic of the main generator. Performing a subset of these tests can lead to unexpected premature failure from a generator requalification program.

Rotor Qualification

Dr Penrose's assessment started with a teardown of a main generator that had failed after only (7) seven weeks of use and focused on how the rotor circuit was being qualified.

The Main Generator overhaul facility was testing the rotor coils circuit using Hipot testing and a surge tester.

Hipot Test-"The hipot test is a nondestructive test that determines the adequacy of electrical insulation for the normally occurring over voltage transient. This is a high-voltage test that is applied to all devices for a specific time in order to ensure that the insulation is not marginal" (Jiguparmar, 2011), Ref. IEEE 95.

Surge Test- Surge testing is a technique to test the dielectric strength of the insulation in windings. These windings can be solenoids, coils, transformers, or some other type of winding like those found in electric motors. The technique involves applying a fast rise time current pulse to the winding which induces a turn to turn voltage between adjacent loops of wire. If that induced voltage is high enough to overcome weak insulation, an arc will be formed between the wires. This arc is picked up by the surge test equipment and displayed for the operator. Ref. IEEE 1068-2015.

Figure 1: Rotor Coils mounted on the rotor for testing.

Figure 2: A good sine wave on the surge tester.

The surge test passed and the hipot test found one grounded coil. These results would require replacing the one grounded coil and passing the rotor testing.

The assessment noted that a very important test was not being executed: the voltage drop test. A voltage drop test is important as the test is checking for increased resistance in a circuit. The increased resistance results in a higher voltage drop.

Upon completion of the voltage drop test, two more coils failed and required replacement (Figure 3).

Coil	Voltage	Coil	Voltage
1	10.8	6	13.5
2	13.6	7	13.2
3	13.2	8	13.6
4	13.4	9	10.7
5	13.2	10	Grounded

Figure 3: Coil 1 and Coil 9 failed voltage drop test as they were not within 10% of the others.

During setup for testing of the rotor in Figure 1, it was noted that a completed rotor being staged to be re-assembled had three different coils present on the rotor (Figure 1). The different coils were identified as being the same part number.

Coil	Resistance (Ohms)	Phase Angle in degrees (Fi)	Current Frequency Response (I/F)	Impedance (Z) in AC Ohms	Inductance (L) in millihenries
Vendor A	0.113	79.5	-45.5	51.8	41.2
Vendor B	0.115	80.8	-46.2	54.6	43.5
Vendor C	0.126	73.2	-42.6	46.1	36.7

Figure 4: Comparison of three different coils

An ATPro5 tester was used to test the 3 different coils (Figure 4). It was noted that the coils also varied in magnetic field strength based upon subtle differences in the pole pieces that marked them slightly different, such as tabs, etc. Different field coil cores (laminations) that are different thicknesses, different steels, and even the same steel but different ages or stripped differently can cause variations between each field coil, which are directly affected by the magnetic properties of the field core. A best practice is to use coils with similar characteristics.

Voltage Drop Test-. "In the latest repair standards including IEEE Std 1068-2015, "IEEE Standard for the Repair and Rewinding of AC Electric Motors in the Petroleum, Chemical, and Process Industries," 6.3.3 'Pole Pieces and Field Coils for Synchronous Rotors,' still states to perform an AC voltage drop test across field coils with a tolerance of 10% from the average reading (5% with a DC voltage drop test). The test is normally performed at 120 – 240Vac. The ANSI/EASA AR100-2020, "Recommended Practice for the Repair of Rotating Electrical Apparatus," p. 16, "Shunt, Series, Interpole, Compensating, and Synchronous Rotor Windings," recommend an AC voltage drop test (as well as providing other options; however, the AC Voltage Drop test has been the gold standard for over 150 years). Additional testing such as the surge test may also continue to be used, but it should be performed by sending impulses in one direction then switching the leads and running the opposite direction" (Penrose, 2022).

