

# **LMOA**

**Locomotive Maintenance Officers Association**

**Proceedings of the  
67th Annual Meeting**

**September 19 - 20, 2005**

**Chicago Hilton & Towers**

**720 S. Michigan Ave.**

**Chicago, Illinois**



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*The sleek, new 3,600-hp MPXpress™ units are the first commuter locomotives in service that meet APTA crashworthiness standards for optimized crew safety. The clean burning engines exceed current EPA standards and have reduced fuel consumption by more than 20% when compared to the units they replaced.*

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## 2004 LMOA MVP RECIPIENTS

The executive board of LMOA wishes to congratulate the following individuals who were selected as the Most Valuable People of their respective committees in 2004.

<u>Name</u>	<u>Company</u>	<u>Committee</u>
Dean Becker	Electro Motive Division	Diesel Electrical Maintenance
Jeff Cutright	Norfolk Southern Corp.	Diesel Mechanical Maintenance
Rich Dalton	Motive Power Inc.	New Technologies
Chris Fette	Trans Equipment Supply	Shop Equipment & Processes
Fred Girshick	Infineum	Fuel, Lubrication & Environmental
Pat Johnson	Norfolk Southern Corp.	Diesel Material Control

This honor is bestowed on an annual basis to those individuals who perform meritorious service and make significant contributions to their respective technical committees.

## LMOA EXECUTIVE COMMITTEE

**THE LMOA EXECUTIVE COMMITTEE  
WOULD LIKE TO EXPRESS THEIR  
SINCERE APPRECIATION TO  
THE BURLINGTON NORTHERN  
SANTA FE RAILWAY FOR HOSTING  
THE 8TH ANNUAL LMOA  
JOINT TECHNICAL COMMITTEE  
MEETINGS IN OVERLAND PARK,  
KANSAS ON MAY 1ST AND 2ND, 2005  
AND FOR THE SHOP TOUR OF  
ARGENTINE SHOP AND THE TOUR OF  
THE BNSF TRAINING FACILITY.  
SPECIAL THANKS GO TO GLENN  
BOWEN AND BRAD QUEEN OF THE BNSF  
FOR COORDINATING THE DETAILS  
OF THE MEETINGS**

**WE THANK YOU FOR YOUR SUPPORT  
OF OUR ORGANIZATION,  
LMOA GENERAL  
EXECUTIVE COMMITTEE**

## PAST PRESIDENTS

- 1939 & 1949 -** F. B. DOWNEY (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) Asst. Vice-Pres.- Equipment, Seaboard 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, Seaboard 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, Southern 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) Gen. 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 Joilet & 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, Burlington Northern Railroad  
**1975 -** L. H. BOOTH, Retired Assistant C.M.O.-Locomotive, Chessie System, 906-13th Ave., Huntington, W.V. 25701  
**1976 -** J. D. SCHROEDER, Retired Assistant C.M.O.-Locomotive Burlington 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, Retired Senior Vice President Equipment, Trailer Train Company, 289 Belmont Road, King of Prussia, PA 19406

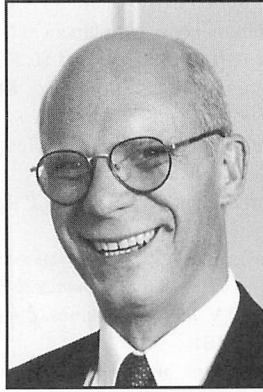
- 1980 -** J. H. LONG, Retired Manager Locomotive Dept., Chessie System  
5454 Cleander Drive, Cincinnati, OH 45238
- 1981 -** R. G. CLEVENGER, Retired General Electrical Foreman, Atchison, Topeka & Sante Fe Rwy.
- 1982 -** N.A. BUSKEY (Deceased) Asst. General Manager-Locomotive, Chessie System
- 1983 -** F. D. BRUNER (Deceased) Asst. Chief Mechanical Officer-R. & D. Union Pacific Railroad
- 1984 -** R. R. HOLMES, Retired, Director Chemical Labs and Environment, Union Pacific
- 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 & Vice President, Ontrack,  
8913 West 161st St., Overland Park, KS 66085
- 1987 -** D. L. WARD, (Deceased) Coord.-Quality Safety & Tech. Trng. Burlington Northern R.R.
- 1988 -** D.G. GOEHRING, Retired, Supt. Loco. Maint., National RR Passenger Corp.,  
1408 Monroe, Lewisburg, PA 17837
- 1989 -** WILLIAM A. BROWN, Retired, I&M Rail Link,  
9047 NE 109th St., Kansas City, MO 64157
- 1990 -** P. F. HOERATH, Retired Sr. Mech, Engr. Shops, Conrail,  
Box 134, R.R. 4, Hollidaysburg, PA 16648
- 1991 -** D. D. HUDGENS, Retired, Sr. Mgr. R & D, Union Pacific, 16711 Pine St.,  
Omaha, NE 68130
- 1992 -** K. ALLEN KELLER, Retired, Supt. Loco. Maint., Reading, R.R.,  
241 E. Chestnut, Cleona, PA 17042
- 1993 -** W. R. DOYLE, Bombardier Transit, Los Angeles, CA 90065
- 1994 -** M.A. COLES, Senior Mgr.-Loco. Engineering & Quality, Union Pacific R.R.  
1400 Douglas St., Stop 1050, Omaha, NE 68179
- 1995 -** C.A.MILLER, Retired, Mgr.-Loco. Engineering & Quality, Union Pacific RR.  
1728 S. 167 Circle, Omaha, NE 68130
- 1996 -** G.J. BRUNO, Supt. - Mechanical,  
Amtrak, 187 S. Holgate St., Ste B., Seattle, WA 98134
- 1997-** D.M. WETMORE, General Supt. - Fuel Opns., NJT Rail Opns.  
1148 Newark Turnpike, Kearny, NJ 07032
- 1998-** H.H. (MIKE) PENNELL, Ellcon National, 1016 Williamsburg Lane,  
Keller, TX 76248
- 1999-** JAKE VASQUEZ, Retired, Asst. Superintendent-Terminal Services, Amtrak  
1130 Walnut Ave., Osawatomie, KS 66067
- 2000-** RON LODOWSKI, Asst. Shift Supt., CSX Transportation  
Selkirk, NY 12158
- 2001-** LOU CALA, Consultant, LJC Rail, Duncansville, PA 16635
- 2002-** BOB RUNYON, Engineering Consultant, Roanoke, VA 24019
- 2003-** BRIAN HATHAWAY, Mechanical Trainer, OmniTrax Locomotive Services,  
Temple, TX 76504
- 2004-** BILL LECHNER, Senior General Foreman-Insourcing-Air Brakes, Governors & Injectors, Norfolk Southern Corp., Altoona, PA 16601

## HONORARY LIFE MEMBERS

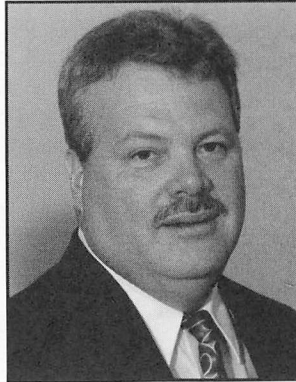
- F. W. BUNCE,** Retired Chief Mech. Officer, Milwaukee Road.
- J. J. BUTLER,** Retired Chief Mech. Officer, Consolidated Rail Corp., 158  
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- OWEN CLARKE,** Retired Vice-President, Chesapeake & Ohio Ry., Cleveland, Ohio
- B. A. CUMBEA,** Retired Mgr. Loco. Maint.-Engr., Chessie System, 310 Cherokee  
Trail, Huntington, WV 25705
- N. C. ECKERLE,** Sales Mgr. Specialty Chem., Nalco Chem. Co., 2901 Butterfield  
Rd., Oak Brook, IL 60521

- W. EWING,** Retired, Altoona Gear Co., Calbassas, CA  
**W. T. FARICY,** Retired Chairman of the Board, A.A.R.  
**J. G. GERMAN,** Retired V. Pres.-Engr. Missouri Pacific Railroad Co.  
**J. J. GREGORY,** Retired Project Mgr.-Heavy Repair Shop, Consolidated Rail Corp.,  
603 Ruskin Drive, Altoona PA 16602
- DONALD GRAAB,** Director - Loco. Maintenance, Norfolk Southern  
Box 78 110 Franklin Road SE, Roanoke, VA 24042
- S. GRAHAM HAMILTON,** President, Global Group, Inc., P.O. Box 2024, Winter Park, FL  
32790
- W. J. HARRIS,** Retired V. Pres., Research & Test Dept., Assn. of American  
Railroads, Washington, D.C.
- H. W. HAYWARD,** Retired Chief M.P. & R. S., CP Rail, Montreal 101, Quebec,  
Canada
- D. W. HENDERSON,** V.P.-Technology, Engr. & Maint. Burlington Northern RR, 9401  
Indian Creek Pkwy., Overland Park, KS 66210
- JOHN H. HERTO,** Retired V. Pres. Operations, Burlington Northern, Inc., St. Paul,  
MN 55101
- JOHN W. INGRAM,** Retired Pres. and Chief Executive Officer, Chicago, Rock Island  
and Pacific Railroad Co.
- A. W. JOHNSON,** Retired, V. Pres. of Opns. and Maint., Assoc. of American RR,  
Washington, D.C.
- JACK L. KUHNS,** Retired Mgr. Plng. & Maint., CSX Transp.,  
7015 Bedford Lane, Louisville, KY 40222
- R. M. McDONALD,** Retired Dir. of Opns., Brd. of Transport, Commissioners for  
Canada, Ottawa, Ont., Canada
- J. F. McDONOUGH,** Retired Asst. V. P.-Mechanical, Union Pacific RR, 12225 Farnum  
St., Omaha, NE 68154
- R. G. RAY BURN,** Retired Executive V.P.-Operations, Chessie System, Baltimore, MD  
**H.P. RODES,** Pres., General Motors Institute, Flint, MI 48502  
**F. R. RUSSELL,** Retired Chief Mech. Off., Southern Pacific Co., San Francisco, CA  
**L. G. SALTS,** Retired, AT&SF Rwy., Topeka, KS  
**H. L. SCOTT, JR.,** Retired Sr. V.P. and Chief Mech. Off. Norfolk Southern, Corp.  
**C. M. SMITH,** Retired Mgr-Mech. Engr.-Passenger and Loco. Consolidated Rail  
Corp., 3 Princeton Rd., Strafford-Wayne, PA 19087
- R. D. SPENCE,** Retired Executive V.P.-Operations, Seaboard System RR  
**J. TAGGART,** Retired System Mechanical Officer-Motive Power, CN Rail, 655  
Richmond Road, Unit 45, Ottawa, Ontario K2A 3Y3
- M. L. VARNIS,** Retired, BN RR, 111 So. Greenfield Rd. #385, Mesa, AZ 85206  
**R. W. VITEK,** VP - Sales and Leasing, Omnitrax, Cicero, IL

## OUR OFFICERS

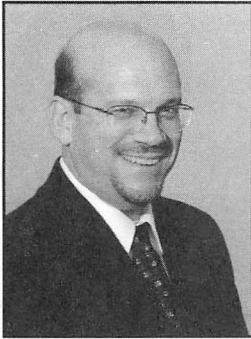


Our President  
**TAD VOLKMANN**  
**Director-Mechanical Engineering**  
Union Pacific Railroad  
Omaha, NE 68179



Our Chairman of the Nominating Committee  
**MR. BILL LECHNER**  
**Insourcing-Air Brakes, Governors & Injectors**  
Norfolk Southern Corp.  
Altoona, PA 16601

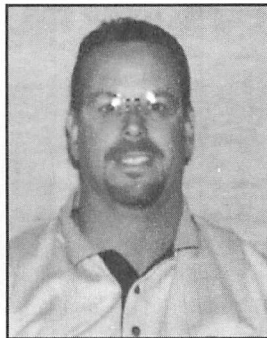
# OUR OFFICERS



1st Vice President  
**MR. BRUCE KEHE**  
Manager -  
**Maintenance Locomotives**  
EJ&E Railway Co.  
Gary, IN 46402

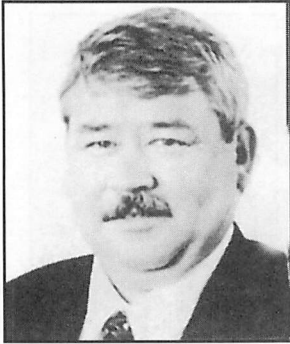


2nd Vice President  
**MR. LES WHITE**  
Tech. Sales Rep.  
Bach Simpson  
London Ontario, N5W 2C2



3rd Vice President  
**MR. MIKE SCARINGE**  
Director - Warranty Enforcement  
Amtrak  
Beech Grove, IN 46107

## OUR PAST PRESIDENTS



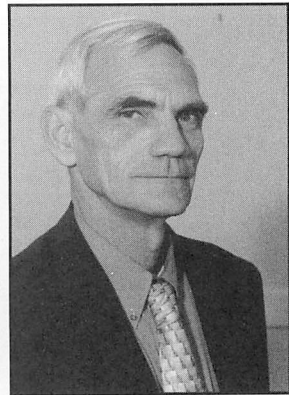
**MR. GIL BRUNO**  
**Supt.-Mechanical**  
 Amtrak  
 Seattle, WA 98134



**MR. MARK COLES**  
**Senior Manager - Loco.**  
**Engineering & Quality**  
 Union Pacific Railroad  
 Omaha, NE 68179



**MR. WEYLIN R. DOYLE**  
 Bombardier Transit  
 Los Angeles, CA 90065



**MR. BRIAN HATHAWAY**  
**Mechanical Trainer**  
 Omnitrax Locomotive Services  
 Temple, TX 76504

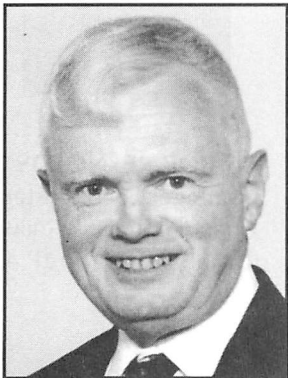
## OUR PAST PRESIDENTS



**MR. RONALD R. LODOWSKI**  
Asst. Shift Superintendent  
CSX Transportation  
Selkirk, NY 12158



**MR. H.H. (MIKE) PENNELL**  
Ellcon National  
Keller, TX 76248



**MR. ROBERT RUNYON**  
(Retired Norfolk Southern Corp.)  
Engineering Consultant  
Roanoke, VA 24042



**MR. DAVID M. WETMORE**  
General Supt. - Fuel Operations  
NJT Rail Opns  
Kearny, NJ 07032

## OUR REGIONAL EXECUTIVES



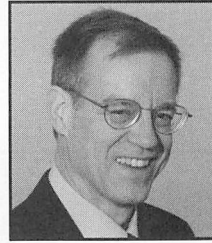
**MR. GLENN BOWEN**  
Director - Lab Services  
BNSF Rwy  
Topeka, KS 66616



**MR. JOHN BRAWLEY**  
Director-Material Management  
Amtrak  
Beech Grove, IN 46107

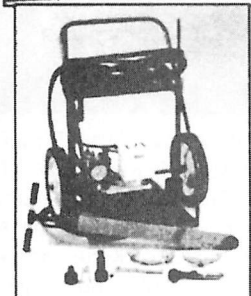
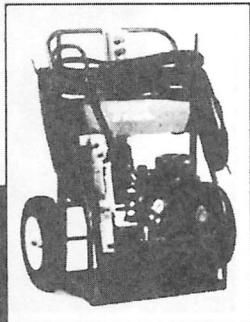
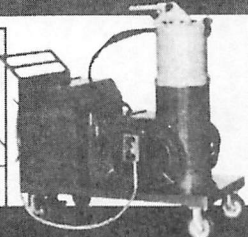
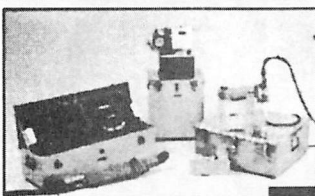


**DENNIS NOTT**  
VP - Sales & Marketing  
Motive Power, Inc.  
Boise, ID 83716



**BOB REYNOLDS**  
Manager-LoCo. Systems  
Canadian Pacific Railway  
Calgary, Alberta T2P 4Z4

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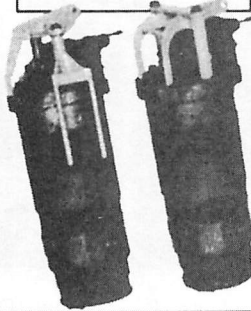
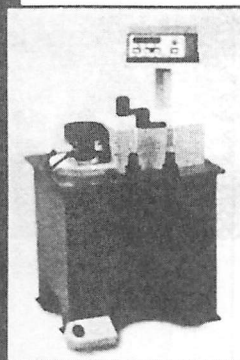
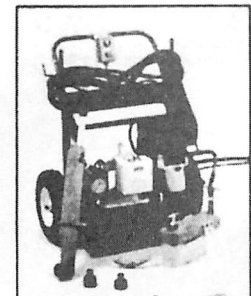
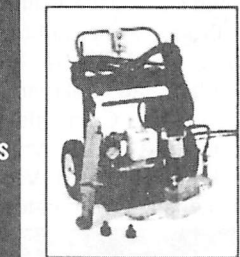
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General Executive Committee Members: Bottom Row (left to right) Past Presidents Gil Bruno, Brian Hathaway, Jake Vasquez, David Wetmore, Bob Runyon and Dale Propp - Middle Row (left to right) Regional Executive Tim Black, newly elected President Tad Volkmann, outgoing President Bill Lechner, Chairman of the New Technologies Committee, Brad Queen, newly elected 1st VP Bruce Kehe and newly elected 2nd VP, Les White - Back Row (left to right) Regional Executive Bob Reynolds, newly elected 3rd VP, Mike Scaringe and Chairman of the Diesel Electrical Maintenance Committee, Ron Bartels.



Past Presidents: Gil Bruno, Brian Hathaway, Jake Vasquez, Bill Lechner, David Wetmore, Bob Runyon and Dale Propp.



Regional Executive Tim Black, Union Pacific (left) presents LMOA attache bag to newly appointed Chairman of the New Technologies Committee, Brad Queen, BNSF. Ceremony was witnessed by newly elected President Tad Volkmann, Union Pacific and newly elected 1st VP, Bruce Kehe, EJ&E Rwy.



Past President Gil Bruno, Amtrak (right) presents LMOA blazer to newly elected 3rd VP Mike Scaringe, Amtrak, as Past President Jake Vasquez (retired Amtrak) looks on.



Past President Brian Hathaway, Omnitrax Locomotive Services (right) presents Past President's Pin to outgoing President Bill Lechner, Norfolk Southern. Past President David Wetmore, New Jersey Transit, was in attendance.



Outgoing President Bill Lechner, Norfolk Southern (center) presents gavel to newly elected President Tad Volkmann, Union Pacific, which was witnessed by newly elected 1st VP Bruce Kehe, EJ&E Rwy.



Past Presidents, Brian Hathaway, Omnitrax Locomotive Services, (left) and Jake Vasquez, retired Amtrak, converse with Past President Gil Bruno, Amtrak, during a luncheon sponsored by Dwight Beebe of Temple Engineering.

**STATE OF THE UNION SPEECH**  
**President Bill Lechner,**  
**September 27, 2004**

I would like to open this session by reminiscing a little of my past years with the LMOA. I joined the Material committee around 1990 under the leadership of Lou Cala, who was then the chairman of this committee and who had the reputation of selecting very comfortable locations for our meetings. I thought "What the heck. Get a little vacation time by giving a little help on creating papers for our meetings, and getting away from work at the same time". This committee fitted my needs very well, and so I got involved. Little did I know how important this organization was and how dedicated a lot of those technical committees were to creating papers that were extremely helpful to the railroad industry and its suppliers. As time went on, I saw the importance of the LMOA committees and how dedicated everyone was in spreading the new waves of technology with each other and, naturally, with all the railroads and suppliers. I noticed a bond and camaraderie that was formed among members of the committee. Needless to say, it was a great move on my part.

But now I would like to move in another direction and discuss some issues facing our organization in the near future. Due to the downsizing of Class I railroads and suppliers, we have had problems staffing some of our committees, mostly due to the fact that people are wearing too many hats and having a hard time

getting permission to attend meetings.

We definitely need a commitment from our Executive committee and Technical committee members that they will meet and talk to the leaders of our railroads and show them the importance and value of belonging to our committees, that sharing new technology with all railroads will help improve our services to our customers and reduce costs. Secondly, we need to become fiscally responsible and find better ways to help cut our expenses while still keeping organizations strong. We have had great support from a number of railroads and vendors that have hosted various technical committee meetings this past year. The vendors and rebuilders also help support the organization by advertising in our proceedings publication and by registering with LMOA at the conventions. Our thanks and appreciation go out to all of these vendors and railroads for their help and support.

To continue on the matter of being fiscally responsible and increasing our membership, we had an Executive Committee meeting in Memphis, TN that was very well attended by approximately 56 people. This meeting was graciously hosted by Jim Danielwicz of the Canadian National, who had everything well organized; and to top it off, he volunteered four individuals to fill spots on four different committees.

The meeting was then turned over to Tad Volkmann who discussed the recent RSI Executive Board announcement that they would not

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be able to financially support the four coordinated associations at non-exhibit year conventions.

Tad distributed a recap of the concessions that Howard Tonn of the RSI had received from the Hilton Hotel in regards to sleeping room rates and various convention-related hotel expenditures. The Hilton is also making the NE exhibition hall available free for vendors' tabletop exhibits in 2005. We are still negotiating a charge per table for displays. A portion of the revenue will be shared by four organizations (LMOA, IAROO, Air Brake and Marts). Additionally, there will be no RSI registration, so the RSI members attending the convention would be encouraged to register and pay membership dues to one of the four organizations in 2005. Organizations will be required to provide table registration personnel and badge checkers outside the meeting rooms. Also, by using our own equipment, we can reduce AV expenses. The RSI Board also voted to indemnify the four associations against loss up to a maximum of \$25,000 at the 2005 technical conference.

Discussions ensued about other alternatives such as joining up with Shortlines at their annual operations and maintenance meetings, and holding meetings at locations other than Chicago. We discussed these in detail and are still looking into other possibilities.

Suppliers expressed concern about the ability to entice vendors to pay for the tabletop space. At the joint committee meeting we dis-

cussed, and are currently looking into, using coffee breaks, wine and cheese parties, and other social gathering ideas in order to get attendees to congregate at tabletop displays, thereby giving vendors an opportunity to promote their ware.