ATPRO5 Test- Low voltage and frequency-based testing methodology which includes resistance, impedance, inductance, phase angle, current-frequency response, and insulation resistance. Used to compare phases or coils to each other with variations in windings, insulation breakdown, loose connections, wire size and other variations identified. Reference IEEE 1415-2006.

Stator Qualification

The assessment continued with reviewing how stators are qualified. Stators are qualified using a megger to detect any grounds. If a ground was found, the stator would be sent to a vendor for repair. It was determined that more testing could be done to detect stator failures and ensure an even more reliable main generator was produced. While working with the vendors that repair the stators, they recommended performing a core loss test.

Figure 5: Core loss test being performed.

A generator is designed to produce electricity. Core loss testing is measuring how much efficiency is being lost during the electricity generating process.

Core loss test: This is the test that is automatically performed by the core loss tester. This test is used to identify damaged or deteriorated sections of the core that may contribute to increased energy losses. This test energizes the stator to the normal operating current. This process tests for eddy current and hysteresis loss. Core loss test uses Watts per pound to measure how much efficiency is being lost in the core laminations. For generators watts is electrical energy being wasted as heat. The lesser amount of W/lb the more efficient the generator will perform. Ref. IEEE 62.2 and 1068-2015.

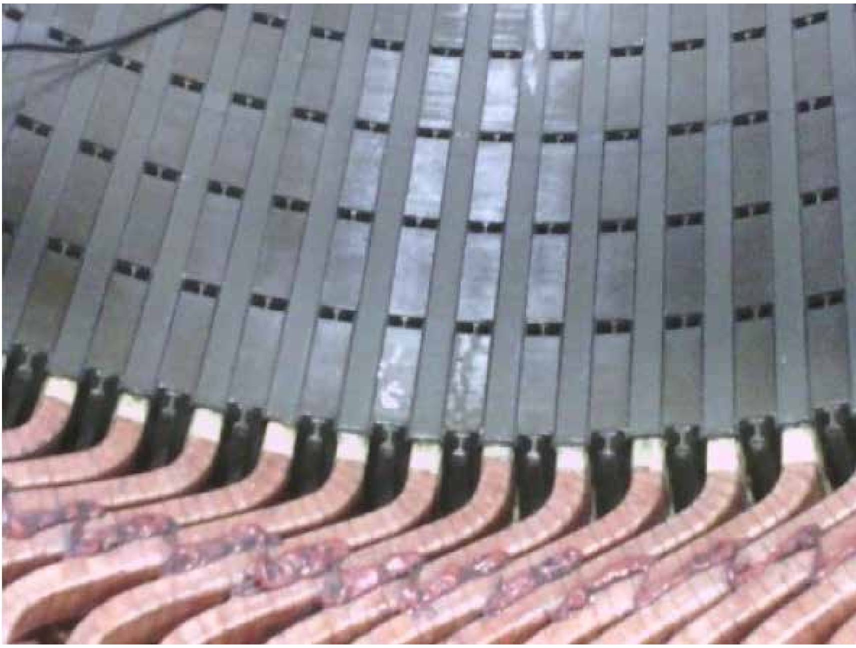


Figure 6: Core laminations being tested during core loss test.

1. Hysteresis loss (watts): energy loss caused by the continuous reversal of magnetic domains in the core material as it follows the alternating magnetic field. This value can only be changed in newer energy and premium efficient core steels with extreme heat beyond what is expected through industry standard temperature-controlled burnout oven practices as identified by EASA (Electrical Apparatus Service Association and the US Department of Energy).
2. Eddy current loss (watts): energy loss due to the circulation of induced currents within the core material. The separation of laminations with insulating material is used to keep this value low. Small shorts from smearing, breakdown of insulating material, small burrs across laminations, and other defects.
3. To some extent warped laminations will also cause deficiencies in core loss and hot spot tests due to a fringing effect.

Hot Spot Test: Hot spot test energizes the stator to an above normal operating condition to see if any laminations are shorted together and to check if any insulation is breaking down in the stator Figure 7 and figure 8). This is not considered a destructive test under IEEE 1415 and hot spots shall not exceed 10C over the ambient of the core.

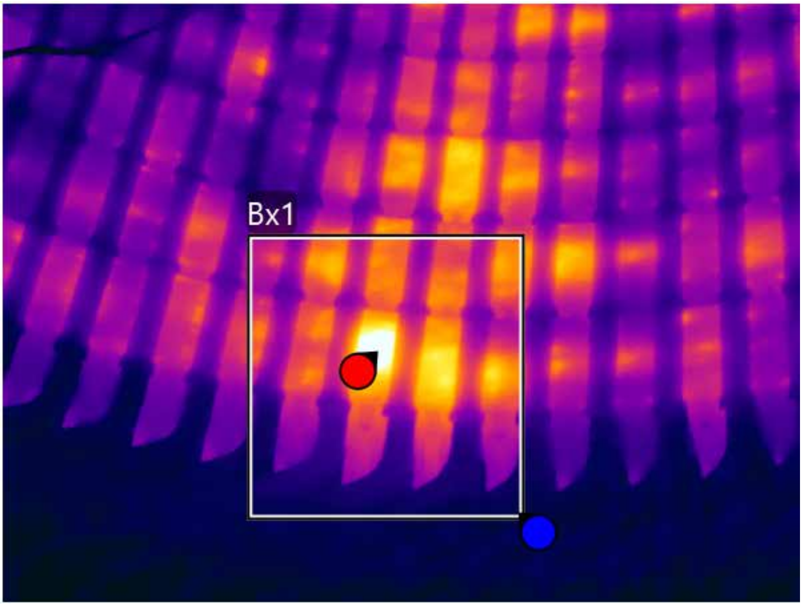
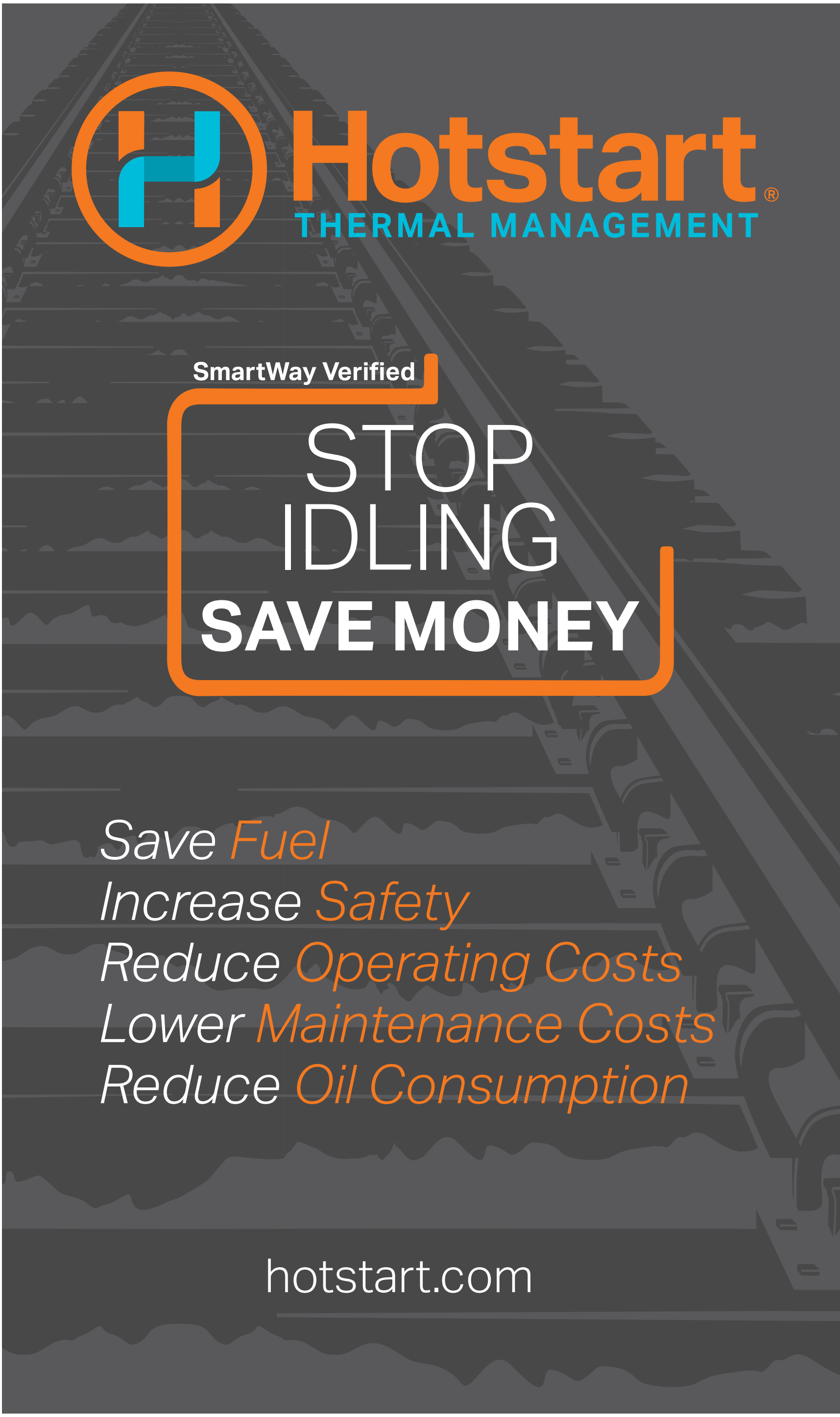