I would like to give a special thanks to Ron Delevan for donating a LCD projector to the LMOA to help defray the audiovisual expenses incurred by the Association. Thanks, Ron.

Again, I would like to thank all suppliers and railroads that helped sponsor meetings this year. Without your support we would not be the successful organization that we are. Also a big thank you to Ron Pondel for helping me get through the year as president. As I have always said, Ron is the force that keeps LMOA going. Thanks, Ron.

Finally, I would like to thank Tad Volkmann for taking the lead on all the changes that are occurring in our organization and representing us well at the meetings. Tad is committed and is going to be an excellent president this coming year.

Thank you!

**ACCEPTANCE SPEECH  
President Tad Volkmann,  
September 28, 2004**

Mr. Chairman, members of the Executive Committee, Mr. Secretary-Treasurer, fellow members, and honored guest:

As I assume leadership of the Locomotive Maintenance Officers' Association as its 65th president, the leadership team and I reflect back on a rich heritage while looking forward to a host of exciting challenges and opportunities.

LMOA is a proud organization born in 1940 to foster the sharing of information germane to the maintenance of steam locomotives and those new-fangled diesel electrics, just beginning to make an impact in the railroad industry. One of the first technical papers produced by LMOA pored over the details of my employer's new Big Boy steam locomotive, touted as the world's largest. This claim would be disputed three years later by Norfolk & Western whose Y6B articulated steamer was heavier and boasted more starting tractive effort.

As the years passed, the wholesale conversion to diesel-electric locomotives, railroad mergers, bankruptcies, and deregulation forced a dramatic re-shaping of LMOA's market.

Today, there are but a few Class I's, more Regionals, and a host of Shortlines. The bulk of the shortlines are controlled by a few conglomerates. LMOA must find ways to remain a value to the Class I roads while becoming a value to our regional and shortline partners.

The old days of leisure and parties are long gone. LMOA is about business - the business of sharing valuable, beneficial locomotive maintenance information with all participating roads. Our joint committee meetings next Spring will not be held in Las Vegas or Tahoe; we will meet at BNSF's Overland Park, KS training center and committee members will take a benchmarking tour of the Argentine locomotive shop. **WE ARE ABOUT BUSINESS!**

In 2005, LMOA and the other coordinated associations will face a new challenge. The Railway Supply Institute, as Bill Lechner told you yesterday, will be unable to financially support our coordinated technical meetings in September. But, LMOA and the coordinated associations are determined to move forward with joint technical meetings in 2005, financial support or not. We will meet again in September 2005 at the Chicago Hilton. We may consider other locations in the future.

I view this challenge as very exciting, as it gives us, the LMOA and our supplier partners, the opportunity to further focus our joint resources and support our mutual goals, in parallel, to the benefit of all. Let me explain:

By nature, equipment maintenance is a drain on any railroad's bottom line. Mechanical departments don't make money, they cost the company money. All maintenance functions in any industry must constantly seek to enhance the efficiency of the dollars we consume, and further seek to maintain the same or better equipment reliability while reducing the maintenance

budget. We need the help of our supplier partners to show us how, with new, innovative products and services to achieve our equipment maintenance goals.

Our suppliers need a venue to bring innovative products to the attention of the railroads, which need them to increase their maintenance efficiency. Both parties, railroads and suppliers, need a forum to reach our parallel goals in 2005. With this in mind, I urge and challenge our supply industry partners to do something completely different next September - I want you to spend much less money during the technical meetings, support LMOA, and gain exposure for your products and services. I propose that our LMOA suppliers forego the renting of a hospitality suite, and instead sponsor a product display table in the Northeast Exhibition Hall. We will provide morning and afternoon breaks to insure that attendees will see your table displays.

We do not need hospitality suites; both railroads and our suppliers do need a forum to network, learn, and share information. I pledge to guide LMOA in the path of sharing best practices, networking between railroads both large and small, and benchmarking for the benefit of all of our employers and the industry at large.

Thank you!



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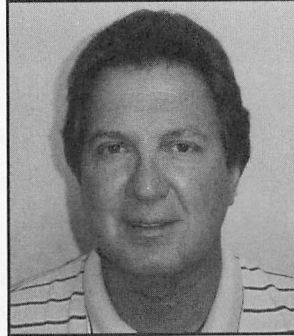
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REPORT OF THE COMMITTEE  
ON DIESEL MATERIAL CONTROL

MONDAY, SEPTEMBER 19, 2005  
8:30 A.M.



Chairman

**BOB HARVILLA**

Regional Sales Manager  
Standard Car Locomotive Group  
Stongsville, OH

Vice Chairman

**JOHN MINNIE**

Materials Manager  
BNSF Railway  
Burlington, IA

**COMMITTEE MEMBERS**

B. Ames	Sls. & Mktg. Mgr.	Progress Rail	Chicago, IL
T. Aspinwall	Dir.-Parts Sourcing	ALSTOM	Lisle, IL
R. Delevan	Mgr.-Transp. Prod.	National Carbon	Wilkes, PA
M. Gast	Sr. Procurement Mgr.	CSX Transp.	Jacksonville, FL
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P. Johnson	Supt.-Locos.	Norfolk Southern	Atlanta, GA
A. Pettigrew	Purchasing Mgr.	Rail America	Boca Raton, FL
K. Smith	Sales Mgr.	GE Transp. Rail	Jacksonville, FL
R. Sulewski	Sls. & Mktg. Mgr.	Rail Prod. Int'l	St. Louis, MO

## PERSONAL HISTORY

*Bob Harvilla*

*Regional Sales Manager*

*Standard Car Truck Co., Standard Locomotive Group*

Bob Harvilla began his career in 1973 at the General Electric Co. Cleveland Apparatus Service Center, and had a total of 22 years of service with GE. He is currently responsible for sales of the Standard Locomotive Group Companies - Durox, Triangle Engineered Products and Railway

Equipment Associates. He resides in Medina, Ohio, and works out of the Durox offices in Strongsville, Ohio.

Bob and his wife Barb have been married 29 years and have two sons: Rob, 27 and Ryan, 22.

**THE DIESEL MATERIAL  
CONTROL COMMITTEE  
WISHES TO EXPRESS THEIR SINCERE  
APPRECIATION TO THE FOLLOWING  
RAILROADS FOR HOSTING AND  
SPONSORING THEIR MEETING  
IN JACKSONVILLE, FLORIDA IN  
JANUARY, 2005**

**CSX TRANSPORTATION  
MARK GAST**

**FLORIDA EAST COAST RWY.  
GARY SUMPTER**

**THANK YOU,  
DIESEL MATERIAL  
CONTROL COMMITTEE**

## I. CENTRALIZED MATERIALS MANAGEMENT

*Prepared by Tommy Aspinwall,  
Purchasing & Logistics Director  
ALSTOM Transport*

This presentation is a step by step approach to defining, developing and implementing a centralized materials management methodology and process, that is based on a strong supply chain.

To be able to design and develop a material solution for supply chain management, you need to understand the expectations of both the customer and the supplier. Then as the service provider, you will use a number of tools and techniques, processes and methods designed to deliver the expectations of both. The detail of these tools and techniques will be described later.

The only way to meet the expectations is to identify them at the beginning.

First you need to understand what is meant by the term 'supply-chain'. The diagram of Fig. 1 shows the start and finish point from when a purchase order is placed, to when a part is delivered to the point of use. This is broken down by the key functional areas; the activity that has to take place; the type of role and a typical system you would use. The goal of this type of supply-chain and structure is to drive common systems, processes, measurement, visibility and benefits across all areas of the business and to enable the sharing of best practices and organization-

al structure to meet the goals of the customer and business.

It is recommended that this be kept simple, that it is a solution for all supply-chain activities across the total business and seamless to other functional areas of the business.

Once you have the supply-chain defined, then you have to insure that there is integration across all of those elements. Again, this can be achieved by common systems and common processes.

The supply-chain can be fragmented across all areas when implemented from supplier all the way through to the customer. The aim of integration from materials viewpoint is to eliminate duplication, inventory and time between those fragmented points.

The goal is to have single order point, single stock management, demand and usage information and a single set of tools and training. This is called ERP (enterprise resource planning).

This will give you an integrated approach to access stock, unnecessary delay and duplication across the supply chain.

The goal of the supply-chain and the targets of the business should be aligned. The key areas that we have to achieve customer satisfaction, at the same time reduce and optimize inventory, keep complete control and visibility, reduce cost but improve performance.

What this demonstrates is that there is more to supply-chain management than just the movement of the material, in fact it is a science.

There are a number of key strategies that also have to be aligned to the supply-chain. The strategy will determine the lower level changes that may have to be made to the supply-chain to meet this overall strategy (Fig. 2).

Some of the areas that you may want to consider are sourcing and procurement, optimizing the supply base, outsourcing, partnerships and very clear performance indicators.

The strategy should be complementary to the supply-chain structure and the changes to the supply-chain should be minimum as the core is standardized.

To enable control of all materials, a robust common approach is to move to part classification.

Part classification consists of breaking down your parts by value and usage. The first pass at this is to go by cost. Typically this would be A, B, and C-Class parts.

A-Class parts are high value, low volume, C-Class parts are low value, high volume and B-Class parts are those parts that fall out of the first two categories.

Once parts are classified, you can then determine how those parts are to be managed through different processes or through tools and techniques, such as JIT Kanban and Kitting (Fig. 3).

The goal of these tools is to insure material management, mate-

rial tracking, just-in-time methodology and the removal of detailed management from volume.

Once part classification has been carried out, this should then determine your logistics and distribution strategy. Such things as: consignment stocking, distribution centers, inventory policy and transportation network can all be defined from part classification.

Align this to your company systems, which should automate material movement, stock replenishment and material locations.

When talking about material management and supply-chain management, it is important to understand your organizational structure and culture. Typically, in the materials function there has been a large emphasis on expediting and date-of-collection and reporting. This type of activity can be seen as non-value added. If the effort in expending is redirected to planning, data accuracy and inventory policy then the need for expediting is greatly reduced. These activities then become value added.

If the planning activity is managed correctly, the cost of expediting is reduced and percentage of on-time delivery increases. Order planning and management is the key to on-time delivery.

As far as culture is concerned in supply-chain management, as in other functions, it is critical that everybody understands their role in the supply-chain.

One way of achieving this is to insure that everybody in the sup-

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ply-chain is clear on the inputs they require to carry out their function in the supply chain and clearly what their deliverable (output) is to the next activity or person in the supply chain.

Once these are communicated and understood, there is clear focus on who does what and when.

When you bring all of these elements together you end up with a total value-chain structure which consists of your strategy, your culture, your systems, your tools and techniques and the service that you offer.

Once this is clear and in place it allows you to go out into the marketplace and offer supply-chain management as a saleable product. It also insures centralized and controlled materials management.

In the supply chain schematic, Figure 4, you can see that whether it is a maintenance depot, a customer warehouse or a point of use for material, this will enable the customer to concentrate on this core activity of maintenance or train operation and allows a supply-chain organization to concentrate on its core activity, which is material management and supply.

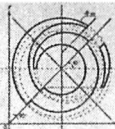
The customer will push a demand or product through the supply window to the supply chain organization and it is then their role to manage the supply-chain so as to satisfy that demand or return of product back to the customer.

As shown and discussed in this presentation, the schematic/model shows how all the elements that

have been discussed fit into the supply-chain model.

Once you have control and implemented the supply-chain model this enables you to offer different levels of materials management service, from the selling of individual parts, to a totally outsourced spares and logistics management requirement.

When your supply-chain is in place, then again you may want to revisit your customer and supplier expectations to insure that the supply-chain you've implemented satisfied both. This is a continual process since both customer and supplier expectations will change.



# Service Sourcing, Logistics & Parts – What is a Supply Chain

**ALSTOM**

	PURCHASING		WAREHOUSE MANAGEMENT								CUSTOMER SATISFACTION
ACTIVITY	Material Order	Supplier Performance	Goods Reception	Storage	Logistics Tooling (ABC)	Forecast Call-off	Depot Management	Kitting	WIP Tracking	Transport	KPI/Review
ORGANISATION	Material Planning		Warehousing / Logistics Operations			Material Planner	Warehousing / Logistics Operation				Customer Sales / Order Tracking
SYSTEMS	ERP system								radio FQ	radio FQ	ERP

### Goal

- |  |   |  |
|--|---|--|
| <ul style="list-style-type: none"> <li>- Common Systems</li> <li>- Common Processes</li> <li>- Generic Measurement</li> <li>- Best Practice Sharing</li> <li>- Agreed Benefits</li> <li>- Total Visibility</li> <li>- Common Organization</li> </ul> | } | <ul style="list-style-type: none"> <li>- Keep it Simple</li> <li>- Global Solution</li> <li>- Seamless Into Global Sourcing</li> </ul> |
|--|---|--|

It is the use of an effective supply chain that sells the business

Figure 1



## Service Sourcing, Logistics & Parts – Sourcing strategy Alignment

**ALSTOM**

- **Sourcing Strategy:**
  - Optimize the number of suppliers.
  - Introduce world class suppliers.
  - Develop existing supply chain to world class performance.
  - Introduce more demanding QCD (Quality, Cost, Delivery) targets into the supply chain.
  - Tier the supply chain to introduce “service providers”.
  - Develop a supply base to manage and supply all commodities (repair and new).
  - Outsourcing internally manufactured components, where it is economical to do so.
  - Develop the KPI’s (Key performance indicators) to reflect the improvement.
  - Form partnerships with common agree goals.

Strategy must be complementary to structure

Figure 2



# Service Sourcing, Logistics & Parts – Logistics Strategy Alignment

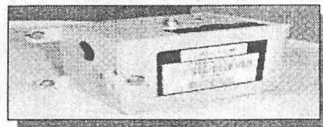
# ALSTOM

## Logistics Tools

Driving improvement into our Parts Service is integral to our business. These are some of the tools and techniques in operation with our customers today.

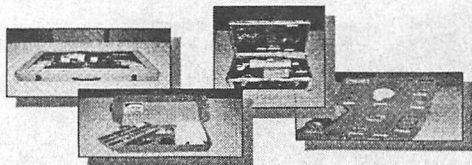
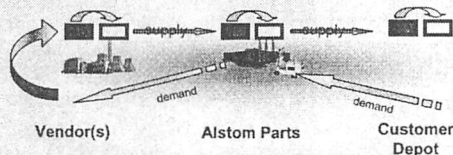


The introduction of 2-bin systems for "C" class parts in customer depots, with automatic replenishment, ensures 100% parts availability with minimum fuss.



Repairable tracking; represent two thirds of the Parts market, yet lack of identification leads to valuable parts being disposed of by mistake. Our asset tracking system minimises this problem.

More sophisticated Kanban systems are introduced for "A" class parts, optimising availability



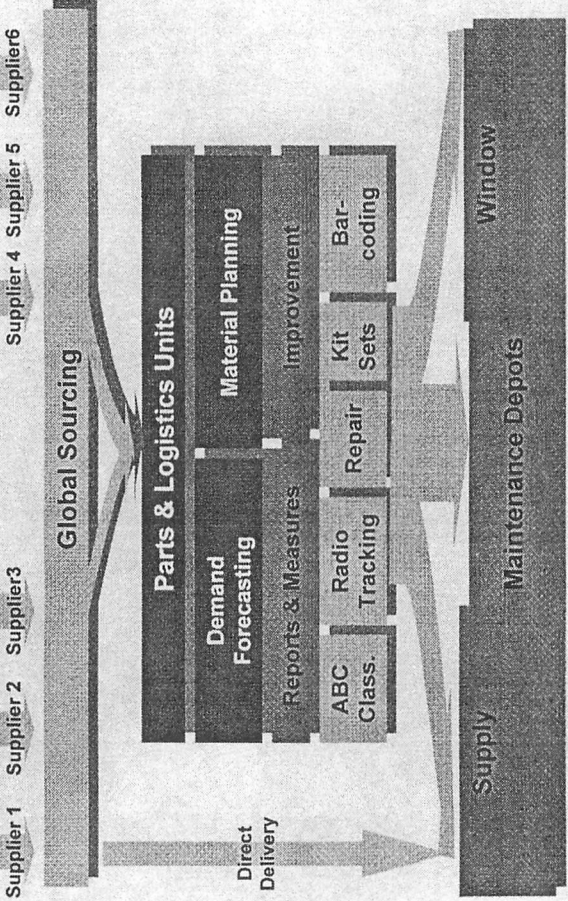
We work jointly with customers to define kits. Kits offer many benefits, including optimised maintenance activity, improved flow of repairables and "one shot" ordering.

*"Our Logistic Tools bring world-class techniques to our customer base, enhancing our Parts service to Customer"*

Figure 3

# Service Sourcing, Logistics & Parts - Supply Chain Schematic

## ALSTOM



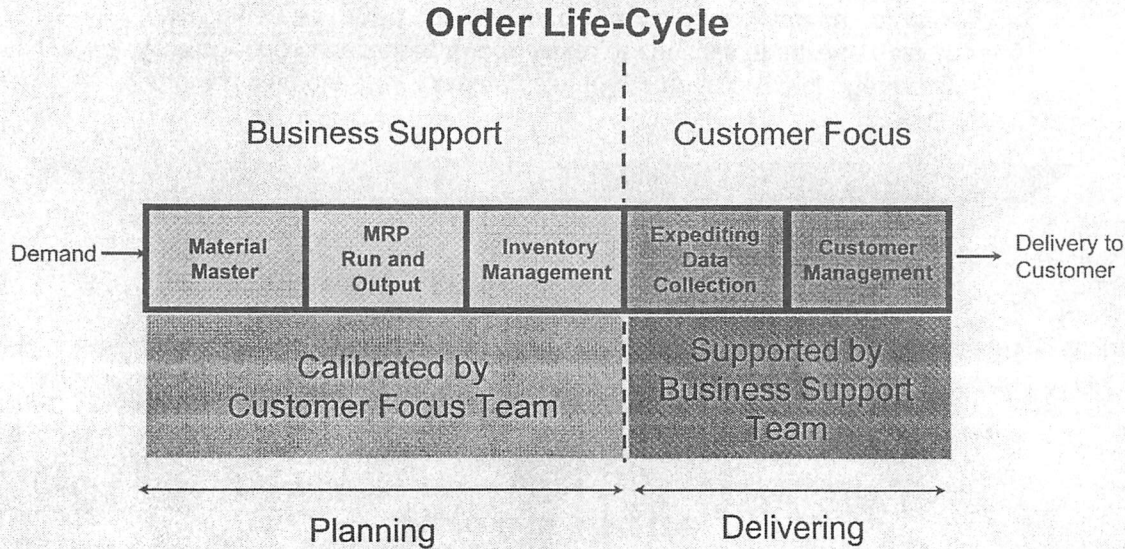
The Model for a complete materials management network

Figure 4



# Service Sourcing, Logistics & Parts - Operational Organization Structure

# ALSTOM



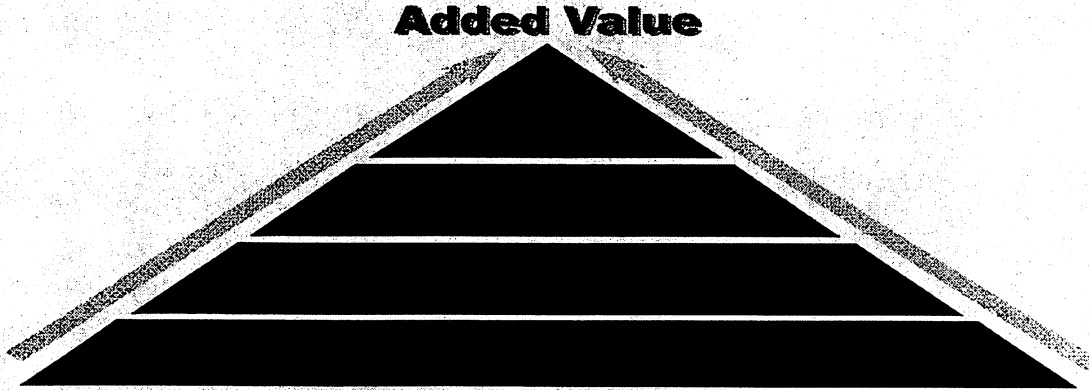
Order planning and management is key to on time delivery

Figure 5



# Service Sourcing, Logistics & Parts – Service offer

**ALSTOM**



Combined with our 100% materials management, product offering, the service offering is designed to add value. It consists of service packages which can be mixed and matched in accordance with customer requirements.

Once you have control, you have scope and flexibility

Figure 6

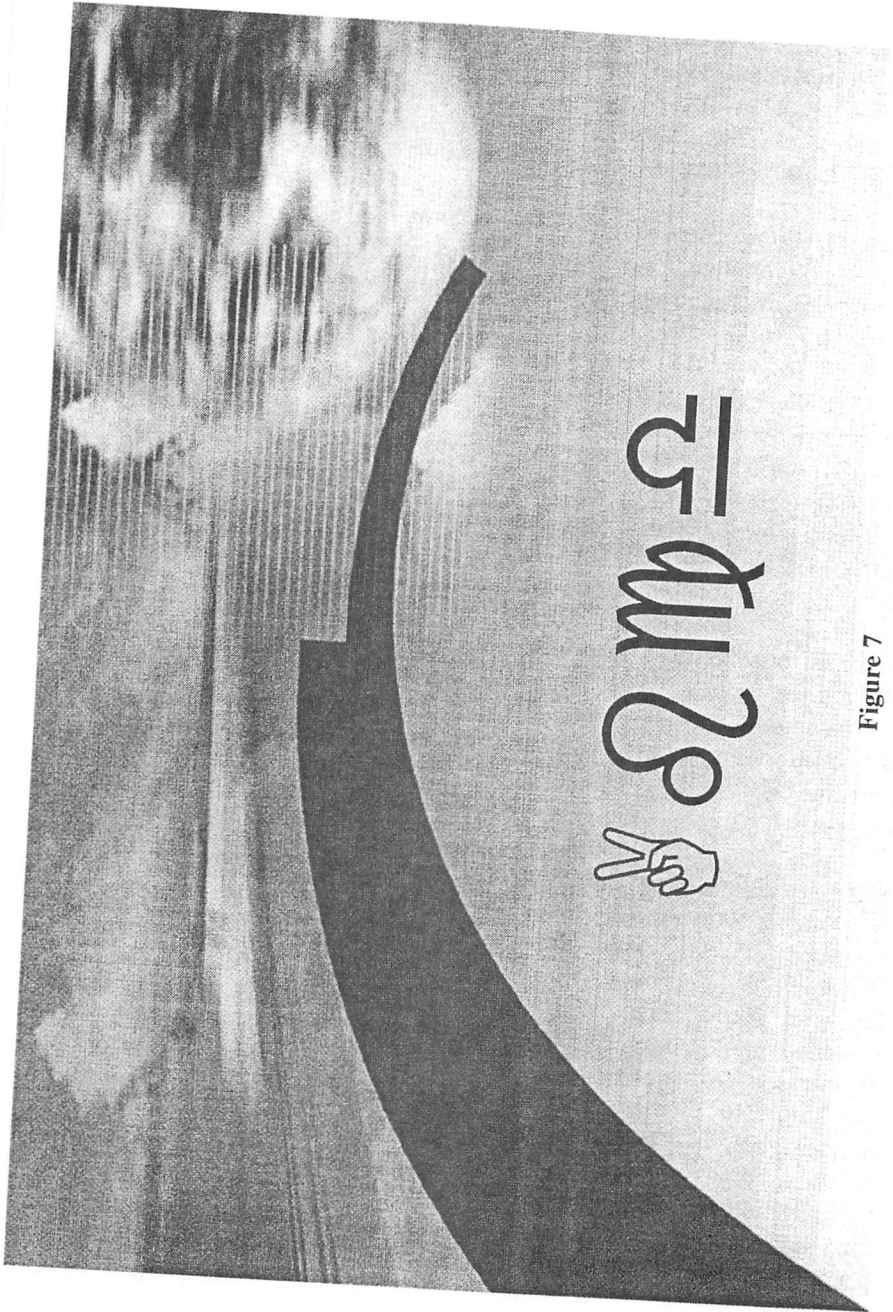


Figure 7

## II. CENTRALIZED COMPONENT CORE MANAGEMENT - CENTRALIZED WAREHOUSE - LOCOMOTIVE COMPONENTS PART A: BNSF

*Written by: John Minnie,  
BNSF Railway*

After 120 years of building, overhauling, and repairing locomotives, the decision was made in 2004 to move the locomotive overhaul work to our BNSF facility in Topeka, KS. Prior to the 1996 Burlington Northern - Santa Fe Railroad merger, the West Burlington shops worked over 200 overhauls and almost 100 necessities a year, in addition to remanufacturing almost all of the EMD style locomotive components, from injectors to generators, from valve bridges to engines. West Burlington also rebuilt a majority of the GE components necessary to support the B-30-7 and C-30-7 fleet of GE locomotives.