Figure 7: Example of a hot spot due to insulation breaking down.


Figure 8: Insulation defect identified with visual inspections.


Hotstart®
THERMAL MANAGEMENT
SmartWay Verified
STOP
IDLING
SAVE MONEY
Save Fuel
Increase Safety
Reduce Operating Costs
Lower Maintenance Costs
Reduce Oil Consumption
hotstart.com

In summary for core loss testing: Core loss testing is measuring the efficiency of the actual core lamination sections in the stator. The hot spot test is checking for shorted laminations and the effectiveness of the insulation between the laminations. The two test are important and are needed to determine how much efficiency is being lost in the laminations and insulation. Too much efficiency loss will cause the stator to prematurely fail due to excessive heat.

Closing:

Partnering with generator industry leaders, peers and vendors can be a great way to benchmark processes that can be integrated into existing processes that can improve the reliability of components. There are many characteristics of a Locomotive Main Generator. Carefully considering how to qualify these many characteristics and implementing these tests will reduce premature failures.

References

IEEE. (n.d.). *IEEE Standards Association*. Retrieved from IEEE.org: https://standards.ieee.org/ieee/1068/5899/

Jiguparmar. (2011, Dec 22). *What is Hipot Testing (Dialectirc Strenght Test?* Retrieved from EEP: https://electrical-engineering-portal.com/what-is-hipot-testing-dielectric-strength-test

Penrose, D. H. (2022). *TA17 Generator Repair Report*.

Electrical Component Lifecycle

By:
Jeremy Jovenall, Cattron Global

Introduction

This paper will discuss the methods to improve component lifecycle and overall system reliability during the design phase and in production. We will also discuss how reliability and component lifecycles affect the overall functional safety of a system or subsystem, along with regulations that affect locomotive electronics.

Acronyms

<table>
<tr><td>AAR</td><td>Association of American Railroads</td><td>HASS</td><td>Highly Accelerated Stress Screening</td></tr>
<tr><td>CFR</td><td>Code of Federal Regulations</td><td>IEC</td><td>International Electrotechnical Commission</td></tr>
<tr><td>FRA</td><td>Federal Rail Administration</td><td rowspan="2">MSRP</td><td rowspan="2">Manual of Standards and Recommended Practices</td></tr>
<tr><td>EMI</td><td>Electromagnetic Interference</td></tr>
<tr><td>ESD</td><td>Electro-static Discharge</td><td>RFI</td><td>Radio Frequency Interference</td></tr>
<tr><td>HALT</td><td>Highly Accelerated Lifecycle Testing</td><td>SIL</td><td>Safety Integrity Level</td></tr>
</table>

49 CFR 229 Subpart E

This subpart of the Code of Federal Regulations defines requirements for safe design, operation and maintenance of safety-critical electronic locomotive control systems, subsystems and components. There are more stringent Subparts H and I for train control systems.

49 CFR 229 Subpart E predominantly defines processes that are required for locomotive electronics design and operation from a safety viewpoint. In Appendix F for this Subpart, seven standards are recognized by the FRA as being sufficient guidance for risk analysis processes during design of safety-critical locomotive electronics. One of the recognized standards is IEC 61508, which will be discussed in this document. The six other standards that will not be covered in this presentation are:

- U.S. Department of Defense Military Standard (MIL-STD) 882C, “System Safety Program Requirements”
- The most recent CENLE/IEC Standards as follows:
    - EN50126:/IEC 62278, Railway Applications: Communications, Signaling, and Processing Systems Specification and Demonstration of Reliability, Availability, Maintainability and Safety (RAMS);
    - EN50128/IEC 62279, Railway Applications: Communications, Signaling, and Processing Systems Software for Railway Control and Protection Systems;
    - EN50129, Railway Applications: Communications, Signaling, and Processing Systems-Safety Related Electronic Systems for Signaling; and
    - EN50155, Railway Applications: Electronic Equipment Used in Rolling Stock.
- ATCS Specification 140, Recommended Practices for Safety and Systems Assurance.
- ATCS Specification 130, Software Quality Assurance.
- Safety of High Speed Ground Transportation Systems. Analytical Methodology for Safety Validation of Computer Controlled Subsystems. Volume II: Development of a Safety Validation Methodology. Final Report September 1995.
- ANSI/GEIA-STD-0010: Standard Best Practices for System Safety Program Development and Execution

(Source: eCFR)

IEC 61508

IEC 61508 is an international standard published by the International Electrotechnical Commission. During the design of a safety-critical or vital system, IEC 61508 defines methods on designing, deploying and maintaining safety systems. Within these methods, safety is directly tied to reliability since a properly designed system should have safety hazards sufficiently mitigated until a hardware failure occurs.

Another point made in this standard is that adding diagnostic coverage can help the system detect a failure, but this has limited value if there is no recourse designed into the system. Using checked redundancy in critical circuits is one way to reduce the probability of a failure on demand. With this approach, there are multiple paths or methods for the system to accomplish the function. If one path cannot complete the function the alternate path does. For this approach to be practical, the system has to have diagnostic coverage to both paths, or the ability to determine which path was used. This is required so that the failure of one path can be detected and repaired at the first convenient time with minimal impact on operation.

The standard also defines Safety Integrity Levels of 1 – 4. This SIL rating is derived from a calculation of hours before a failure on demand is considered acceptable. There are many variables that go into the SIL rating calculations, but the primary goal is to determine the estimated amount of time before a failure that affects safety occurs.

The target SIL rating depends on application. Figure 1 shows an example of SIL ratings, probability of a failure on demand and industries / application examples for SIL ratings. Locomotive electronics are typically between SIL 2 and SIL 3 depending on their application and regulatory bodies monitoring their operation. While SIL rating only applies to developments made under IEC 61508 guidelines, a similar level of planning, documentation, testing etc. is required under Subpart E. As a comparison, air brakes and control systems are likely designed to be equivalent to SIL 3, while less mission-critical subsystems would likely be SIL 2 if they can affect safety.