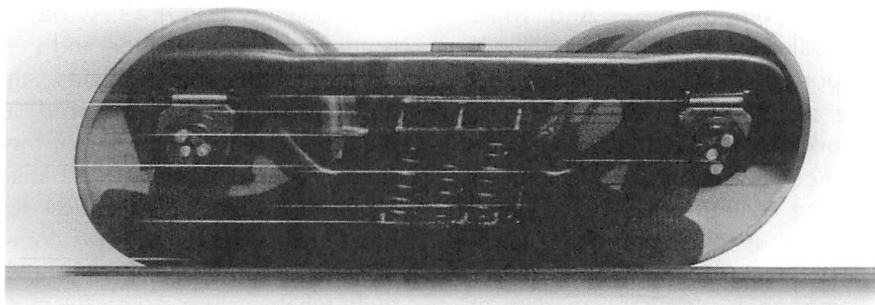
To distribute locomotive components, a dedicated trailer system was established over 25 years ago to move repaired components to the field and bring back the needing repair components. With locations ranging from Chicago to Minneapolis to Seattle and from Galesburg to Denver, and from remote areas like Havre, MT and Alliance, NE it was imperative that the railroad have a distribution system that could get components to point of use in a timely fashion. With the BN-Santa Fe merger, timely distribution of components became even more important.

With over 30,000 miles of track and additional locations extending from Chicago to Los Angeles and covering most of the Southwest United States, additional logistics challenges had to be addressed. While additional locations were added with the merger, Burlington continued to provide components to all field locations and Topeka took over the rebuild of traction motor wheel combo's.

With the announcement in 2004 that the West Burlington Shops would close at the end of the year, it was decided that the internal EMD components repair cost would be analyzed, and if it made sense and met certain criteria the components would be outsourced. Approximately 170 components met the appropriate criteria and starting January 1, 2005, the BNSF Railway Company began outsourcing specific components. Exceptions included traction motors, generators and alternators, and other specific components that will be rebuilt at Topeka. Lincoln continues to provide air brake components for the BNSF, as it had in the past.

Prior to outsourcing components a decision was made to maintain a centralized warehouse to handle the logistics involved with repairable components. Our primary concern was how to effectively and efficiently move rebuilt components to the multitude of locations on the railroad and return the needing repair components to the supplier. When the West Burlington Shop repaired

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components, all of the needing repair components had to come back to West Burlington, but did it make sense now, to continue to return needing repair components to Burlington since the Mechanical Department was gone?

The answer was yes, at least for the present time, primarily due to the amount of additional work involved with handling needing repair components. And while centralizing component handling is important for many reasons, where the warehouse is located is only important in relation to transportation cost. Burlington, IA is located on the eastern edge of the BNSF Railway, is close to major transportation lanes and most of our component suppliers are east of our location. As a result repaired components are funneled into Burlington, some via our dedicated trailer system starting in Chicago, or via LTL, or by whatever means is cost effective. These components are then receipted and placed in inventory to await orders from our field locations. Distribution via our dedicated trailer system is then utilized for all but the most distant locations where LTL, or truck load shipments are used, such as in the case of deliveries to Barstow, CA or Seattle, WA.

With the decision to outsource locomotive component, one of our primary goals was to complete the outsourcing process without creating additional work for our customers, the Mechanical department, in addition to insuring that service levels remained high.

Continuing to centralize the handling of these components accomplished those goals and required no changes at any of our field locations. Field locations continued to be set up to order their components automatically from the central warehouse in Burlington. When a component is used at a field location, it is charged out and if it breaks the established reorder point quantity (RPQ) a new order is generated in Burlington and the replenishment process begins. In the past when this occurred a request would be given to the shops, usually on a weekly basis, specifying what they needed to build to support the systems component use. The shops would build whatever was asked for plus specified shelf quantities for the warehouse and the warehouse would fill the demand, material would then be staged and shipped via our dedicated trailer system on a daily or weekly schedule. The field locations would then ship the needing repair components back to Burlington on the return leg of the dedicated trailer. The difference now is that instead of needing repair being sent to the shops for rebuild, the components are sent to an external source for repair. From the standpoint of our field customers the switch from internally repair components to outsourced components was seamless. The field continues to place all of their needing repair components in shipping containers and return the needing repair to Burlington. No paper work is

required and no additional effort is expended. Burlington sorts and identifies all needing repair components when they arrive and decides when and what needs to be repaired. Material sent out for repair is accompanied by a corresponding purchase order and all of the required paper work, i.e. packing list, bill of lading, return goods tags, etc.

The decision on what should be sent out for repair is based on system demand, historical usage, lead time and protection. In some cases usage may be low but due to the importance of the component, to protect the operation of a certain type of locomotive, inventory is kept on hand. The Burlington warehouse also monitors daily Mechanical conference calls to respond to any material issues and is in frequent contact with our Mechanical locations. Burlington also has the ability to change reorder point and order quantities at all locations in order to better respond to changes in demand.

### **What are the benefits of centralizing component handling?**

1. One stop shopping - The BNSF has 14 primary locomotive repair facilities. Instead of all of these locations contacting the various vendors with component requests they can contact Burlington and get a response on any of the 170 components handled through the central warehouse.

2. Ease of doing business - Field

locations are set up to automatically replenish stock. They simply charge the component out when they use it and if it reduces inventory to below their established reorder point, an order is automatically generated for replenishment from Burlington. No paper work is required to return needing repair components to the central warehouse. This is in direct contrast to all of the paperwork associated with repair and return or unit exchange. Purchase orders, packing list, return goods tags are all handled by the material warehouse in Burlington, which frees up craft people to repair locomotives, not handle paper work.

3. More efficient use of component pools. Component and core pools can be managed better, especially where there are limited cores. Our central warehouse ships to customers based on need vs. want by analyzing usage to determine realistic inventory levels. We also look at the logistics involved; where is the facility located, how often do we deliver to that location, how long does it take to get material to a specific location and what is the cost of expediting a shipment if necessary. Efficiently utilizing lean pools reduces the cost of maintaining expensive components in inventory.

4. Deciding when to purchase additional inventory due to attrition. It is difficult for the using department to determine when and how to replenish core compo-

nents. One location handling the pool is able to look at the entire system to determine what needs to be replenished. A centralized location can also look at cost of rebuildable cores or running take outs as opposed to buying new. Field locations want to repair locomotives, not shop for parts.

5. Reduced transportation cost - Instead of hundreds and hundreds of components being shipped to a multitude of field locations, components are now shipped to one location and redistributed via dedicated trailers. Strategically located on the eastern edge of our system the Burlington location provides reduced travel from supplier to warehouse and shipments are larger, resulting in more efficiencies, Instead of 6 injectors going to a location, Burlington may receive hundreds of injectors, instead of 4 power assemblies, we may receive a trailer load. On the distribution side we may ship 2 injectors, but they are packed in a container with a multitude of other components which are shipped in a trailer to the field location, saving inbound and outbound freight charges. With the Burlington warehouse strategically located, transit times are also reduced. Transit times between Burlington and our field locations are substantially less than commercial transportation. Burlington, IA to Minneapolis, Lincoln, Kansas City or Topeka is less than 1 day and moves to Alliance, NE or Glendive, MT are only 2 days, allowing us to run daily or weekly

schedules. Moving via dedicated trailer, in truck load quantities on an established schedule reduces cost.

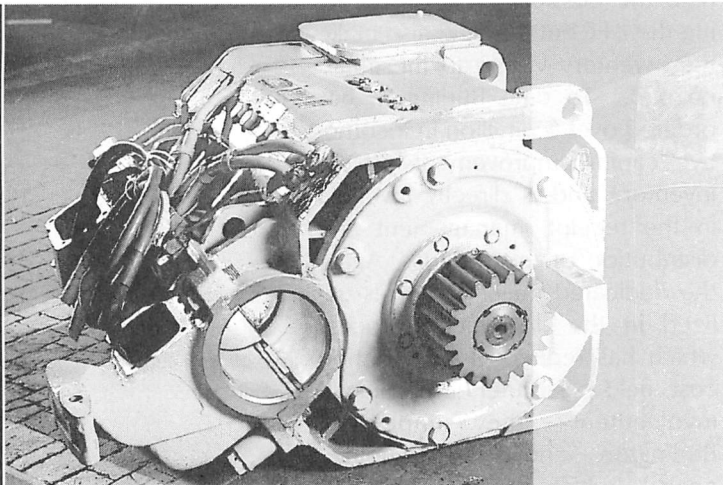
6. Material expertise and minimal staffing - The centralized warehouse personnel are experienced in handling and recognizing warranty. Over the past 12 months the Burlington warehouse has recognized and captured \$142,000 in warranty missed by the field. We also know components, and know the right questions to ask when a field location calls needing a component but does not have all of the necessary information. And if a part needs to be expedited, we know how to get it to the destination in the most timely but cost effective manner. All of this with a reduced staff - the entire operation consist of only 7 people.

Along with maintaining repairable components in a central warehouse the concept also opens the door for additional opportunities. Another project, to better utilize the central warehouse and the dedicated trailer system, was also implemented at Burlington this year.

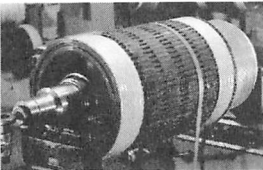
In order to make capital materials more visible it was decided to order and maintain the inventory of capital projects materials at Burlington on 2005. Instead of every location ordering what they needed it was decided that Burlington would order the material and distribute the material to the field locations on an "as called for basis." Not only would this elimi-

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nate the possibility of overspending the AFE but it would also make the inventory visible to the entire railroad. To date Burlington has ordered over \$5 million in locomotive capital improvement project inventory and is directly involved in the receipt, management and distribution of these parts. Again the dedicated trailer system is utilized in the distribution process which has reduced transportation cost, field personnel have minimal involvement - they simply call Burlington - and order what they need - which reduces handling cost, and Burlington provides information to the system on a regular basis of what is on hand or on order and what has been shipped.

Centralizing the handling of specific materials, specifically, in our case, locomotive components, has been key in maintaining an efficient cost effective method of managing expensive components. Being able to effectively manage a limited number of components can only be accomplished by centralizing the material management process in one location. Centralization of these types of materials save cost in almost every area of materials management including labor, inventory, warranty management and transportation and has proven to be extremely successful on the BNSF. While the importance of location impacts transportation savings, it is the concept of centralizing this type of inventory that provides the most amount of savings, and is imperative in improving locomotive availability

and reducing downtime waiting components.

## II. CENTRALIZED COMPONENT CORE MANAGEMENT - ROTABLE WAREHOUSE PART B: NORFOLK SOUTHERN

*Prepared by Pat Johnson,  
Norfolk Southern Corporation*

To begin I'd like to define a couple of terms that will be used in this paper. SKU is defined as a "Stock Keeping Unit" and corresponds to a unique part. For example, if your total inventory corresponds to 10 identical filters then you have 1 SKU. Conversely, if your inventory corresponds to 10 different filters then you have 10 SKU's. A rotatable part is defined as any part which is not discarded once dirty, broken or worn out but instead is rebuilt, repaired or cleaned. Typically, the cost to rebuild, repair or clean the part far outweighs the price to buy this part new. This paper details a concept for a rotatable warehouse which would centralize rotatable inventory handling for reduced expenses and increased availability.

Norfolk Southern has experienced a similar evolution in part repair as the BNSF. Norfolk Southern didn't have the luxury of an established centralized warehouse to manage the outsourced parts in advance of the outsourcing. Using concepts born out of LMOA Diesel Material Committee meetings, Norfolk Southern is in the throes of establishing a centralized warehouse titled "Rotatable Warehouse." The addition of a middle man (Rotatable Warehouse) can actually reduce handling by

reducing the quantity of shipments through reducing origin-destination (OD) pairs. As the supplier base and NS repair shops are increased in number the rotatable warehouse will effectively minimize the OD pairs necessary. NS is working with approximately 25 rotatable part suppliers so the OD pairs will be reduced from 325 currently to 38 after implementation of the rotatable warehouse.

### Overview

As an overview of the presentation we will be discussing the problems which the rotatable warehouse was conceived to solve.

We will discuss the current conditions which led to the problem and the objective in solving the problem.

We will discuss the concept for the objective and the resources needed to implement. In addition we will share with you the pay back that Norfolk Southern can realize as a result of implementing these changes.

And finally, we will discuss the suggested next steps to implement this solution.

### Problem statement

With the growing amount of rotatable material sourced from external suppliers, forecasting the demand has become problematic. Further, it is difficult to manage these inventories for the proper pool sizes, while regulating inventory levels at the multiple stocking locations has proven to be labor intensive.

### **Current conditions**

There has been a steady increase in rotatable activity with external suppliers over the last three years (Fig. 1). This trend is expected to continue because of renewed interest in outsourcing initiatives and increased maintenance activity due to EPA and Norfolk Southern requirements. Since the rotatables are tracked in our system at the value of the repair, the spend figure grossly understates the value of the material being handled. A 20 million dollar spend on rotatable repairs easily represents 100-150 million dollars worth of cores being handled.

### **Objective**

The objective of the rotatable warehouse is to achieve a system in which rotatable material stock levels can be forecast and pool sizes can be controlled without a dedicated and knowledgeable labor resource at each stocking location.

### **Concept**

The concept of the Rotatable Warehouse is an NS run storehouse facility located conveniently both for Milk Run access and to the locations which it is designed to serve.

The warehouse would inventory approximately 1000 different parts which are repaired or rebuilt by external suppliers.

The locations served by the warehouse would reduce outbound and inbound shipments since they would be sending and

receiving all of these parts to or from one location instead of having separate shipments to Wabtec, Quantum, EMD, GE etc. The rotatable warehouse would reduce outbound and inbound shipments with external suppliers because the shipments would be consolidated with cores from multiple locations.

Frequently, consumption is very uniform at the macro or system level but highly variable when looking at individual stocking locations. The rotatable warehouse would manage and distribute safety/project stock.

### **Resources**

To run a rotatable warehouse we would need a facility and two employees. The facility would need ample parts storage space as well as space for the code 3 and code 1 handlers to stage their work.

The rotatable warehouse would rely on the existing workforce at the warehouse location to perform loading and unloading at the dock with Milk Run and other carriers. The rotatable warehouse would also rely on the existing workforce for vacancy relief manpower.

### **Code 3 handler**

The code 3 handler would track each code 3 part from receiving all the way through shipping. A portion of the code 3 handler's day would be spent receiving and the remaining portion would be spent shipping. On each inbound code 3 shipment the code 3 handler would log into the code 3 handling

database class and item number, warranty status and quantities of every part received. The receiving activity would initiate core credits to return to consuming location to offset core charge which they received at consumption. While receiving, the database would determine the appropriate supplier for each part and print a PO number/CIC label for each piece. Once the code 3 handler applied labels to parts, parts would be moved to the appropriate shipment staging area for that supplier. For example, a large box for Quantum parts to be shipped every other day or a plastic crate for shipping Elcon the EMD modules they furnish us weekly.

In the shipping portion of the code 3 handler's day, the employee would finish packaging, do freight bill paperwork and lastly close the open requisition for shipments he desired to ship. Once the requisition is closed by the code 3 handler in the database, the database would do the mainframe entry portion of the requisition in the material system. The database would use option 17 and populate the notes field which is transmitted to the supplier with important tracking information and a disclaimer. The notes would read something to the effect of "THE CONTENTS OF THIS PURCHASE ORDER WAS SHIPPED TO EMD ON 3/10/2005 VIA UPS ON TRACKING NUMBER 1Z123456789, IT IS YOUR RESPONSIBILITY TO CONTACT NORFOLK SOUTHERN AT

rotatable@nscorp.com WITHIN 60 DAYS IN THE EVENT THAT AFTER 30 DAYS YOU HAVE NOT RECEIVED ALL OF THE CORES TO PAY THIS ORDER IN FULL. FAILURE TO NOTIFY NORFOLK SOUTHERN WITHIN 60 DAYS THAT THERE WAS A DISCREPANCY IN THE CORES RECEIVED IS ACKNOWLEDGEMENT THAT THE CORES DUE WERE RECEIVED IN FULL."

Lastly, the code 3 handler would transport outbound shipments to the dock for loading.

### **Code 1 handler**

The code 1 handler would track each code 1 part from receiving all the way through shipping or onto the shelf within the warehouse. The code 1 handlers' day would be divided into portions for receiving, picking and shipping. On each inbound code 1 shipment the code 1 handler would receipt and apply labels to each piece using RCIS. The handler would then move the part to a staging area for put away or pending shipment staging area if there are open picks for the part.

The put away, picking, and preparing outbound shipments portion of the day for the code 1 handler would be very similar to stockman jobs we have now at the various storehouses.

### **Payback**

Although we have made significant improvements in recent years in locomotive out of service time due to material shortages we will

be able to raise the bar (or lower the bar in this case) with a 15% improvement. This improvement will be achieved through the ability to forecast and achieve desired stocking levels at each stocking location. Currently, this material is handled in a fashion where the supplier always returns the material to the sender which tends to perpetuate imbalances.

By limiting the core exchange activity to one location which is using a database tool specifically designed for this task, we will virtually eliminate future core debt exposure.

Pool sizes required to support system demand will be reduced since lead times as viewed from an individual stocking location will be reduced. This is a direct result of the individual stocking locations having UTEX service as opposed to Repair and Return service.

With a rotatable warehouse we would gain the ability to visually recognize whether pool sizes are too large or too small. When pool size increases were needed they could be done at the rotatable warehouse with tight control over how they are expensed. When pool size decreases are warranted the surplus pool would be concentrated to one location for ease of disposal.

### **Current status**

Norfolk Southern Mechanical Department management has approved the Rotatable Warehouse Project. The chosen location to establish this warehouse is at

Juniata Locomotive Shop in Altoona, PA.

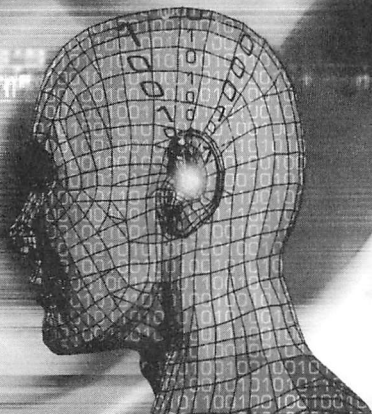
In order to successfully run a rotatable warehouse with the limited labor resources we've allocated to the warehouse, we will need to overhaul the processes typically used to conduct these activities. Development has begun on a PC database to manage the activity of the rotatable warehouse. Concurrently, a team has been organized which is rationalizing the list of parts which the rotatable warehouse will handle, as well as collect photos and weights for each of the parts.

Norfolk Southern expects to start up the rotatable warehouse in the 1st quarter of 2006.

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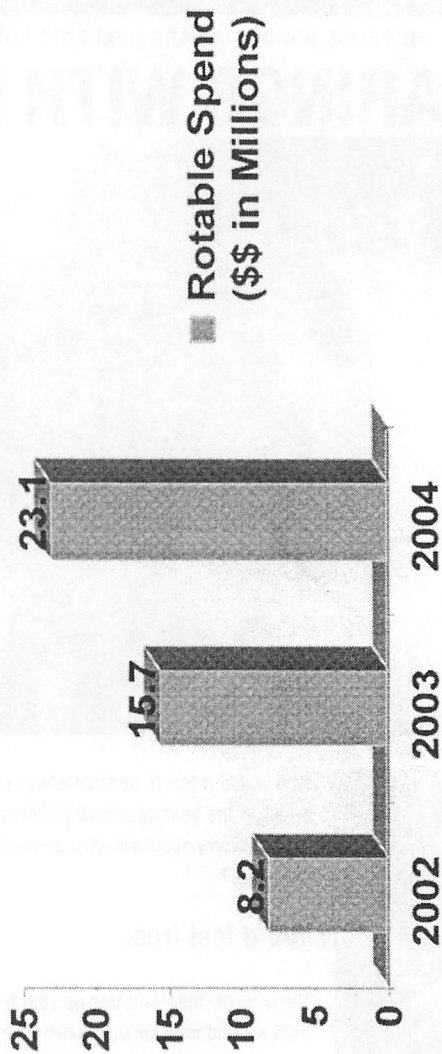
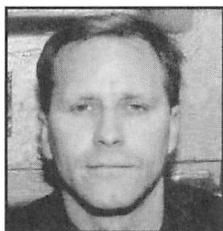


Figure 1

REPORT OF THE COMMITTEE  
ON NEW TECHNOLOGIES

MONDAY, SEPTEMBER 19, 2005  
9:45 A.M.



Chairman

**R. BRAD QUEEN**

General Foreman-Locomotives,  
BNSF Railway  
Barstow, CA

Vice Chairman

**RICH DALTON**

Director-Project Management  
Motive Power Inc.  
Boise, ID

**COMMITTEE MEMBERS**

J. Christoff	Mgr-Transportation Prod.	Nat. Elect. Carbon Prod.	Cicero, NY
M. Durham	Engineering Director	ALSTOM	Lisle, IL
J. Fedora	Specifications & Stds. Engr.	Amtrak	Wilmington, DE
K. Gilbert	Mgr.-Loco. Parts Sls.	GE Transp. Rail	Montreal, PQ
C. Prudian	Senior Systems Engineer	Electro Motive Divn.	LaGrange, IL
J. Whitmer	Loco. Rel. Specialist	CN RR	Homewood, IL

## PERSONAL HISTORY

*Ralph Brad Queen  
General Foreman-Locomotives  
BNSF Railway*

Brad, Chairman of the New Technologies Committee, was born in 1965. He graduated from high school in Lansing, MI in 1984. He entered active service in the U.S. Navy in 1984 and served in Pearl Harbor. He also did a stint in the Naval Reserves.

Brad started with the Burlington Northern Railroad as an electrician

in 1994 in Lincoln, Nebraska. In 2000, he was promoted to Locomotive Supervisor at the Topeka, Kansas Back Shop.

He was recently promoted to General Foreman-Locomotives at the BNSF Bartow, California LMIT Shop.

Brad's wife is Karen and they have been married for 12 years.

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**VEHICLE PROJECTS, LLC.  
DR. ARNOLD MILLER, Phd.  
DENVER, COLORADO  
MARCH, 2005**

## I. PL42 AC LOCOMOTIVE - OVERVIEW

*Presented by: Mark Durham,  
Engineering Director,  
ALSTOM Train Life Service, US*

### Introduction

The PL42 AC locomotive has been developed to meet the requirement of New Jersey Transit for a high performance, environmentally friendly diesel commuter locomotive.

The PL42 AC is developed from the PRIMA locomotive range using a standard platform and proven sub-systems integrated to provide a complete solution to meet demanding requirements. The locomotive is designed specifically to meet critical performance requirements including:

- 100 mph operation
- Weigh <288,000 lbs.
- Meet current structural requirements
- Meet Tier 1 emissions requirements
- Emit < 88dB with 500kW HEP load when stationary
- Meet NJ Transit acceleration performance requirements

See Figure 1 for full specification.

### Safety and environment

Critical to the design of the PL42 AC is the ability to meet current legislation for safety and environment. Specifically the use of the proven EMD prime mover, the 710G3H, has allowed the locomotive to meet the requirements of 40CFR92 for Tier 1 emissions.

Structural requirements specified in 49CFR238 and APTA C&S speci-

cations have been met by use of a monococque body structure that also provides a low gross weight. An instrumented structure has been successfully tested to demonstrate compliance with all necessary requirements.

Also, a dedicated cab cell that fits into the monococque structure provides increased crash protection for the crew, transmitting compressive longitudinal forces into the vehicle structure. See Figure 2 for a view of the cab/body structure.

Noise emissions are minimized through the use of the prime mover for HEP and the inclusion of a larger, more efficient muffler. This provides for excellent noise performance with emissions being greatly reduced compared to the existing diesel locomotive fleet.

- Idle - 60.3 dB
- Throttle 8 - 77.3dB

Noise protection for the crew is enhanced by the inclusion of a vestibule that separates the cab and engine room reducing sound levels to well below the requirements of 49CFR229.

### Power generation and HEP

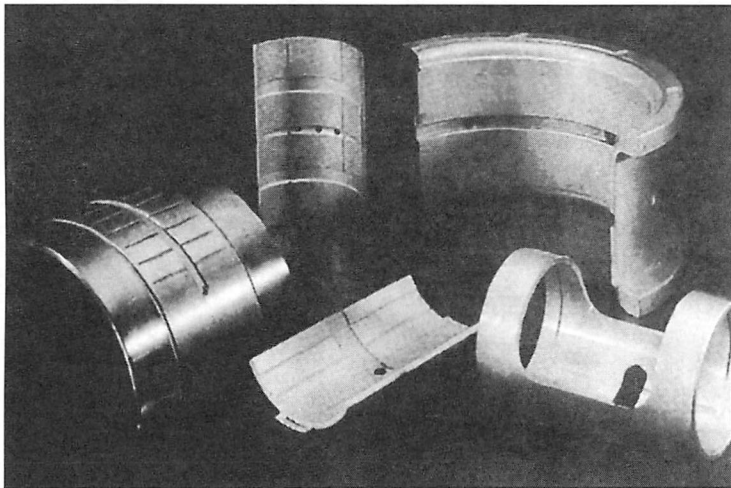
The proven EMD 710 engine is used to generate a maximum of 4200 hp. The EPA Tier 1 compliant 710G3B variant of the engine is used together with the EM2000 control system and ancillary sub-systems from components proven in the US railroad environment. See Figure 3 for a view of the prime mover and ancillary installation.

The 710 engine generates traction and HEP power through a TA17

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Alternator with the ac output being rectified and fed to the dc link.

Provisions of HEP from the prime mover has several advantages including:

- No weight of a dedicated HEP diesel engine
- No maintenance of a dedicated HEP unit required
- Noise from a dedicated HEP diesel engine is eliminated

HEP up to 800kW is provided by a water cooled IGBT inverter that takes power from the dc link. The inverter and dc link can accommodate rapid changes in HEP load in excess of the 400kW step load specified. Additionally, HEP back-up is provided by switching a traction inverter to HEP operation should the dedicated inverter fail.

### **Traction**

Use of an ac traction system provides for several advantages in the PL42 AC design. These include increased efficiency, reduced maintenance, increased reliability, and high starting tractive effort.

The use of ac traction and an approximate 40% improvement in the load rate of the diesel engine allows the optimized station-to-station run time specified to be met, even with the increased trailing load from bi-level cars.

The traction system is built from standard components. Using water cooled IGBT inverters and AGATE control technology each ac traction motor can be controlled to maximize locomotive acceleration. Sanding is automatically controlled by the traction system to enhance

adhesion. The water cooled IGBT inverters have a dedicated water pump and radiator to ensure reliable operation. Designed as line replaceable units the inverters and control units can be quickly replaced by maintenance staff if necessary. See Figure 4 for a view of the inverter module. A full diagnostic suite for the traction system is designed to support routine maintenance and fault finding.

Regenerative dynamic braking power is used for the train supply when in braking mode to increase overall HEP efficiency.

### **Train control**

The train control system uses standard equipment from the AGATE product line. The train control and monitoring system (TCMS) uses two supervision control units (SCU's). These are configured one as master and the other as stand-by. This provides a level of redundancy for this critical system.

The SCU's are modular computers that provide for easy replacement should on board diagnostics recommend board changeout.

The SCU's interface with all other on-board systems and provide integrated control and diagnostic functionality for the systems provided by many different manufacturers:

- Traction control
- HEP control
- EM2000 engine control
- EPIC 2 braking control
- Communication control unit
- Train to wayside communication
- Wheelslip control system
- ATC

The SCU's provide output to the main display unit (MDU) located on the engineer's desk. The MDU provides access to the engineer to all necessary functions through touch-screen selectable menus including:

- Set-up
- Propulsion
- Auxiliary
- Pneumatics
- Engine
- Trainline

All on-board systems have diagnostics and these functions are accessible to the engineer or maintenance staff through the MDU. A copy of all fault events are recorded by the Fault Event Recorder System which is incorporated in the MDU functionally. The fault stack may be viewed directly on the MDU screen or can be downloaded using the PCMCIA slot, wireless connection or remotely while the locomotive is in operation. The event recorder meets FRA requirements with 35 recorded parameters. See Figure 5 for a view of the MDU screen output.

### **Ride performance**

The trucks are fabricated, are bolster-less and have 44" diameter wheels. Truck structure has been validated by FEA and fatigue testing. Testing has been designed to simulate US railroad conditions which vary from those experienced in Europe. Figure 6 shows the structure of the truck.

To reduce unsprung mass to approximately 7,700 lbs. the ac traction motors are frame mounted and drive through a gearbox and flexible

coupling.

Suspension is provided by coil spring and hydraulic dampers for both primary and secondary suspension systems.

Testing at the TTCI Pueblo, CO facility has been successfully completed up to 110 mph.

### **Braking system**

The braking system uses dynamic and dual-friction systems. Regenerative braking is provided by the ac traction system, while a wheel cheek disc and tread braking system provide friction braking.

The friction braking systems operate with the cheek disc system at 75% and the tread braking system at 25% of the braking load.

An engine driven compressor provides air to the system and a centralized pneumatic rack are located in a "clean room" with easy maintenance access through the bodyside. The EPIC 2 control system is utilized and provides control of all braking functionality.

The optimum dynamic/friction brake ratio is automatically controlled by the TCMS system.

The dynamic brake resistor grids and cooling fan are built as a module that can easily be replaced via a dedicated hatch.

The dynamic brake system also provides a 100% load for self testing of the locomotive.

The parking brake system uses spring applied and air release actuators with a mechanical release system for emergency or shop operation.

**Maintainability & Life cycle Cost**

The design of the PL42 AC has been focused on meeting the critical requirements of NJ Transit, and providing increased maintainability and lower life cycle cost features.

Maintainability features have been built into all aspects of the design, from the choice of the sub-systems to the diagnostics capabilities.

Furthermore, the provision of Interactive Electronic Technical Manuals ensure that documentation required for maintenance and parts supply is easily accessed and controlled.

**Summary**

The PL42 AC locomotive is being introduced into service following extensive type-testing and commissioning.

The PL42 AC offers the prospect of a high performance locomotive that will enable heavier trains to be hauled and continues to meet current schedules. Overall the locomotive is an exciting development in the US railroad market.

**PL42-AC Technical Data**

Safety systems: Cab Signal: US&S,  
Brakes: Wabtec Epic II

**Performance**

Maximum speed: 161 km/h/  
100 mph  
Traction power at the wheels: 2700  
kW/3620 hp  
Starting tractive effort: 311 kN/  
69.975 lbs  
Continuous tractive efforts: 120 kN/  
27,000 lbs

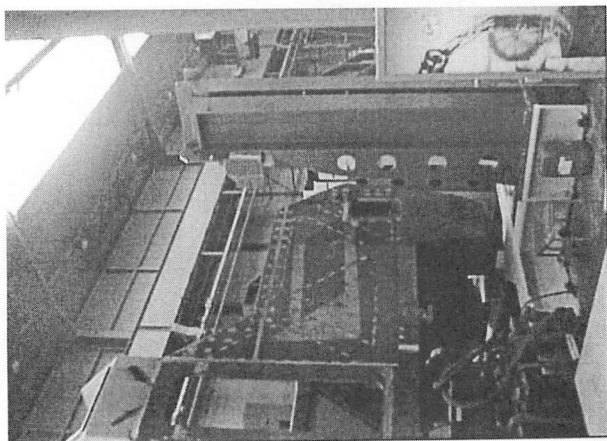
**Mechanical data**

Prime mover: EMD 16-cyl. 710G3B-  
T1  
Track gauge: 1435 mm/ 4 ft. 8½ in.  
Number of cabs: 1  
Wheelset arrangement: Bo-Bo  
Type of truck: Bolsterless two axle  
Type of transmission: AC motors -  
frame mounted  
Max. Axle load: 72,000 lbs  
Max. weight of locomotive: 288,000  
lbs  
Length over couplers: 69ft. 10in.  
Width of locomotive: 10ft. 8in.  
Max. height: 15ft. 5in.  
Wheel diameter: (new/worn):  
44in. / 41in.  
Type of mechanical brakes: disc and  
tread  
Fuel capacity (Useable): 2250 US  
gallons

**Electrical data**

Main alternator: EMD TA-17  
Battery voltage: 64 VDC  
Head End Power supply: 800kW, 3  
x 480 VAC/60 Hz @ 0.8 p.f.  
Traction converter, type: IGBT, water  
cooled  
Communication systems: Analog  
AAR 27-pin, Digital Trainline  
Network (DTN)

**Figure 1**



Cab structure and structural testing  
**Figure 2**

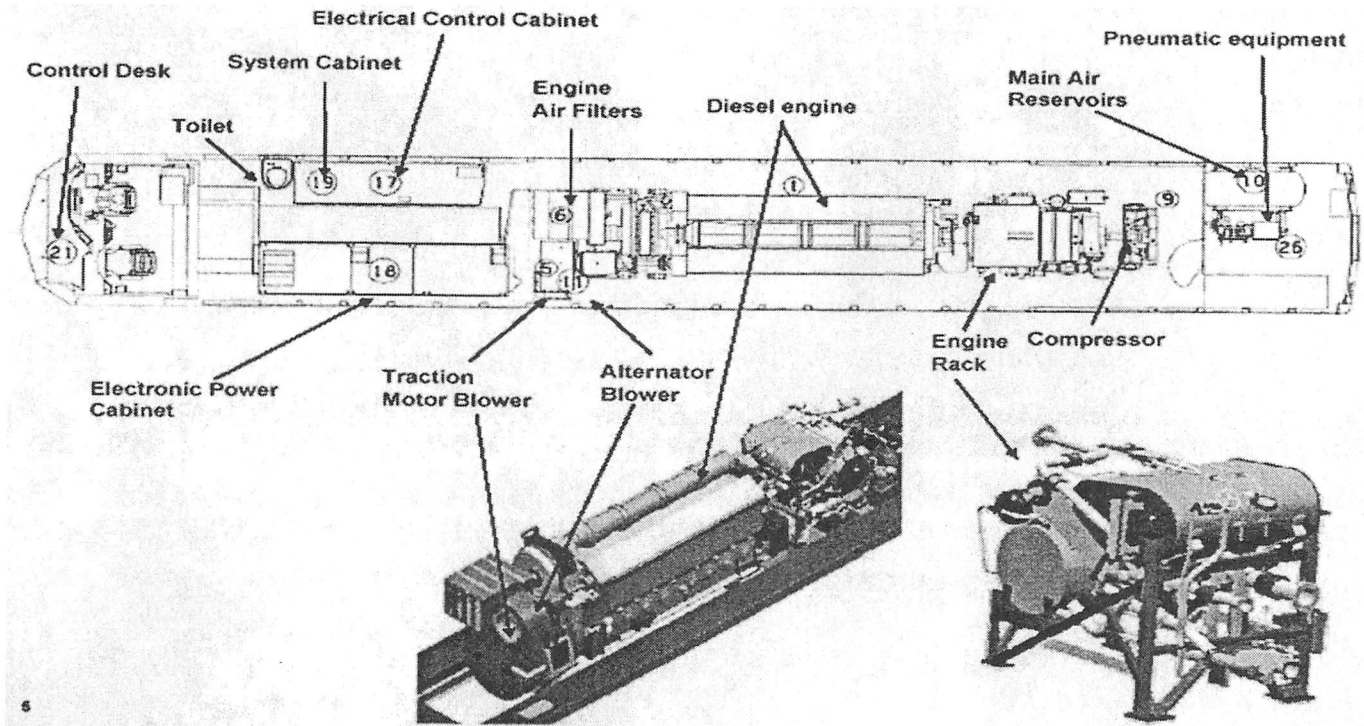
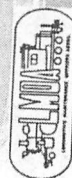
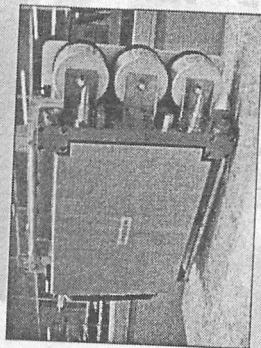


Figure 3

## PL42AC Power System

HEP – 800kW Supply:

- A dedicated HEP Diesel Engine is not required.
- The HEP is fed from the Propulsion DC Link.
- Dedicated 5<sup>th</sup> Inverter used for HEP Supply.
- Dedicated Computer Module controls the HEP Inverter.
- If HEP Inverter shuts down, one of the Traction Inverters will convert into HEP Supply Inverter.
- Dynamic braking power is converted into HEP Supply this saving energy and fuel.



New Technologies Committee

Figure 4

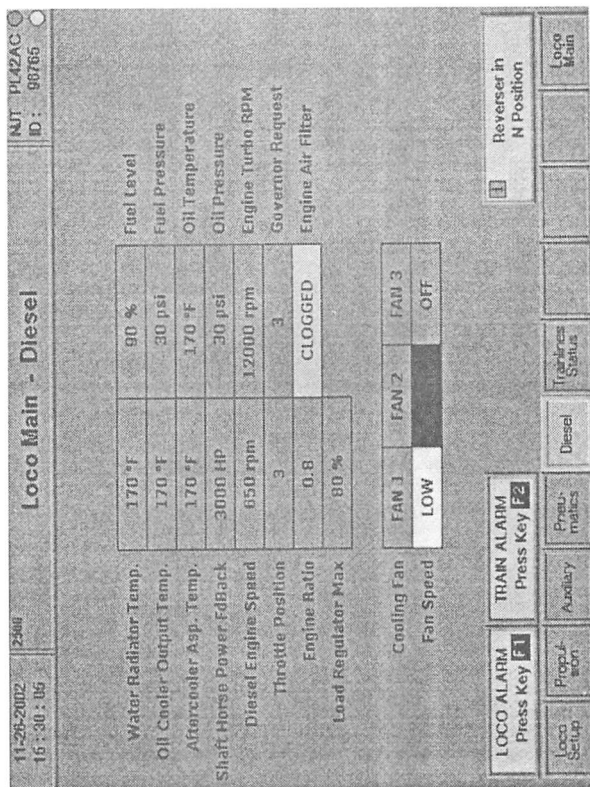
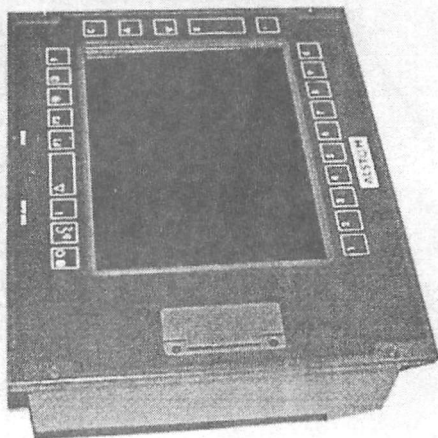


Figure 5



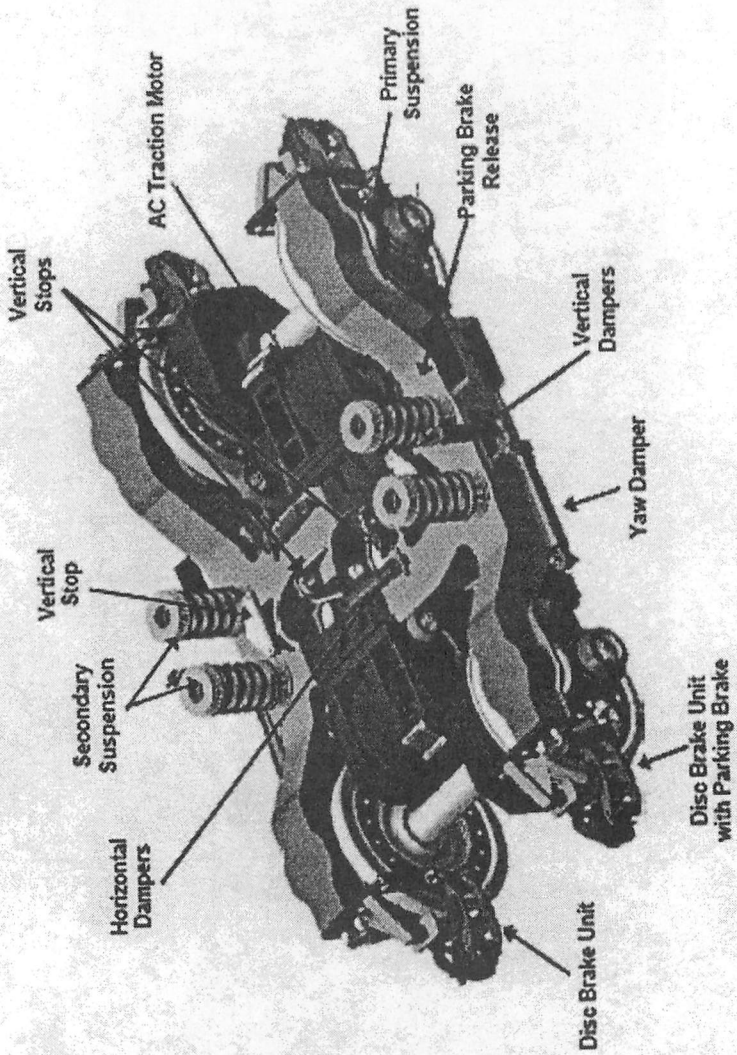


Figure 6

## GE Transportation Rail

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## II. FUELCELL LOCOMOTIVES

*Presented by:*

*Arnold R. Miller, PhD.,  
Vehicle Projects LLC*

### Introduction

Fuelcell rail transportation can provide increased energy and time efficiency, enhanced energy security, and improved environmental quality for the transportation sector. Energy cost and security are critical contemporary issues for the transportation industry. Fuel is one of the largest costs of transportation, and the BNSF Railway, for example, spends more than \$1 billion annually on diesel fuel. Diminishing world oil reserves, coupled with higher demand from the rapidly expanding economies of China and India, could initiate long-term social and economic disruption in the United States within two decades. The railroad industry is well aware of the deleterious effect that high fuel prices have had on the airline industry. Fuelcells are expected to be more efficient than any present motive power - diesel-electric or electric catenary - and locomotives powered by fuelcells will use renewable fuels. Conventional locomotives significantly contribute to air and noise pollution, whereas fuelcell based systems can be pollution-free and nearly silent.

Accordingly, we believe that the US should commence immediately in investigating alternative energy sources for rail transportation. An international industry-government consortium (see table 1), led by Vehicle Projects LLC, is developing a

109 metric-ton, 1.2 MW locomotive for commercial and military railway applications. The locomotive is a road-switcher, a type used for both switching and light line-haul work. Like the mine vehicles previously developed by our consortia, the road-switcher will use proton-exchange membrane (PEM) fuelcells and reversible metal-hydride storage of hydrogen. The powerplant is comprised of eight identical 150-kW modules, each with complete balance of plant (see Fig. 1).