Per the 61508 standard, SIL 1 or SIL 2 ratings can be self-certified by the developing group. SIL 3 and SIL 4 certifications require a 3rd party to review all design documentation, process documentation etc. to certify the developing group's work and calculations.

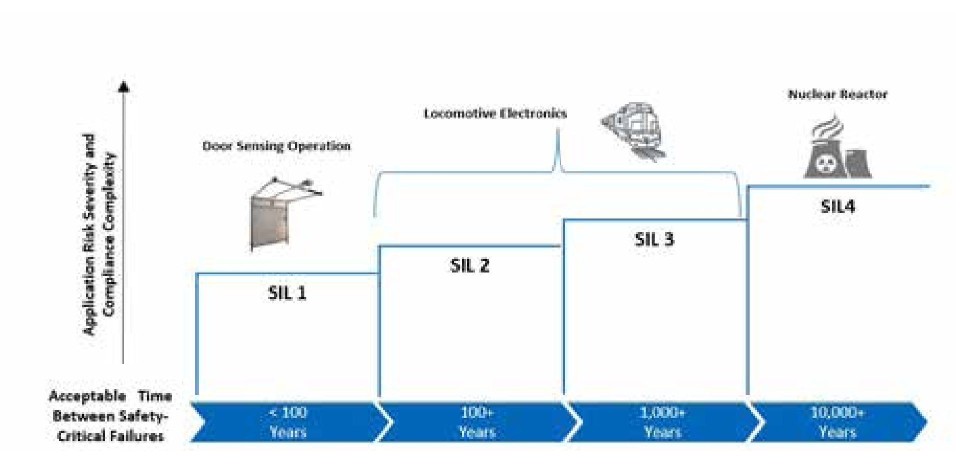


Figure 1. SIL Rating Examples

Environmental Concerns

One of the biggest risks to electrical component lifespan is environmental variables, assuming that the circuit design is sound.

Aside from *extreme* cold, electronic components tend to last longer in colder environments. Heat sinks, cooling fans or active climate control can improve the environment so that the subsystem as a whole can meet AAR MSRP recommendations for temperature ratings. For electro-mechanical devices or circuits such as electrically controlled pneumatic components, freezing is also a concern. Active heating is an important method of preventing freezing, but consideration should also be made when selecting the material for the wetted components. Some operations add chemicals to the locomotive air system to permit lower temperature operation, but these chemicals can damage some rubber and plastic gaskets, diaphragms, etc. The climate control of the system should be validated with as much vigilance as any other portion of the design.

Mechanical shock and vibration can have a horrible effect on the mechanical aspects of components or circuit boards. These effects can include broken solder joints, damage to wiring and stress to multi-layer circuit boards. This type of issue can be extremely difficult to track and trend once a product is fielded, but a controlled environmental qualification can be an early warning to adjust the mechanical aspects of the product prior to production. Vibration damping mounting studs can be valuable, but sometimes simply rearranging a layout, adding mounting holes or other relatively simple methods can reduce the damage to sensitive components and subsystems.

EMI and RFI (Electromagnetic Interference and Radio Frequency Interference) are also common causes of environmental damage to components. This is another situation that must be resolved at the design phase with rigorous testing. Solutions to issues uncovered during EMI/RFI testing can include improving grounds, shielding and filtering with capacitors, coils and/or resistors, depending on what frequency and amplitude of interference needs to be removed.

The Bathtub Curve

Components can fail in what has been termed a ‘bathtub curve’ where the majority of failures are realized in the beginning and end of the product lifecycle. The ‘early failures’ are the highest failures at the beginning of the product life. The ‘wear out’ failures occur toward the end of the product lifecycle due to components wearing out. Not all products have failure rates that follow this curve, but the trend has been noticed and documented for some products and components.