Funded by the US Department of Defense and Department of Energy, objectives of the seven year development and demonstration project are to:

- develop the 109-tonne fuelcell locomotive by retrofitting an Army diesel-electric locomotive with a fuelcell powerplant.
- demonstrate the locomotive as a mobile backup powerplant on a military base.
- demonstrate it in a commercial yard-switching application in Reno, Nevada.

During the first two years of the project, commencing in May 2003, the consortium has completed:

- a comprehensive feasibility analysis
- conceptual design of the onboard fuel storage, refueling system, fuelcell powerplant, and locomotive layout
- the powerplant engineering design, and
- started preparation of the locomotive platform for receiving the powerplant

In year 3, commencing in June

2005, the consortium will build and test one 150-kW module as a prototype. In year 4, commencing June 2006, the plan is to manufacture the remaining modules of the 1.2-MW powerplant.

### Technical background

Vehicles require both an energy storage medium, such as a fuel, and a power production device, such as an engine or fuelcell.

Fuelcells are electrochemical power devices that directly convert the chemical energy of a fuel into electric power. From hydrogen fuel and air (oxygen), they produce electricity and water—the reverse of water electrolysis. While fuelcells share principles of operation with batteries, they differ in that the electrochemically active materials, hydrogen and oxygen, are stored or are available externally and are continuously supplied to the device rather than being stored in the electrodes. They are periodically refueled, like an engine, rather than recharged electrically. Like batteries, individual cells are grouped together into “stacks” to provide any voltage or power required.

Chosen for their safety, reliability, and high power density, fuelcells have provided electric power and drinking water in manned spacecraft for four decades. Since 1992, commercial stationary fuelcell powerplants of 200kW rating have provided high-reliability, clean, quiet, and safe electric power to hospitals, commercial facilities, universities, airports, and military bases.

By separating the energy storage

and power production functions, fuelcells are more convenient, more efficient, and safer than storage batteries. They are more convenient because the refueling process can be completed in a few minutes rather than the hours required for efficient battery recharging. They are more efficient because the electrochemical losses that occur in batteries during recharge, as witnessed by their evolution of heat, do not apply to fuelcells. They are safer because short-circuiting a fuelcell harmlessly dissipates only the energy associated with the small amount of hydrogen present in the cell. In contrast, short-circuiting a battery dissipates all of its stored energy.

Insight into fuelcells follows an understanding of the special place of hydrogen, their natural fuel, among the chemical elements. Most of the elements of nature are metals (See Fig. 2), and while most have the familiar metallic properties, not all do. Mercury (Hg), a liquid, lacks hardness. Hydrogen, a gas, would seem to lack all metallic properties. Nonetheless, the most fundamental characteristic of a metal is its tendency to donate electrons in chemical reactions, and on this basis, hydrogen is classified as an alkali metal in the first column of the table. Moreover, solid hydrogen (at low temperature) has decidedly metallic properties. This construct of hydrogen as a gaseous metal allows us to readily see the fuelcell as a special type of battery: Conventional batteries use a metal such as lead, cadmium, or lithium as the anode material (negative plate). Fuelcells use a

gaseous metal as anode material, and this is the basis of their advantages of separate energy storage and being refuelable.

This simple fact of using gaseous electroactive materials has far-reaching implications:

- The energy storage component is separated from the power-producing component, and unlike a conventional battery, in which the metal electrodes or plates serve as both the energy-storage and power-production functions, the fuelcell separates these two functions, and power and energy are not linked.
- Energy for the vehicle is stored in a fuel tank, analogous to the fuel tank of a conventional engine, and the vehicle may be rapidly refueled by refilling its fuel tank.

Because fuelcells are electrochemical power devices, essentially "refuelable" batteries, they are not limited in efficiency by the Carnot limit faced by heat engines. Fuelcells do have an analogous limit, namely, "intrinsic maximum efficiency," which is the Gibbs free energy divided by the enthalpy of the chemical reaction of the fuelcell. Depending on the fuelcell type, the intrinsic maximum efficiency is typically in the range of 80-90%. As a rule of thumb, the overall practical efficiency of a fuelcell powerplant is on the order of 50%.

The type of fuelcell used in our projects and exclusively favored by the auto industry is the proton-exchange membrane (PEM) type, which uses a solid ion-exchange

membrane for its electrolyte.

Storage of hydrogen onboard the vehicle is a greater technical challenge than producing power from a fuelcell. Methods of storage include:

- direct storage of hydrogen as a compressed gas, a liquid, or a reversible metal hydride.
- onboard chemical transformation of a feedstock, such as a hydrocarbon or alcohol, to hydrogen.
- physical dissociation of liquid ammonia to hydrogen.

Each method has advantages and disadvantages. For some rail applications, reversible metal-hydride storage is appealing, and this is the method we have used in all of our vehicles to date.

Reversible metal hydrides are low-flammability, solid materials that use metal-hydrogen chemical bonds to store hydrogen safely and compactly. Metals, crystalline solids, consist of a regular array or *lattice* of spherical atoms. Spheres cannot pack perfectly, and the lattice of atoms also forms a superimposed lattice of holes or *interstices* (see Fig. 3). The interstices interconnect to form a three-dimensional network of channels. Because hydrogen is the smallest atom, it chemically bonds to the metal atoms while occupying the interstices. Transition metals form hydrides that are readily reversible and constitute a safe, solid storage medium for hydrogen. By removing low-temperature heat from the crystal, hydrogen atoms enter the interstices throughout the crystal and *charge* the metal. Conversely, by providing low temperature heat (60 -

70 C) to a charged crystal, the process is reversed and the metal is *discharged*. The gas pressure is approximately constant during the process and can be very low, even below atmospheric.

Unlike liquid or gaseous fuels, metal hydrides are of low flammability. This is because hydrogen is trapped in the metal matrix or lattice, and the rate at which hydrogen atoms can file through the channels, recombine into hydrogen molecules, and be released is limited by the rate of heat transfer into the crystal. Rupture of a hydride system is self-limiting: As hydrogen escapes, the bed naturally cools because chemical bonds are being broken, and the colder bed has a lower rate of atom migration. The metal matrix, moreover, forces the hydrogen atoms close together, as close as in liquid hydrogen, and is responsible for the high volumetric energy density. Although meta-hydride storage is heavy, weight is generally not an issue for locomotives.

While reforming of hydrocarbons or alcohols, which involves high temperature catalyzed reaction of the feedstock with water, has been strongly pursued by the auto industry, it suffers the disadvantages of high volume, high complexity, and relatively low thermodynamic efficiency. Its large potential advantage is that a hydrocarbon-fuel infrastructure is already in place.

Ammonia, as feedstock for catalytic dissociation to hydrogen, is a non-carbon-based, renewable commodity that is typically transported by rail tank car. Because ammonia dissoci-

ation does not involve a chemical reaction with another reactant (water, in the case of reforming), it is easier than reforming hydrocarbons or alcohols and cleanly produces a mixture of 75% hydrogen and 25% nitrogen. The nitrogen is separated and harmlessly exhausted to the atmosphere. For rail applications such as line-haul freight and high-speed passenger trains, we believe an energy-dense liquid fuel such as ammonia is necessary. Although ammonia has the disadvantage of being a strong tissue irritant, it offers the advantage of being nonflammable under the conditions of intended use. It is classified by regulatory agencies as a nonflammable material.

### **Application background**

Vehicle Projects LLC conceives, organizes, funds, and manages multi-institutional, international projects to develop and demonstrate advanced vehicles. Our current projects are developing fuelcell vehicles for the underground mining and railway industries.

The mining industry, one of the most regulated, faces economic losses resulting from the health and safety deficiencies of conventional underground traction power sources, primarily diesel engines, batteries and tethers (cables) - none of which is simultaneously clean, safe, and productive. Solution of this problem by fuelcells would provide powerful cost offsets to the current high capital cost of the technology.

Our Mine Locomotive Project [1], commencing in 1999 and complet-

ed in 2002, developed and demonstrated the world's first fuelcell-powered underground vehicle and first locomotive, a 3.6 tonne mine locomotive (see Fig. 4). The project was funded by the US Department of Energy (DOE), Natural Resources Canada, and industry. Power is provided by 17-kW proton-exchange-membrane (PEM) fuelcell stacks, and hydrogen fuel is safely and compactly stored onboard as a reversible metal hydride. The locomotive is a pure fuelcell vehicle, i.e., it requires no traction battery. The project included a rigorous safety permitting process approved by the Government of Canada that allowed the vehicle to operate in a working mine. Working alongside conventional locomotives, it successfully hauled ore cars in a working gold mine in Canada. Compared to the battery version of the vehicle, the fuelcell locomotive provides equal acceleration, more than twice the power, the ability to pull longer trains, much shorter recharge time, and longer operating time. Comparison of the battery and fuelcell versions of the locomotive is summarized in Table 2.

Another international industry government consortium led by Vehicle Projects LLC is developing a fuelcell-powered loader [2] for the mining industry (see Fig.5). With funding from DOE, Natural Resources Canada, and industry, the Mine Loader Project commenced March 1, 2002, and is now in its third phase. The fuelcell powerplant is complete and has been delivered to Caterpillar for installation into a spe-

cial electric-drive version of a commercial loader. In Phase 3, the consortium will build the vehicle and demonstrate it in working gold mines in Nevada and Canada. Because of the sharp power peaks in a loader's duty cycle [3], the powerplant is a fuelcell battery hybrid (see Fig. 6). Compared to the mainstay diesel, expected benefits of the fuelcell loader include zero underground emissions, lower acoustic noise, increased torque, hydraulic power independent of traction power, and lower recurring costs such as fuel and brake maintenance. Lower vehicle recurring costs, reduced mine ventilation costs, and higher vehicle productivity are expected to make the fuelcell mine loader cost-competitive several years before surface applications.

### Results and discussion

The powerplant of the 109-tonne, 1.2 MW locomotive, (Fig. 1) using proton-exchange membrane (PEM) fuelcells and onboard reversible metal-hydride storage, is analogous to that of the mine locomotive. It is, however, 70 times larger in power and will be the largest and most powerful fuelcell vehicle so far developed [4]. Onboard storage of 250 kg of hydrogen allows operation of the locomotive for 30-40 hours under its normal duty cycle as a switcher. Refueling will require approximately 30 minutes.

The 109-ton locomotive is a road-switcher to be derived by retrofitting an Army diesel-electric GP-10 locomotive with the 1.2-MW fuelcell powerplant. Minor body-shell modi-

fications will update and distinguish the fuelcell version from the original diesel-electric. Besides serving as a switcher, the locomotive will be demonstrated as a 1.2-MW mobile powerplant supplying power to the electrical grid of a military base.

The powerplant design consists of eight identical 150-kW power modules using PEM fuelcells (see Fig. 7). Each module includes a complete balance of plant. Modules will be connected electrically in parallel to drive the four DC series traction motors. Powerplant output voltage is 600 V at a continuous gross current of 2000 A. Because balance-of-plant components (for example, air compressors and water pumps) are estimated to use about 13% of gross power, the net power output will be slightly more than 1.0 MW. Nuvera Fuel Cells, Inc. (Cambridge, USA, and Milan, Italy) has been selected to provide the fuelcell stacks for the powerplant. Nuvera's *FORZA™* stacks were chosen because of the ruggedness and compactness of their metal bipolar plates and the compactness and simplicity of their proprietary direct-water-injection system serving both stack cooling and membrane humidification.

Fuel identity and storage are major issues impacting eventual commercialization of fuelcell locomotives. Probably no single fuel or storage technology is practical for all rail applications, which range from subway transit to line-haul freight. Reversible metal-hydride storage is the sole onboard fuel storage for the locomotive under development. Hydride storage offers benefits of

efficiency, compactness, and low pressure and is appropriate for switchers and subway applications where safety requirements are exceptional. However, for rail applications such as line-haul freight and high-speed passenger service, we believe an energy-dense liquid fuel such as ammonia is necessary.

A block diagram of the conceptual design of the locomotive's refueling system is shown in Fig. 8. The system utilizes a stationary storage tank of compressed hydrogen for recharging the onboard metal-hydride system at 25 bar absolute - the compressed hydrogen will be either purchased as merchant hydrogen or produced onsite. A rate of heat removal from the hydride bed of nearly 2 MW, achieved by use of a large water-based heat sink, allows a hydrogen refueling rate of 8 kg/min. Initially, the water is at ambient temperature in a large tank labeled "Cool-Water Tank." After passage through the hydride bed's internal heat exchanger, hot water at approximately 40°C above ambient is discharged into an initially empty tank labeled "Hot-Water Tank." In a slower process taking place while the locomotive is in operation, the hot water passes through a radiator and is returned to the ambient temperature cool-water tank.

The pros and cons of fuelcell power for rail transportation may be summarized as follows.

Positive features include:

- it is a naturally renewable energy-based system, with hydrogen or ammonia being readily derived from nuclear or

- coal primary energy.
- It potentially has the highest efficiency of rail-power technologies because it is not limited by the Carnot limit on heat engines.
- It is environmentally benign, with zero vehicle emissions and low acoustic noise. Although there may be emissions from the primary energy use, it is arguable that central-point emissions are more controllable than emissions from every vehicle in a fleet.
- It will have a relatively low infrastructure cost compared to the electric catenary system. Nuclear hydrogen will be inexpensive, and the fuel distribution system would be different from but not necessarily much more costly than a diesel-fuel infrastructure.

Neutral features are safety and performance. All fuels, as energy storage media, have safety risks. While the safety issues for hydrogen or ammonia are different than for diesel fuel, appropriate engineering and application procedures should be capable of reducing risk to acceptable values. Performance will likewise be different but entirely satisfactory, if not superior. Our working-mine experience with the mine locomotive showed superior performance in almost every respect to the counterpart battery locomotive. Our tractive effort and speed calculations for the mine loader predict superior performance in most respects to a diesel loader.

Negative features include present

high capital cost of fuelcells and hydrogen storage and the requirement of establishing a new fuel infrastructure for fuelcell locomotives. We expect the capital cost of the hardware to fall, due to economy of scale, as the market size increases. A superficial analogy exists between the decline in price of computer IC chips and fuelcells. The analogy is not perfect because the personal computer did not face entrenched technologies as the fuelcell does. Heat-engine locomotives and catenary-electric locomotive have a manufacturing experience of more than a century, and it will be more difficult to displace these current technologies than it was to replace the typewriter with a desktop computer.

It is impossible to predict the rate of decline of fuelcell price. We presently pay approximately half as much per kilowatt for fuelcell stacks as we did in 1999. I do believe, however, that the future price of fuelcells is intimately linked to the future world price of oil. If oil price continues to rise, more demand will be placed on the hydrogen-fuelcell alternative. If the price of oil exceeds \$100 per barrel, then we could see significant inroads in the market for fuelcell locomotives within a decade. If the price of oil recedes, to say \$20 per barrel, then market penetration will take longer.

### Conclusions

By advancing the commercialization of fuelcell vehicles, benefits of the project could include increased energy efficiency of the transportation sector, increased national ener-

gy security by reducing dependency on imported oil, improved environmental quality, and positioning the consortium members into leadership roles in advanced rail transportation. Because it will develop and demonstrate the largest fuelcell vehicle to date, the project will benefit the development and demonstration of large defense vehicles such as naval ships. Demonstration of the locomotive as a mobile backup powerplant on a military base can lead to enhanced base capabilities and security.

For the future of fuelcell rail transportation, we believe the following are likely technical characteristics: The primary energy source will be nuclear power, from which hydrogen will be produced by electrolytic or thermal water splitting. Derived from the nuclear primary energy, two renewable onboard fuels appear promising, namely, hydrogen stored as an advanced metal hydride and anhydrous ammonia. As is the case for current rail vehicles, a single fuel for all applications appears unlikely. Some applications, such as subway transit and light-rail, will prefer metal-hydride storage, while others, such as line-haul freight and high-speed rail, may use ammonia.

### References

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- (4) A.R. Miller, D.L. Barnes, O. Velev, L. Sheppard, P. Chintawar, A. Delfrate, M. Golben and T. Vencill, Fuelcell Locomotive for Commercial and Military Railways. Proceedings of 2004 Fuel Cell Seminar, San Antonio, USA, 1-5 November 2004

### Acknowledgements

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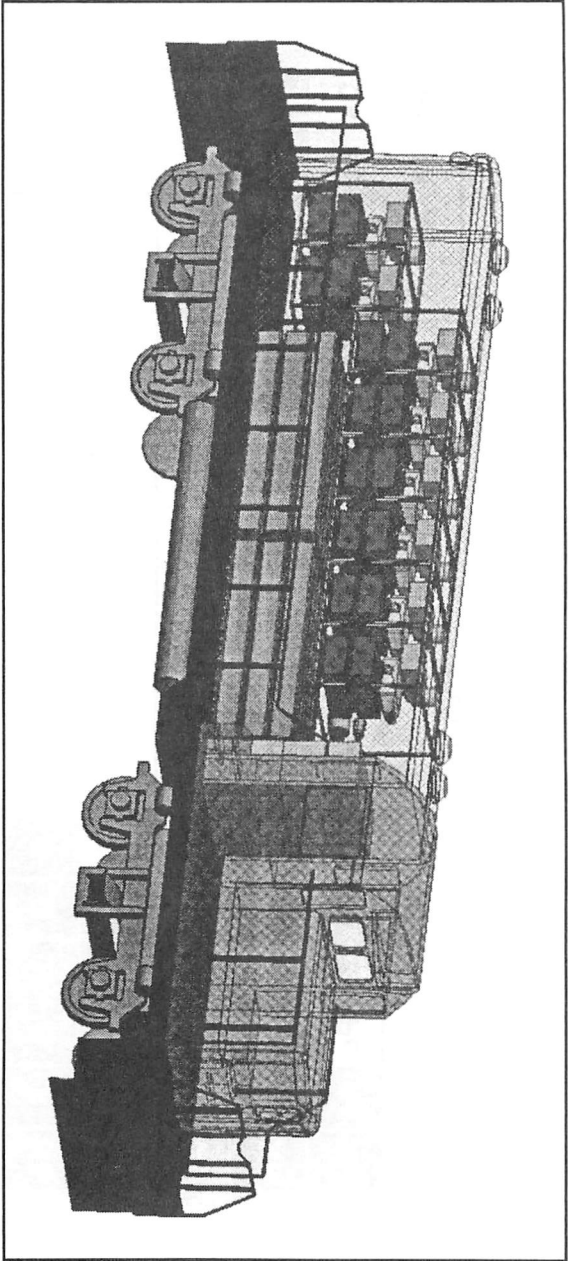
*Disclaimer:* Funding support from the US Department of Energy, US Department of Defense, Natural Resources Canada, or Government of Canada does not constitute an endorsement by same of the views expressed in this article. Project participation by the institutions listed in Table 1 does not constitute their endorsement of the views expressed herein.

### TABLE 1: FUELCELL LOCOMOTIVE CONSORTIUM

*BNSF Railway Company, USA:* Heavy freight applications  
*Defense NTG & Rail Equipment Center, USA:* Packaging and integration  
*DOT Volpe Nat'l Transportation Systems Center, USA:* Safety and economics  
*Fuelcell Propulsion Institute, USA:* Project advocacy  
*General Atomics, USA:* Power Electronics  
*General Motors: Electro-Motive Division, USA:* Observer  
*Ovonic Hydrogen Systems, USA:* Metal-hydride storage  
*Modine Manufacturing Co, USA:* Heat exchangers  
*New York City Transit, USA:* Subway transit applications  
*Nuvera Fuel Cells, USA:* Module balance of plant  
*Nuvera Fuel Cells Europe, Italy:* Fuelcell stacks  
*Railway Technical Research Institute, Japan:* Passenger rail applications  
*Regional Transportation District – Denver, USA:* Light rail applications  
*Transportation Technology Center Inc, USA:* Locomotive performance  
*University of Nevada - Reno:* Refueling system  
*Vehicle Projects LLC, USA:* Prime contractor

Table 2: Comparison of Battery and Fuelcell 3.6-Tonne Mine Locomotives

Parameter	Battery	Fuelcell
Power, rated continuous	7.1 kW (gross)	17 kW (gross)
Current, rated continuous	76 A	135 A
Voltage at continuous rating	94 V (est.)	126 V
Energy capacity, electrical	43 kWh	48 kWh
Operating time	6 h (available)	7.5 h
Recharge time	8 h (min)	1 h (max)
Vehicle weight	3,600 kg	2,500 (without ballast)



**Figure 1 – Conceptual Design of Fuelcell Locomotive:** Fuelcell road-switcher, based on an Army 109-metric-ton GP-10, will employ 1.2 MW of fuelcell power (blue) and 250 kg of hydrogen in reversible metal-hydride storage (orange). Powerplant design consists of eight identical 150-kW stand-alone modules (blue plus yellow).