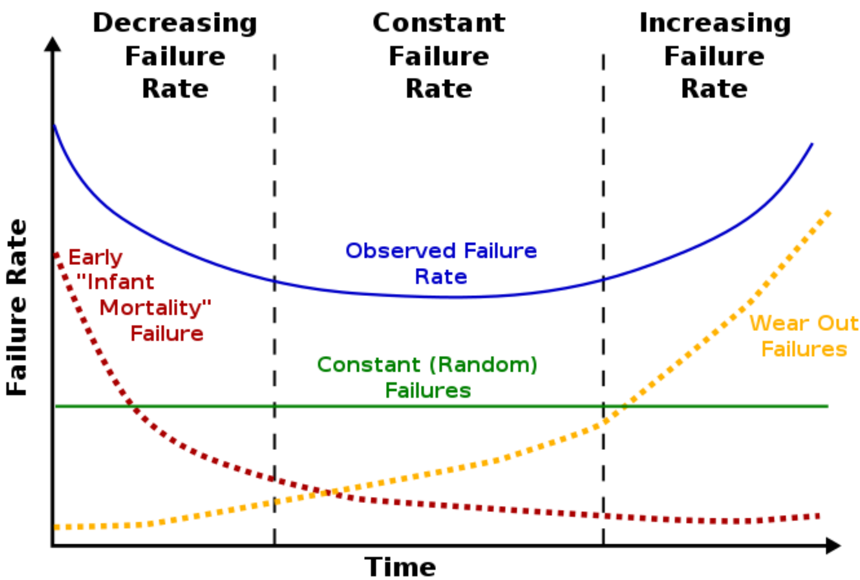


Figure 2. Bathtub Curve (Source: Wikipedia)

HALT and HASS Methods

During design validation, the HALT method (Highly Accelerated Life Test) can be a valuable way to understand where the system's environmental breaking point is. HALT is a test-to-fail method where the prototype is subjected to environmental conditions beyond specifications or expected real world conditions. The intent with this type of testing is to understand what fails and why, which leads to decisions on whether or not to improve the prototype to survive the intentionally out-of-specification conditions that it was intentionally put through. The HALT method can increase the time before 'wear out' failures occur in a product lifecycle if the potential improvements were made after the assessment.

At the production level, the HASS method (Highly Accelerated Stress Screening) exposes the system to critical environmental exposure in an effort to weed out weak components, process damage and assembly issues prior to shipment. Some environmental testing that can occur during the HASS process include high and low temperature extremes and/or vibration. The HASS method can cause early failures in a product to be discovered during QA testing instead of in the field.

ESD Protection

ESD, or electrostatic discharge, is a transfer of electrical charge between two points. If you've ever received a shock while touching a doorknob or other metal fixture in low humidity conditions, you are familiar with ESD. Surprisingly though, ESD events that cannot even be felt still have the potential to damage solid state electronics.

As locomotive electronics become more complex and microprocessor based, ESD protection should be observed on applicable components. When installing cards that the vendor ships in ESD-protection bags, the cards should remain in the protective bag until installation. It is also recommended that the card that is being replaced is stored in the ESD-protection bag after it is removed from the system. In some shop conditions, ESD-protective wrist straps or heel straps can be used to mitigate the potential component damage use to ESD.

The following images are two examples of ESD warnings. If these or similar icons are present on bags holding electronics, extra care should be taken when handling the hardware.

Figures 3 & 4. ESD Warning Sign Examples

Figure 5. Card in ESD protective bag. Note that the card is shown sticking out for example only, the bag needs to be sealed to be effective.