# PERIODIC TABLE OF THE ELEMENTS

Alkali Metals

Gas

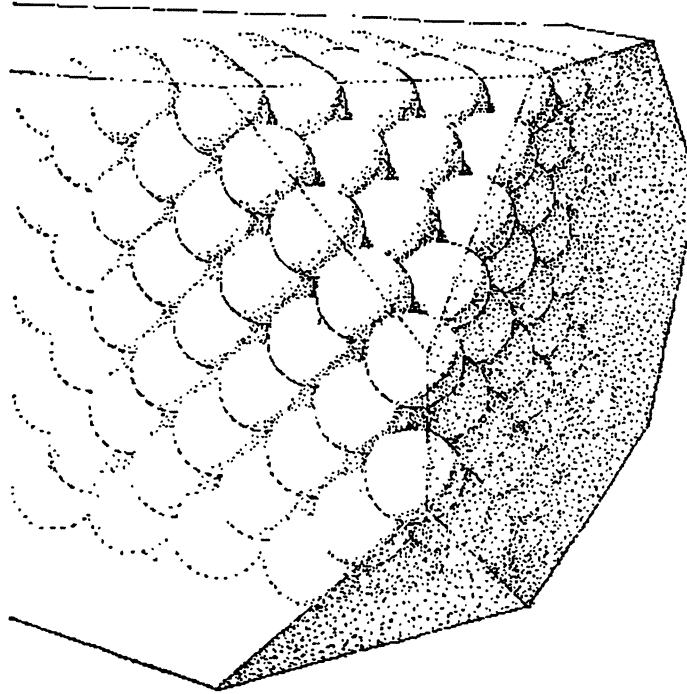
Nonmetals

Metals

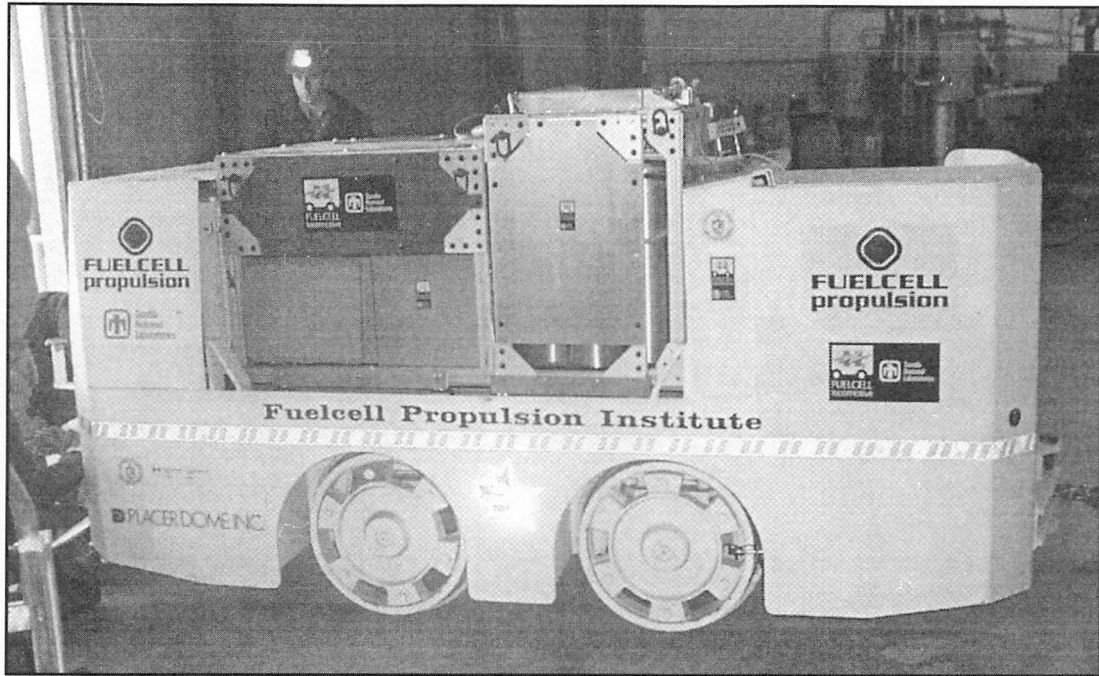
Liquid

<b>H</b>																			<b>He</b>
<b>Li</b>	<b>Be</b>											<b>B</b>	<b>C</b>	<b>N</b>	<b>O</b>	<b>F</b>			<b>Ne</b>
<b>Na</b>	<b>Mg</b>											<b>Al</b>	<b>Si</b>	<b>P</b>	<b>S</b>	<b>Cl</b>			<b>Ar</b>
<b>K</b>	<b>Ca</b>	<b>Sc</b>	<b>Ti</b>	<b>V</b>	<b>Cr</b>	<b>Mn</b>	<b>Fe</b>	<b>Co</b>	<b>Ni</b>	<b>Cu</b>	<b>Zn</b>	<b>Ga</b>	<b>Ge</b>	<b>As</b>	<b>Se</b>	<b>Br</b>			<b>Kr</b>
<b>Rb</b>	<b>Sr</b>	<b>Y</b>	<b>Zr</b>	<b>Nb</b>	<b>Mo</b>	<b>Tc</b>	<b>Ru</b>	<b>Rh</b>	<b>Pd</b>	<b>Ag</b>	<b>Cd</b>	<b>In</b>	<b>Sn</b>	<b>Sb</b>	<b>Te</b>	<b>I</b>			<b>Xe</b>
<b>Cs</b>	<b>Ba</b>	<b>La</b>	<b>Hf</b>	<b>Ta</b>	<b>W</b>	<b>Re</b>	<b>Os</b>	<b>Ir</b>	<b>Pt</b>	<b>Au</b>	<b>Hg</b>	<b>Tl</b>	<b>Pb</b>	<b>Bi</b>	<b>Po</b>	<b>At</b>			<b>Rn</b>
<b>Fr</b>	<b>Ra</b>	<b>Ac</b>																	

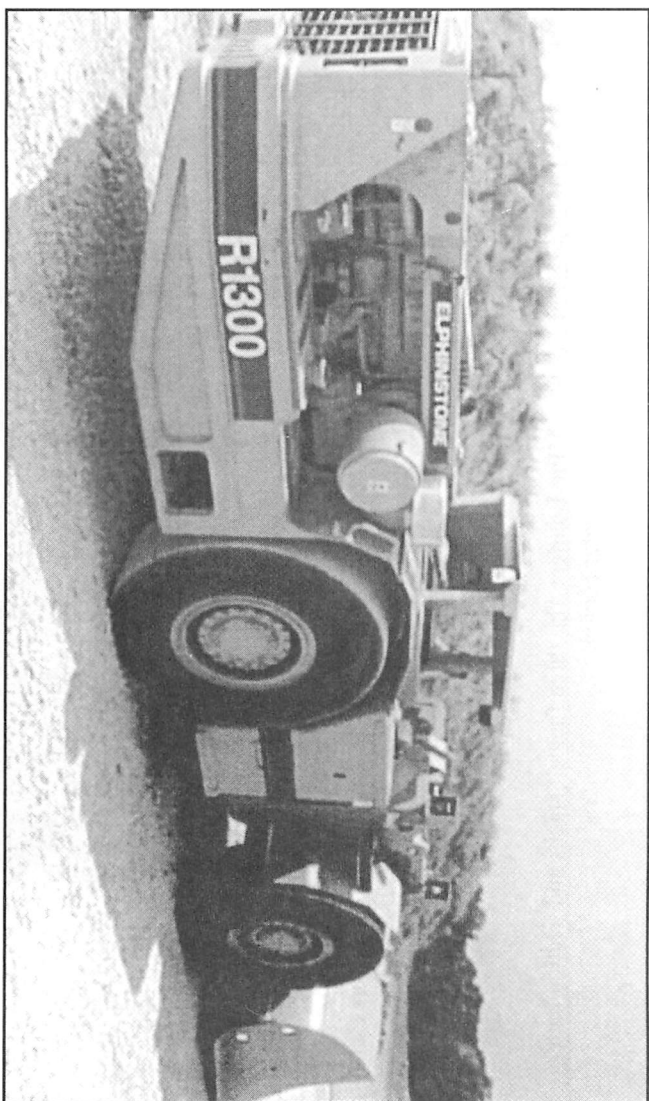
Figure 2 – Periodic Table of the Elements



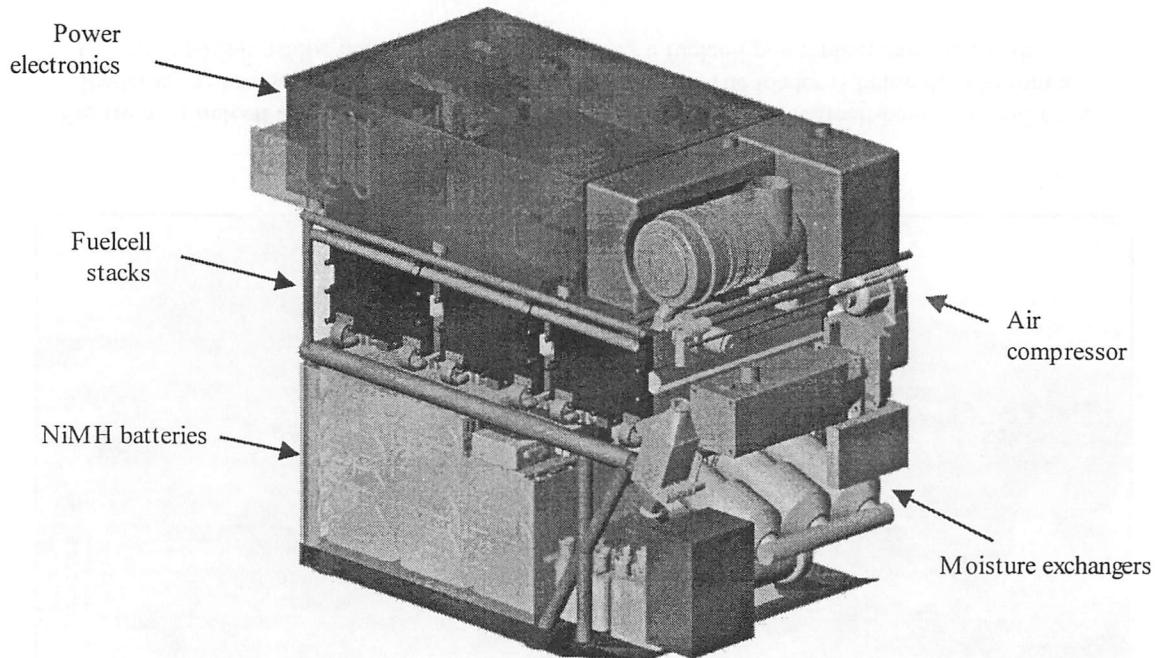
**Figure 3 – Metal Crystal:** Crystal lattice of a metal showing interstices



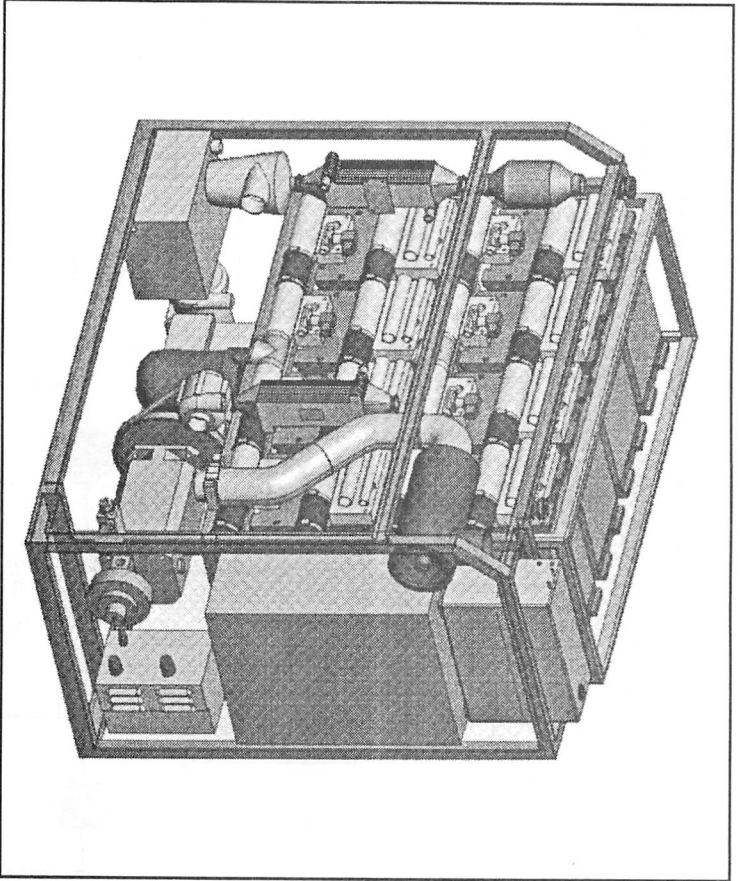
**Figure 4 – Fuelcell Mine Locomotive:** Completed in 2002, this is the first fuelcell underground vehicle and locomotive. Weighing 3.6 metric tons, it develops 17 kW of continuous power and stores 3 kg of hydrogen in the form of a reversible metal hydride.



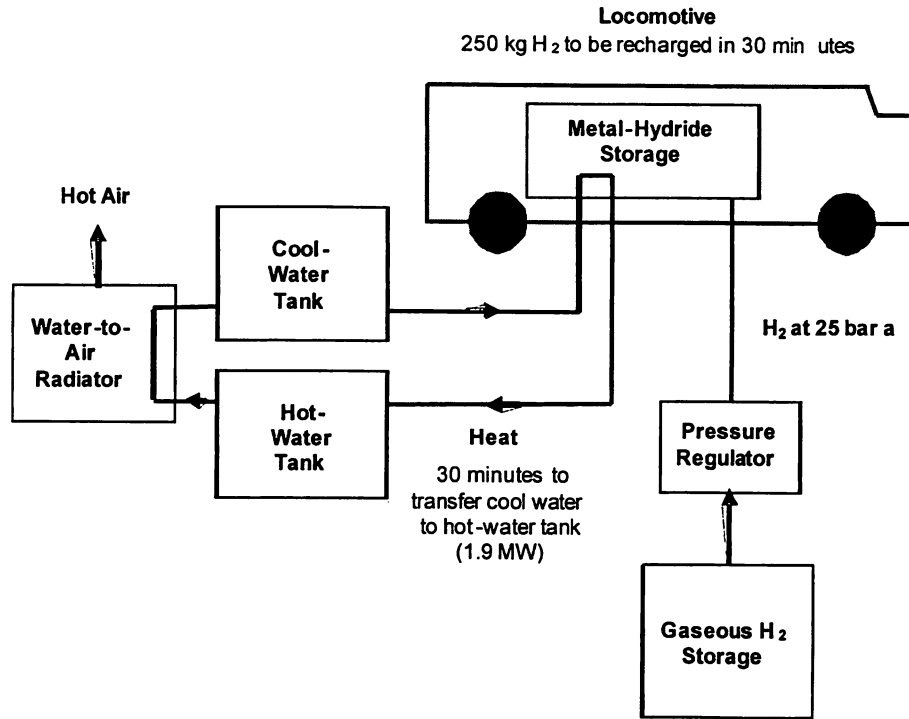
**Figure 5 - Fuelcell Mine Loader:** At 23 metric-tons, this 160-kW fuelcell-battery hybrid mine loader is the heaviest fuelcell land vehicle yet developed. The loader is being derived from a Caterpillar-Elphinstone diesel (shown) by installing a fuelcell powerplant and electric drive.



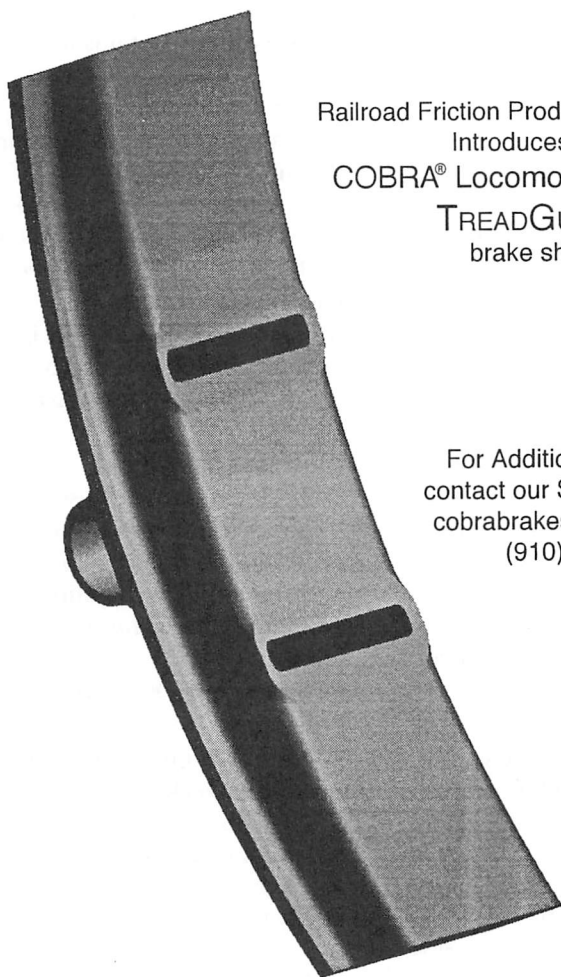
**Figure 6 - Powerplant of Fuelcell Mine Loader:** The three fuelcell stacks and traction battery are water cooled.



**Figure 7 – Powerplant module:** The 150-kW module, eight of which comprise the 1.2-MW locomotive powerplant



**Figure 8 – Refueling System of Locomotive:** 250 kg of hydrogen is stored onboard as a reversible metal hydride, which can be recharged or refueled within 30 minutes.



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### III. LOCOMOTIVE ELECTRIC HAND-BRAKE SYSTEMS

*Presented by: Keith Gilbert,  
Manager Locomotive  
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GE Transportation - Rail*

#### Introduction

This paper is intended to be an overview of the locomotive electric hand-brake systems available for new and retrofit application. The systems to be discussed are the Graham White **SafeSet™** and the GE Transportation **PowerPark™** (Fig. 1).

This paper will focus on the locomotive handbrake environment and general features of the systems; for more in-depth information please contact the respective manufacturers.

Let's start things off by first looking at what is required by the regulatory agencies:

#### Regulations

##### locomotive handbrake

49 CFR Ch 11 (10-1-04 Edition)

All locomotives ordered on or before August 01, 2002 or placed in service for the first time on or after April 01, 2004 shall be equipped with a hand or parking brake that is:

- Capable of application or activation by hand, and:
- Capable of release by hand, and:
- Capable of holding the unit on a 3 percent grade.

Considering the above requirements and the regulations involved, failure to meet them could result in something unfortunate like this (Fig. 2).

Now that we know what can happen if the handbrake fails, let's look

at our topics of discussion:

**What is an Electric handbrake?**

**Common Specifications**

**What types of systems are available?**

**Installation examples**

**Advantages vs Manual Systems**

**Potential Applications**

For the purposes of this paper, our handy Webster's gives us Gilbert's definition of electric handbrake.

**Electric Handbrake:**

**A manual handbrake that is applied and/or released by means of an electric assist.**

**Or**

**Look Ma - No Hands!**

Both systems to be discussed in this paper have mainly common specifications as listed below:

#### Common specifications

- **4,000/6,300 lbs nominal chain force**

- **Overcurrent/Overvoltage Protection**

- **Optional Control Location**

- **Under Deck**

- **In Cab**

- **Manual Override**

The typical locomotive handbrake exists in two forms - the lever type, found on older units (Figures 3 & 4) and the wheel type (Figures 5, 6 & 7). Let's now take a look at some of the more common locations for the handbrake on road and switcher type locomotives.

So far, we have asked & answered the following:

- What is a handbrake and what does it have to do?
- What can happen without one?
- What manual systems exist today and where are they located on

the locomotives?

Now, let's have a look at our two subject systems and see what they bring to the party!

The Graham White **SafeSet™** is available to replace both the lever and wheel types while the GE **PowerPark™** currently replaces the wheel type only. (Figures 8 & 9) show the **SafeSet™** in both configurations.

Note in the photos that on this particular application of the lever type, the set & release buttons are built into the systems while on the wheel type they are located on a separate panel. This is one of the optional features that we will discuss later in this paper.

Figures 10 & 11 show a little more detail on the inner workings and features of the **SafeSet™**.

Note that the manual application and release levers are similar to the manual systems, so no crew training issues here!

The GE **PowerPark™** (Fig. 12) is shown in a typical hood mount location. Note that the manual override is the handle at the center of the wheel.

Fig. 13 shows a side view of the **PowerPark™**. The protrusion shown at the upper left rear of the system is the electric motor that does all the work.

From these slides, it should be noted that both systems are designed to be easy replacements for an existing handbrake. The installation usually involves some slight welding & cutting of the surrounding car-body to accommodate the new system, typically in the area of sand

boxes, etc. The installation times are less than a shift.

Next let's look at some of the options available.

Both systems offer the flexibility of mounting the control box separate from the main system. The **SafeSet™** is a surface mount panel (Fig. 14) while the **PowerPark™** is a flush mount (Fig. 15).

Another option available with the **SafeSet™** is a key lock system to prevent unauthorized handbrake release (Fig. 16).

Let's look at some of the main reasons for considering an electric handbrake system.

#### **Advantages electric handbrake**

- **Personal Safety-Back Injury Reduction**
- **Automatic Full Application**
- **Automatic Full Release**
- **Integration With Power System-<Flatspots**

Every railroad has more than its share of lost time due to injury with back and shoulder ailments being among the more frequent. These systems eliminate the heavy pull required to manually set the handbrake, which in turn eliminates the injury risk, which in turn means:

- An electric handbrake will always provide a full application, even if the operator has a sore back!
- On the handbrake release side of the equation, an electric handbrake will always provide a full release, not just give the wheel a spin!

Lastly, it is possible to integrate the handbrake into the locomotive

control system so the locomotive can't load if the brake is applied, drastically reducing the bane of yard locomotives - the skid flat!

Now that we've seen the advantages, where can we get the most bang for the buck?

### **Potential Applications**

Yard Locomotives

- Reduce injuries

RCL Locomotives

- Keep the crew on the ground

Integrate with AESS

- In-Train locomotives

As we have mentioned, avoiding personal injury is a major benefit of these systems so yard locomotive applications should be a major consideration. Also in the yards, consider using the optional feature of mounting the control box below the running board for RCL (remote controlled locomotives).

On AESS applications, a safety enhancement to consider might be to have the electric handbrake automatically apply when the locomotive is in shut down.

In summary, this paper has touched very briefly on the two systems. If you have a particular application in mind, please contact the manufacturers for a more complete presentation of the systems, features, etc.

This paper has used materials previously presented at the Air Brake Association meeting in Chicago September 20, 2000. In addition, I would like to acknowledge the following people for their input.

### **Acknowledgements**

**Graham-White Manufacturing**

• **Dave Pettengill, Product Manager**

• **Stewart Bruce, VP Marketing**

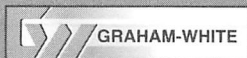
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• **Dave Peterson, NPI Engineering**

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Figure 1



Figure 2

### Lever Type

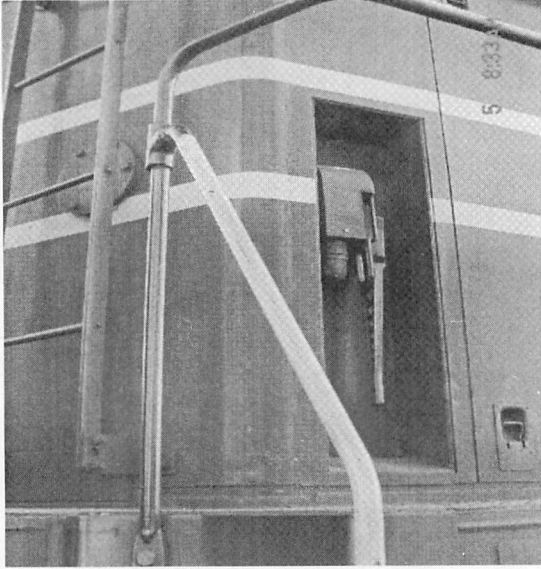


Figure 3

### Lever Type - Switcher Cab



Figure 4

### Wheel Type - Short Hood

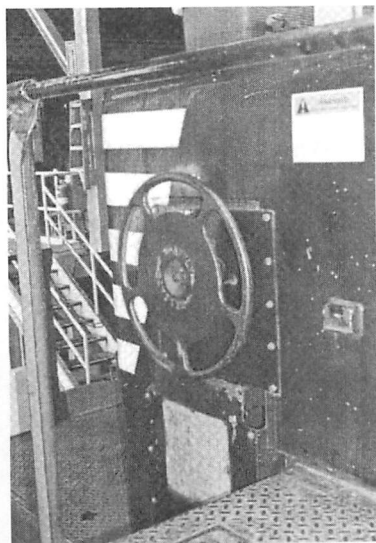


Figure 5

### Wheel Type - Long Hood

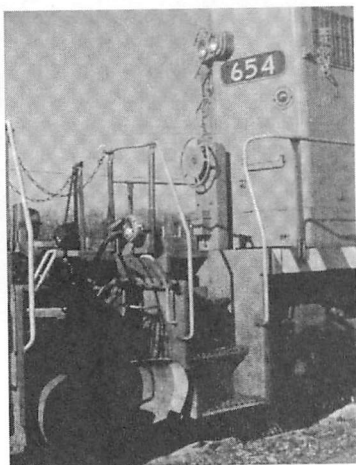


Figure 6

Wheel Type - Switcher Cab

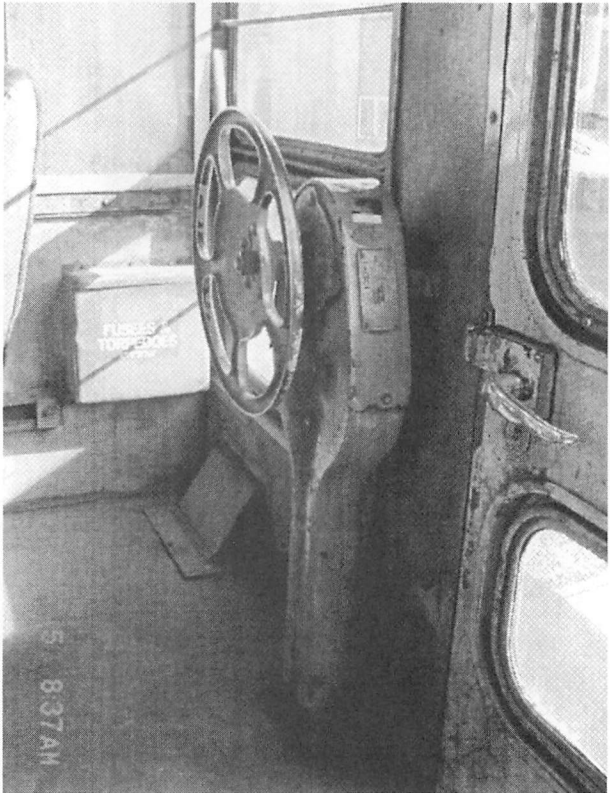


Figure 7

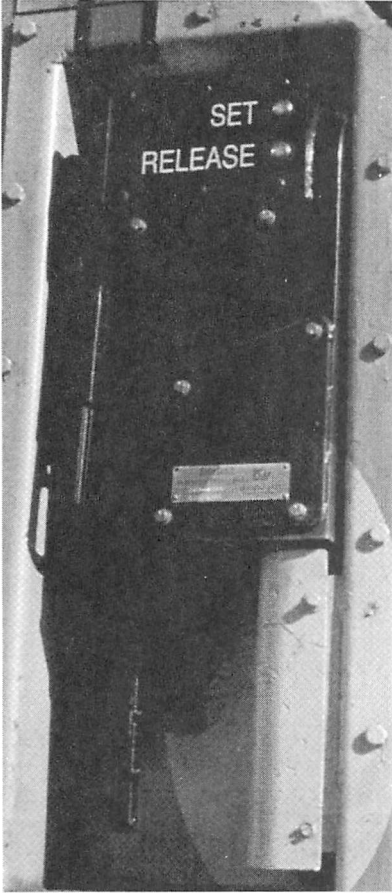


Figure 8

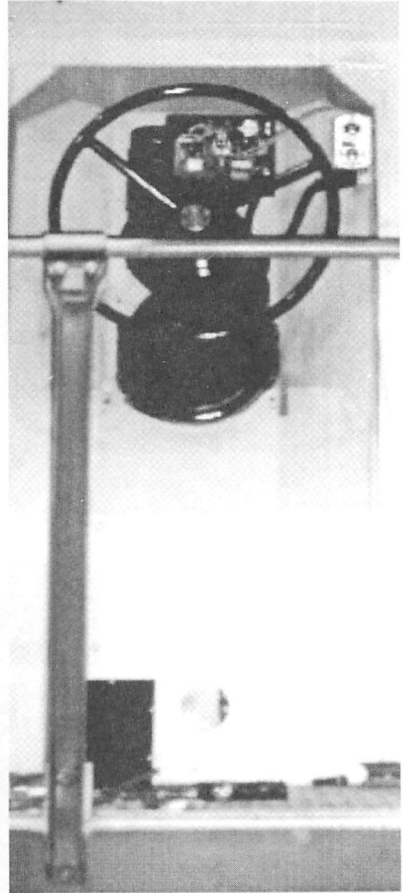


Figure 9

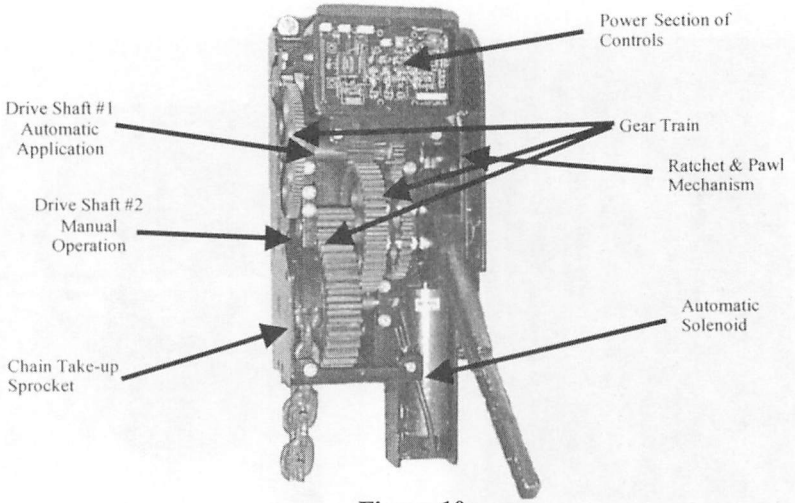


Figure 10

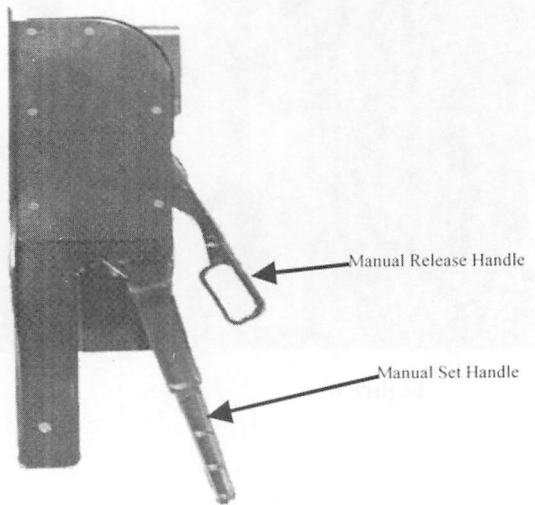


Figure 11



Figure 12

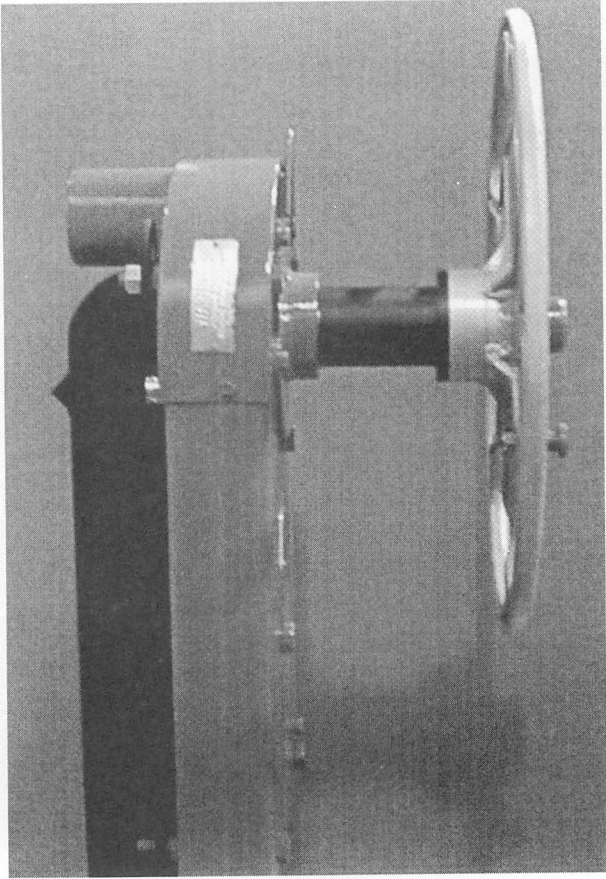


Figure 13

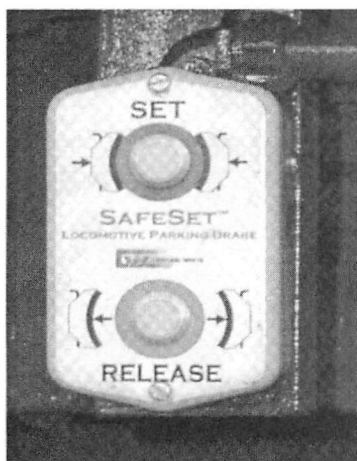


Figure 14



Figure 15

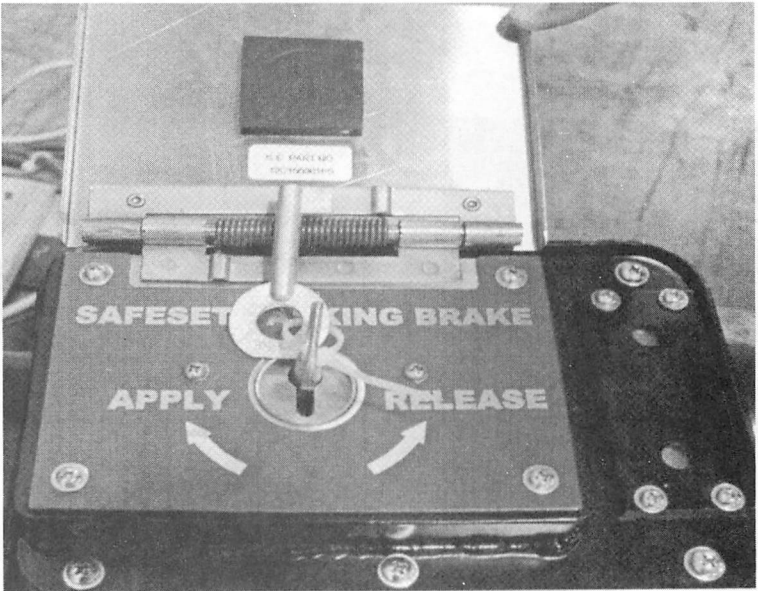


Figure 16

REPORT OF THE COMMITTEE  
ON SHOP EQUIPMENT AND PROCESSES

MONDAY, SEPTEMBER 19, 2005  
2:00 P.M.



Chairman

**BILL PETERMAN**

President

Peterman Railway Technologies, Inc.  
Baie D'Urfe, Quebec

Vice Chairman

**TOM STEFANSKI**

Tom's Locomotives and Cars  
Plainfield, IL

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IN ALBANY, N.Y. ON  
MARCH 29 AND 30, 2005**

**THANK YOU VERY MUCH FOR  
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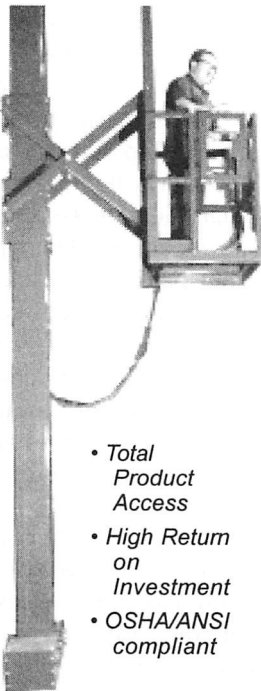
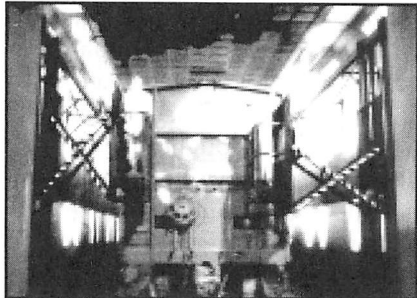
**SHOP EQUIPMENT AND PROCESS  
COMMITTEE**

# SAFETY & FALL PREVENTION SOLUTIONS

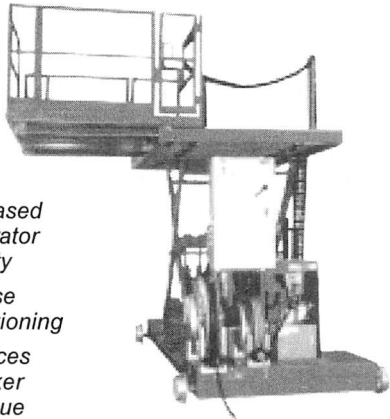
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## **MOBITURN® WHEEL TRUING SERVICES**

*Prepared by: F. Javier Reynoso  
Project Manager  
Mobiturn® Services*

### **I. Introduction**

We can all relate to the fact that systematic wheel truing maintenance can certainly become an event rather than a habitual process if it is not implemented effectively. Numerous wheel maintenance shops throughout the country share an array of common maintenance challenges ranging from budgetary funding, to obtaining reliable resources for the reprofiling of their wheelsets.

Simmons Machine Tool Corporation implemented Mobiturn® Wheel Truing Services as a systematic approach to address these crucial challenges. The objective of Mobiturn® services is to provide customers that outsource wheel truing services to 3rd parties; or perhaps do not own customary wheel truing equipment, with effective on-site wheel truing resources designed to minimize operational and logistical efforts associated with the maintenance process.

Moreover, Mobiturn® services have also appealed to several transit authorities who already own wheel truing machines. These authorities envision applying the services as an added capacity to meet their seasonal / peak demands and to build spare inventory for emergency situations.

Mobiturn® is the first CNC

mobile wheel lathe that comes to the vehicle and not the other way around. This flexibility translates into significant financial and operational savings for customers who implement the services.

### **II. Mobiturn® Services procedural approach**

The services are presented as a complete turnkey that includes transportation of the equipment, installation, truing, and removal. The machine is transported via tractor-trailer to the customer's facility and placed on the actual rail tracks. It is then positioned in the location where the truing operations will occur. Customers must have at least a 15 ton crane available to assist in this process.

The vehicles are raised to the required 65" height from the bottom of the rail to the top of the wheel. Mobiturn® then performs a wheel diameter measuring and provides a recommended depth of cut for that particular profile. The wheelsets are held in position via axial and guide rollers to eliminate any potential movement during the truing process and ensures accuracy. Lastly, the operator enters the desired parameters and commences the truing.

SMTC shares responsibility with the customers' employees in relation to some operational aspects (assist with disposal of chips, crane operations, etc.). The process is repeated until the specified amount of vehicles have been entirely reprofiled.

### III. Direct Comparison of Mobiturn® Wheel Truing Services vs. Underfloor Wheel Truing Machines

Although one of the most significant advantages of Mobiturn® is attributed to the fact that it is easily transportable from one location to another, there are a number of additional advantages that make Mobiturn® wheel truing services a unique and appealing alternative solution for customers. The table below highlights key differentiation elements between the Mobiturn® and a conventional Underfloor Wheel Truing machine:

#### Mobiturn® Wheel Truing Services

- **No** Foundation Required
- **No** Vehicle Progression System Required
- **No** Major Operational Training Costs
- **You** use the services- We own the equipment

#### Underfloor Wheel Truing Machine

- Foundation Costs (Drawings, etc.
- Recommended Vehicle Progression System
- Training Investment (Susceptible to turnover)
- Capital Funding Approval Needed

#### IV. Mobiturn® technical data

Manufacturer  
Hegenscheidt-MFD GmbH & Co.  
KG, Erkelenz  
Length 28.5 ft.

Width	8.7 ft.
Height	5.4 ft.
Weight	42,000 lbs.
Stroke of Roller	
Carrier	<20m/min.
Travel Drive Motor	
(rev. max)	6500 rpm
Rated Power	75k VA
Rated Voltage	480V
Machine Control System	
SIEMENS Sinumerik 840 DE	
Ambient Temperature	
(during operation)	41 °F/104 °F
Maximum Depth of Cut	
(per single pass)	1/4 inch
Maximum Cutting	
Speed	305 m/u
Productivity	
(wheelsets per shift)	9-11
Noise Emission	80dBA
Profile Width	84-145mm

Height required From Both  
of the Wheels to the Top  
of the Rail 65 inches  
Reel Cable Reach 50 mtrs.

#### V. Main operational components

##### - Friction Drive Roller:

The wheelset is driven by two-3 phase synchronous motors with frequency control via toothed belts, shafts, and reduction gear units. There are a total of four (4) drive rollers in the Mobiturn®.

##### - Axial Guide Roller:

Each of the front drive rollers has an integrated axial guide roller for axial centering of the wheelset. The wheelset is axially fixed on the machine with contacting and

clamped axial guide rollers.

**- Clamping Devices:**

SMTC may manufacture on a situational basis, additional (external) clamping devices in order to provide supplementary wheelset stability and eliminate potential axial movement.

**- CNC Siemens Control:**

Able to input a variety of profiles into the main CPU. In addition, a detailed report of each reprofiled wheelset may be easily obtained. This provides the user with the ability to collect relevant and concise historical data for each wheelset produced by the Mobiturn®.



## ***Innovative Mobile Technology***



Simmons Machine Tool Corporation (SMTc) is excited to announce its latest technological development in the North American market; "Mobiturn<sup>®</sup> Wheel Truing Services".

The Mobiturn<sup>®</sup> is a CNC mobile wheel lathe that maintains a variety of profiles ranging from light rail vehicles to locomotives. The Mobiturn provides customers with cost effective wheel truing as an alternative to their present wheel maintenance processes.

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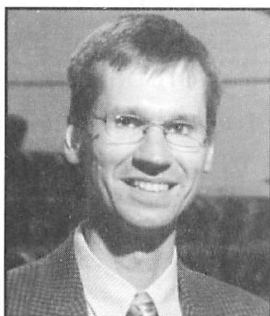
[jreynoso@smtgroup.com](mailto:jreynoso@smtgroup.com)

## VI. Logistics



REPORT OF THE COMMITTEE  
ON DIESEL ELECTRICAL MAINTENANCE

TUESDAY, SEPTEMBER 20, 2005  
8:30 A.M.



Chairman

**RON BARTELS**

Manager, Electrical and Engine Systems  
Via Rail-Canada  
Montreal, Quebec

Vice Chairman

**T. STUART OLSON**

Regional Sales Manager  
WABTEC Corp.  
Alpharetta, GA

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R. Slomski	Dir.-Customer Prog.	RailPower Hybrid	Erie, PA
B. Steffel	Mgr.-Mech. Engrg.	Union Pacific RR	Omaha, NE

## PERSONAL HISTORY

*Ron Bartels,  
Manager Electrical & Engine Systems Group  
VIA Rail Canada*

Ron has always lived in Montreal, Quebec. He was born there in 1965. He attended McGill University and graduated in 1988, receiving a Bachelor of Engineering degree in Electrical Engineering.

He began his career at CN Rail, working for five years in the Motive Power and Car Equipment department. In 1993, he left CN for AMF Technotransport. As Senior/Principal Electrical Eng., and later, manager of testing at AMF, Ron headed the Electrical Engineering and Test Departments, supporting various locomotive and passenger car refurbishment programs.

In January, 1998, Ron took the position of Manager, Electrical

Systems at VIA Rail Canada. Now at VIA, Ron manages the Electrical and Engine Systems Group, which is responsible for the maintenance program and configuration of all electrical and engine systems on VIA's locomotives and passenger cars.

Ron has been a member of the LMOA Diesel Electrical Maintenance Committee since 1998.

A recreational badminton player, Ron also enjoys camping, cycling and cross-country skiing with his wife Karen and daughters Kaitlin and Hannah.

**THE DIESEL ELECTRICAL  
MAINTENANCE COMMITTEE**

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FOR HOSTING AND SUPPORTING  
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**MOTIVE POWER INC.  
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DIESEL ELECTRICAL MAINTENANCE  
COMMITTEE**

## **I. WIRELESS COMMUNICATION TECHNOLOGY OVERVIEW**

*Prepared by Tom Nudds,  
Customer Service Manager  
ZTR Control Systems*

### **Introduction**

The ongoing evolution of publicly available wireless networks has led to inexpensive and secure Internet based data communications across the globe. Various types of wireless technologies have been developed to create this level of interconnectivity using satellite, cellular and wireless LAN radios. Due to the breadth of available options, determining the best possible technology for a particular application can become a daunting task. Using a simple set of criteria helps to differentiate each of the technologies and provide a means to highlight their strengths and weaknesses. This presentation will identify various wireless technologies for use in the rail industry and will explore some of the costs and benefits of each technology.

### **State of wireless today**

Today, the rail industry has significant wireless infrastructure primarily designed for voice based communications. Over the years this technology has served the users well and significantly changed processes and procedures within the industry. Wireless data communications has matured to the point where it can now be considered a viable option to complement the existing voice infrastructure. As the industry moves towards these new technologies, identifying and defining potential

applications will be key. To maximize the benefit of the new networks, the industry must find ways to improve interoperability between devices on the wireless network as well as the wired networks. Sharing the same bandwidth and using common protocols will allow for synergies and a reduction in development and system costs.

### **Decision criteria**

To effectively choose a particular product or service the costs and benefits needs to be defined and compared against the other candidates. Wireless data systems are no exception to this process. The selection criteria have been broken into the following four categories.

The first category is coverage. Coverage affects the ability of the client to maintain communications with the devices on the network. Coverage affects the timeliness of data. If the system is in a region with limited coverage the information to be sent to the network must be stored locally until the device comes into a region of coverage. Typically, receiving data and accessing the device in a timely manner is of high priority to a customer.