Bach-Simpson
A Division of Wabtec Canada, Inc.
MONITORING SOLUTIONS
Established in 1946, Bach-Simpson™ is a leading supplier of electronic instrumentation and control systems for the rail and transit markets.
Known for our quality and reliability, Bach-Simpson offers state-of-the-art products of exceptional performance and reliability tailored to our customer's needs.
TMS
ALARM
WWW.BACH-SIMPSON.COM
• 1-800-265-9706 •

Closing

Premature component failures and unexpected failures on demand can cause safety hazards and damage a product reputation. Through the use of existing standards and methods, products can be designed with reliability and safety as the highest priority and sent into Production after stress screening. Adopting the standards and methods that best fit your products and processes can improve the overall reliability and functional safety of your products.

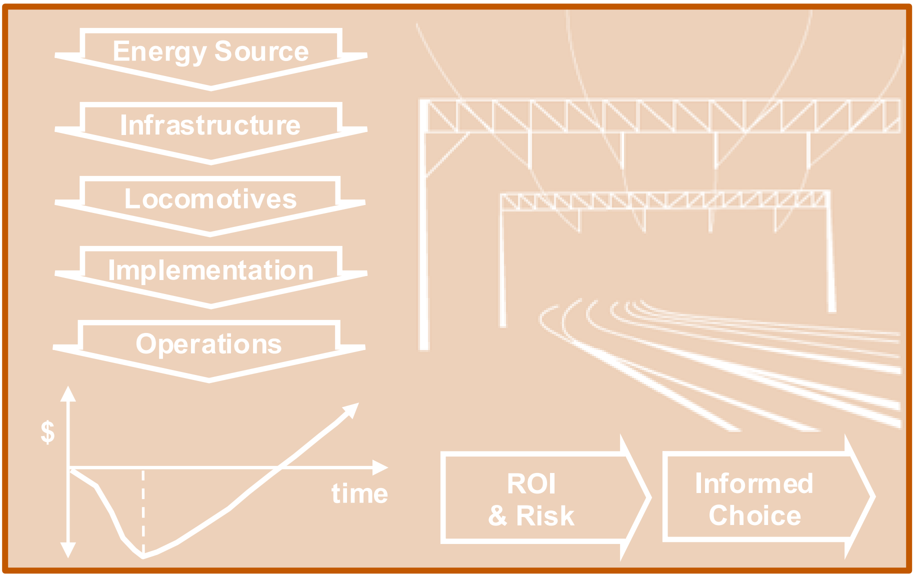
References include citations and electronic links for these works cited:

1. https://www.ecfr.gov/current/title-49/subtitle-B/chapter-II/part-229/subpart-E

2. https://en.wikipedia.org/wiki/Bathtub_curve

3. AAR MSRP K-V ELECTRONICS ENVIRONMENTAL REQUIREMENTS AND SYSTEM MANAGEMENT

Cost and Benefit Risk Framework for Modern Railway Electrification Options (FRA-RS-001)



Expected Outcomes Improving Railroad System:

- holistic understanding of primary barriers
- comprehensive evaluation of new approaches to operations and implementation that improve benefits and reduce costs, timelines and risk will also guide future research and development
- novel Monte Carlo framework for analyzing updated electrification benefits/costs will yield a return on investment distribution to quantify risk
- more informed technology decisions and greater certainty in feasibility of new options to electrify

FRA Task Monitor: TBD

Project Description and Objectives:

- develop updated costs and benefits for modern innovative approaches to railway electrification
- review previous electrification studies to identify critical technical and economic barriers
- scan alternative technologies and operation and implementation approaches to identify solutions
- develop an updated cost-benefit framework that considers carbon-focused decision environment plus uncertainty and risk in return on investment
- case study to show benefit and cost sensitivities

Cost & Schedule:

- FRA Funds Requested $200,000
- Total Project Cost $200,000
- Schedule: 12 months with interim deliverables
- Deliverables: Interim technical memos on past study review and new electrification options; updated benefit-cost framework analysis tool; case studies in final report and presentation

TEXAS
The University of Texas at Austin

Michael Iden, P.E.
Tier 5 Locomotive LLC
Jim Blaze
Railroad Economist

Project Advisory Panel: Rail Industry Experts TBD