Bandwidth represents the amount of information which can be sent through the network by a radio. Networks supporting higher bandwidth will allow for applications requiring more complex data to be collected or an increase in the frequency of the data collection. As an example, sending a GPS location requires a very small amount of bandwidth as compared to a video



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stream. In most cases, greater bandwidth is considered beneficial, as it allows a business to provide a more valuable service to its customers.

Reliability defines the success of receiving the data sent to the client. The more complex a system, the more opportunity for failure and potential for reduced reliability. Lost data and message retries can affect the ability of the application to provide data in an expedient manner. Less reliable networks also result in higher maintenance and engineering costs as more layers of complexity need to be added to overcome the lower reliability.

The final category is cost. Cost can be broken into hardware cost and service cost. For a wireless solution to be viable the value of the data must outweigh the overall costs of the system. Various factors affect hardware cost including available features such as network intelligence, available IO interfaces and the ruggedness and quality of the hardware. The service costs are defined by the wireless service provider. Each wireless provider offers a unique price model. Pricing is generally defined by how long a user is connected to the network or how much data a user sends through the network.

By using these four categories various wireless services can be compared against one another to lead to the best choice for a particular application.

### **Cellular services**

The first wireless technology group to highlight is digital cellular. In

North America there are many cellular providers using various communications technologies. The two primary implementations are either CDMA (Code Division Multiple Access) based systems or GSM (Global System for Mobile communications). The CDMA providers, Verizon, Sprint, Telus and Bell offer what is known as a 1x wireless data service, while GPRS (General Packet Radio Service) is offered by Cingular, T-Mobile and Rogers.

Both 1x and GPRS offer similar capability, as the wireless radios designed for either network can be used to establish a connection to the Internet and provide the device with a standard public IP address. This means that the wireless device now has the potential of leveraging all the technologies and protocols designed for the Internet. This offers significant savings as development effort does not need to be spent on proprietary communications interfaces or protocols. Instead, investment can be made into enhancing application functionality.

Typically, voice service is charged 'per minute.' When a user is connected to the network in a voice call the service provider counts the amount of time the user is connected and then bills them accordingly. With data service the user is no longer charged 'per minute' but rather by the amount of data it sends in bytes. Now a device can be connected at all times to the network but only charged for the amount of data sent through the wireless connection. Being always-on allows for true two-way communication with-



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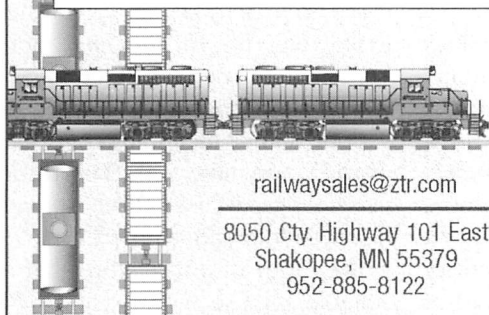
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out the need to dial and establish a connection. This changes how devices are accessed and simplifies back-end system design.

In order to differentiate between 1x and GPRS the decision criteria defined earlier will be applied. Comparing 1x and GPRS coverage is the first item of comparison. Within North America both networks have a similar coverage profile. Nearly 100% of the urban centers are covered while rural areas have limited coverage. Outside of North America GPRS has a distinct advantage over 1x as it is used extensively throughout Europe, Africa and Asia while 1x is mainly used in America.

Depending on the type of application available, bandwidth can be a deciding factor. 1x typically offers 50% more bandwidth than GPRS. In Machine-to-Machine (M2M) applications data tends to be packed in small chunks and sent infrequently, such as once an hour or once a day. In this case the benefits of increased bandwidth are limited. However, in a case where images or large files need to be transferred, extra bandwidth does become a significant factor.

In field testing both 1x and GPRS systems have proven to be extremely reliable. Once a connection is established it is very stable. In a mobile environment loss of connection is possible and not uncommon. When developing solutions using 1x and GPRS this loss of connectivity must be factored into the design of the system.

Hardware costs for 1x systems are typically more expensive due to

licensing costs associated with using CDMA technologies. Service costs must be negotiated with each provider on an individual basis. As data only use has become more common, carriers have developed data-centric solutions providing plans that offer data aggregation and reduced data rates.

Both 1x and GPRS will be superseded by third generation (3G) wireless data solutions. Within the last year Verizon and Sprint have begun installing 1x-EVDO infrastructure and offering 1x-EVDO services. As with 1x, a standard internet connection can be maintained. The available bandwidth of 1x-EVDO is the differentiator, where typical connection speeds of up to 700kbps are possible. This solution offers a significant speed improvement over 1x, allowing for use of multimedia content transfer such as video and voice.

The GPRS upgrade path is through EDGE (Enhanced Data Rates for Global Evolution) technology which has the potential for 3G type data rates. In practice EDGE offers speeds slightly below that which is expected of a 3G solution.

For both 1x-EVDO and EDGE, coverage will be a deciding factor. These are emerging technologies with limited coverage. Radios that support either technology are backwards compatible with their respective siblings. If 1x-EVDO coverage is lost the radio can fall back to 1x.

The types of applications that are suitable for use with 1x and GPRS technologies in the rail industry include event recorder data download, grade crossing monitoring,

locomotive health and location monitoring to name a few. The common aspect of each of these applications is that they typically require a limited amount of data, ~100k, and if the data are sent at longer intervals (hours or days) it will still be meaningful.

More complex applications can be offered via 3G technologies including video monitoring and real-time data monitoring.

### **Satellite services**

Satellite services offer an alternative to digital cellular solutions when the application needs the ability to connect to the wireless device in remote and rural locations. Many satellite services offer complete geographic coverage of North America enabling access to and from the radio in almost any location. One major distinction between Cellular and Satellite is that cellular radios have coverage indoors while satellite radios will always require a sky view to communicate with the user.

Satellite services typically offer much less available bandwidth to the user. This is specifically the case with services that allow a user to use an antenna other than a directional dish. The lowest cost services offer the ability to send a short message packet while the highest bandwidth services offer a 9600 bps streaming connection. Limited bandwidth affects the type of application that are best suited for the technology. Slower connections means less information can be sent to the end user and typically it will be much more expensive.

Satellite service pricing is based on either data or connect time. Services that offer short message solutions typically charge 'per message' while services offering a streaming connection charge 'per minute.' This is significantly different from packet-switched cellular, which offers an always-on connection with 'per byte' charges.

There are a variety of satellite services available today. A short list includes Globalwave, Globalstar, Orbcomm and Iridium. Each offers a unique set of strengths. From an application perspective, Globalwave or Orbcomm are suited for low bandwidth applications such as locomotive fuel or location monitoring as their strength is low cost short messages. Globalwave also offers a very low power solution, which enables the unit to be battery, or solar powered. Iridium offers more capability in terms of true global coverage and higher bandwidth with a choice of streaming or short message communications. Goldstar offers the fastest connect speed, which makes real-time viewing of data on a locomotive possible for short periods. The length of time is constrained mainly by cost as charges are 'per minute.'

Interoperability is also a factor when considering satellite solutions. The providers that offer a streaming connection typically offer internet access as well. Choosing a satellite provider that allows for IP connectivity will ease the development if the application architecture is designed around Internet protocols. Using the Internet protocol stack as a common abstraction layer allows for a simpli-

fied interchange of wireless technologies as it separates the communications hardware from the rest of the system.

### **Wireless LAN**

Recently, Wireless LAN has become very popular with home and business users. It offers a compelling alternative to cellular and satellite services. Choosing a Wireless LAN solution means there are no monthly fees to pay but they are replaced with infrastructure design, installation and maintenance costs. Due to the high volume of radios sold, hardware has dropped to a point where installation has become feasible and a realistic alternative.

Wireless LAN coverage is typically measured in hundreds of square yards. In a practical sense, this means that multiple access points must be setup to cover an area the size of a rail yard. To provide expanded coverage, a wireless LAN radio can be configured to authenticate with multiple access points. These access points in turn can be installed throughout multiple rail yards, greatly expanding coverage. Wireless LAN systems are not designed to match the type of coverage possible with digital cellular or satellite. In the future, radios will support both wireless LAN and cellular or satellite radios, or both to augment the coverage when a wireless LAN signal is no longer available.

The potential bandwidth with Wireless LAN is 10Mbps or higher. This is an order of magnitude greater

than 1x-EVDO. The types of applications Wireless LAN can offer will allow for streaming video, real-time monitoring and remote control.

The WiMAX (802.16) standard represents the next generation of wireless LAN technology. WiMAX is designed to complement the Wireless LAN standard. It's specification is much more ambitious as coverage will be measured in square miles. Data rates for line-of-site applications will be up to 40Mbps while mobile users will see speeds up to 15Mbps.

WiMAX is designed as a last mile solution. The benefit to the rail industry is the ability to cover significantly more area than would be possible with Wireless LAN while avoiding a recurring monthly fee. Today, WiMAX is still an emerging technology with limited installations. It will become more accessible to business consumers in the coming years.

### **Wireless hardware considerations**

There are a number of considerations when choosing wireless hardware. The majority of radios are not designed for the types of environmental conditions that are possible in a rail application. Determining the environmental limitation of any radio is very important. The majority of the hardware available to day is designed for consumer-oriented applications. However, in an effort to meet the more rugged demands hardware manufacturers are designing wireless products for rugged environments.

A second consideration is the type of functionality available from the



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hardware. Does the application require extra IO, a network aware radio with an IP stack, or the ability to program the radio's firmware to add a proprietary algorithm or logic?

A final consideration is the level of support provided by the service provider. This is important when there are connectivity issues that need to be addressed. Typically, most service providers will certify a particular radio for use with their network. Certification ensures that the hardware works with system and that the provider will offer technical support for the product.

### **Conclusions**

Today, there are a significant number of technology choices available for developing wireless data solutions. Each choice has strengths and weaknesses that must be weighed with the type of solution being developed. A one size fits all solution is not available on the market today. Using a defined set of criteria will help differentiate each technology. Pairing technologies that have complementary attributes can make the difference between success and failure in your application.

Having a clear understanding of the application needs and the key features and functionality that add value to the solution is also important for project viability. Defining these requirements upfront will ease the decision process and reduce complexity and uncertainty.

Choosing interoperable technologies will allow the wireless system to grow and benefit from next generation technologies as they mature, as

each successive generation offers more capability. Reducing barriers in the technology upgrade path will allow for continued success in the future.

## II. MAINTENANCE BENEFITS OF THE GREEN GOAT

### PART A:

*Prepared by*

*Brad A. Steffel*

*Manager Mechanical Engineering,  
Union Pacific Railroad*

Higher emission standards and an aging low-horsepower fleet lead many railroads to search for alternatives when developing a strategy for their switcher fleet. RailPower's Green Goat is one option that has been considered by many railroads. This hybrid locomotive has been tested and proves it can provide performance to compete with the currently available switchers and low-horsepower locomotives. As with any mechanical or electrical system, the Green Goat will require periodic maintenance. This paper will highlight some of the maintenance benefits of the Green Goat when compared to a typical yard switcher locomotive.

The first maintenance benefit can be seen when comparing the diesel engines. The Green Goat uses a small diesel engine and main alternator mounted on a common platform. This assembly, referred to as "gen-set", can be removed in cases where repairs need to be completed on the engine or alternator. The time to remove the gen-set is estimated to be comparable to the time required to replace two or three power assemblies in a typical locomotive. After removing the gen-set, repairs can be made to the engine or alternator while the Green Goat is switching cars in the yard. This can

lead to an improvement in availability when compared to cases where significant engine or alternator work is required on a standard yard switcher.

The Green Goat consumes about half as much as diesel fuel as a typical yard switcher. The diesel engine is also not designed to consume oil like a typical larger two-cycle diesel engine. These two items reduce the mechanical needs for servicings, increasing the locomotive's availability. Of course, the typical daily inspection and Federal items still apply and there is still the need to service items in the cab.

With smaller engine components than a conventional locomotive, many maintenance requirements can be performed in the field at locations where the Green Goat operates. By performing field maintenance when minor repairs are needed, days of travel time to a major repair facility can be eliminated. This leads to a significant increase in availability.

As an example, in 2004 a joint study with RailPower and Union Pacific was completed on the low-horsepower fleet in Union Pacific's Central Region. This study found that the average low-horsepower unit experienced 6.6 unscheduled shopping events every year. Each out of service event resulted in an average of eight out of service days per event when including transit and repair times. When calculating the benefits of performing field maintenance on the fleet of low-horsepower locomotives in the Central Region, it was estimated that 41 locomotives could

be eliminated due to the increase in locomotive availability.

The Green Goat contains a micro-processor control computer. This computer provides valuable maintenance information that is not available on a standard switcher locomotive. Future versions of the Green Goat will include fault logs generated by the microprocessor. These fault logs will be available to be downloaded and reviewed. This provides many maintenance advantages currently seen on more modern high-horsepower road units. For example, when integrating a system to perform remote monitoring and diagnostics, there is an opportunity to implement a structured predictive or preventative maintenance strategy to monitor the condition of the locomotive and keep it in top working condition.

The diesel gen-set charges a bank of sealed valve regulated lead acid (VRLA) style batteries. This large battery bank is the primary source of power to the traction motors in the Green Goat. If there is a problem with a battery in one of the racks, the jumpers can be reconfigured to take that rack out of the system and allow the Green Goat to continue working until it is convenient to replace that rack. Even though VRLA batteries require much less maintenance than a typical "wet" cell battery, they do require regular attention and some maintenance. The batteries should be inspected every two weeks for fluid leakage and an equalization charge should also be initiated at this time to ensure peak battery performance.

When a new locomotive model is introduced, railroads have been faced with the challenges involved with training crews and repair personnel. The Green Goat contains several standard components found on most conventional locomotives. These items include standard 26L air brakes, brake rigging, trucks, traction motors and an AAR control stand. By keeping these items standard, railroads do not have to provide costly training sessions to show personnel how to repair these frequently maintained items.

Due to the infancy and continued evolution of the Green Goat, it is hard to predict its long-term reliability and economics. While the system is more sophisticated than a typical switcher that is 50+ years old, RailPower has taken many steps to keep maintenance of the Green Goat as simple as possible. A cost analysis performed by RailPower shows the Green Goat to be economically justifiable. As a result of the emissions and cost benefits, Union Pacific has purchased several Green Goat locomotives as part of our long-term low-horsepower locomotive strategy.


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by RailPower

## HYBRID SWITCHER UPDATE THE GREEN GOAT

### PART: B

*Prepared by  
Randy Slomski  
RailPower Hybrid  
Technologies Corp.*

What's the big deal about hybrids?

- Reduces emissions 70%-90%
- Saves 40% to 60% in fuel consumption
- Reduces noise emissions 70dBA maximum

### History

The first 1,000 hp unit was completed in 2001 and the first 2,000 hp unit was completed in 2002. There are more than 20 units in operation, currently with commitments for more than 90 locomotives with more than 40 to be delivered by end of 2005.

### How hybrid technology works

Diesel fuel is used by an onboard generator. The generator produces electricity that is stored in batteries. Electricity from the batteries is throttled by the chopper board in the electrical cabinet and is then delivered to the traction motors.

"Out of service" idle times and "in service" idle times are reduced when compared to a conventional switcher (Figures 1-4). The battery is charged at the engine's most efficient operating point (Figure 5). The engine/gen-set operates only when necessary to charge batteries (Figure 6).

### Advantages

- Increased tractive effort - instant response from the power stored in the batteries and advanced wheel slip control.
- Outperformed a GP-9 locomotive, 2 SW-1200s
- No idle which equates to no noise, no fuel consumed and no emissions
- Safer (no oil on running boards) - cab is quiet
- Reduced maintenance and servicing (fueling cut in half)
- Reduced operator fatigue

### Main components

The hybrid switcher has microprocessor controls with advanced wheel slip system. It has standard traction motors, trucks and brake rigging. It is Tier 2 or 3 compliant with maintenance free batteries. It is equipped with ac motor driven air compressor and traction motor blowers. It has a standard AAR control stand and air brakes and has microprocessor controls with advanced wheel slip.

### Field experience

The hybrid unit has performed well in various duty cycles on certain Class I Railroads. Figures 7-12 provides general statistics on the operational performance of the hybrid unit.

### Conclusion

While the Green Goat is still in its infancy stages, it has performed admirably to date. Green Goat operators have reported that it is quiet, has good visibility, and has good

pulling power in addition to the fuel savings and emissions reductions experienced while operating this unit.

# Why Hybrid Technology Works

## 1. "Out of Service" Idle Time Reduction



**Operators can NOT defeat the system!**

Figure 1

## Why Hybrid Technology Works

### 2. “In Service” Idle Time Reduction

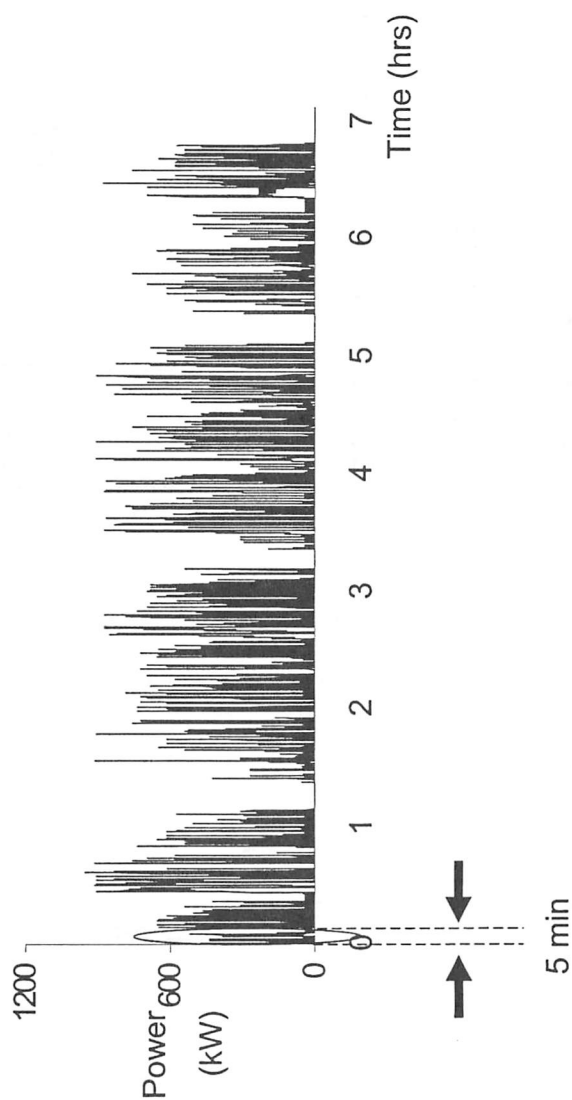


Figure 2

# Why Hybrid Technology Works

## 2. "In Service" Idle Time Reduction

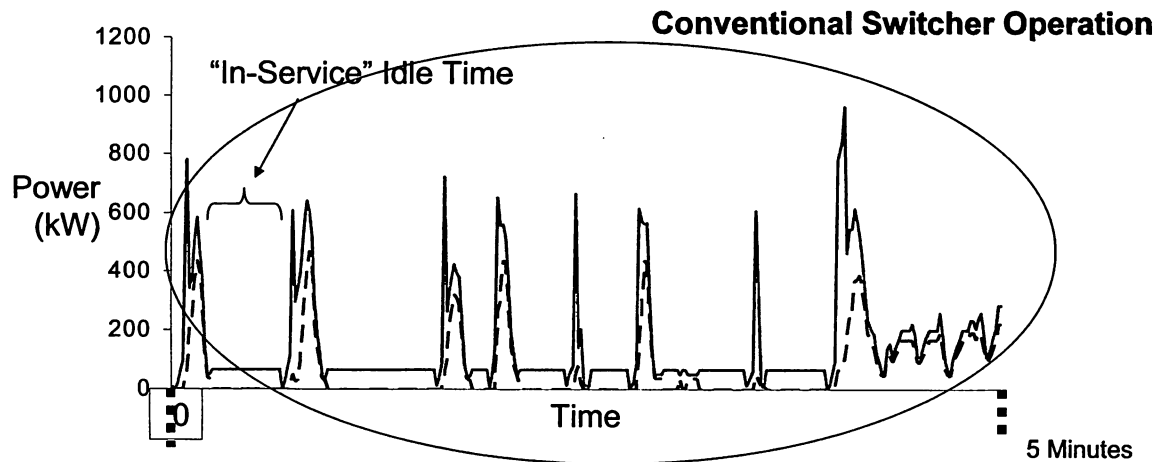
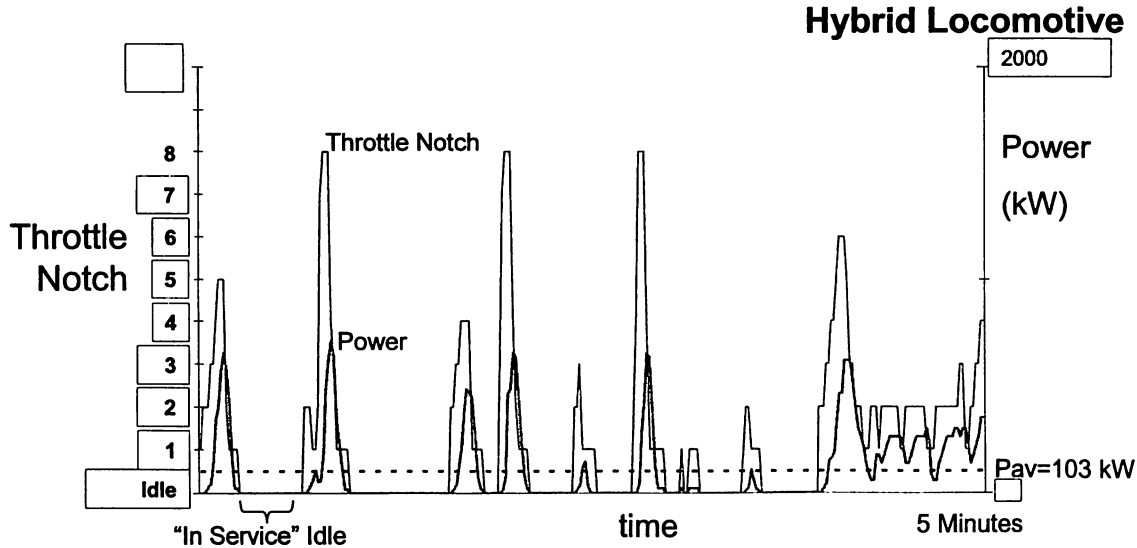


Figure 3

# Why Hybrid Technology Works

## 2. "In Service" Idle Time Reduction



**In-Service Idle Time is Eliminated**

Figure 4

## Why Hybrid Technology Works

### 3. Battery is Charged at the Engine's Most Efficient Operating Point

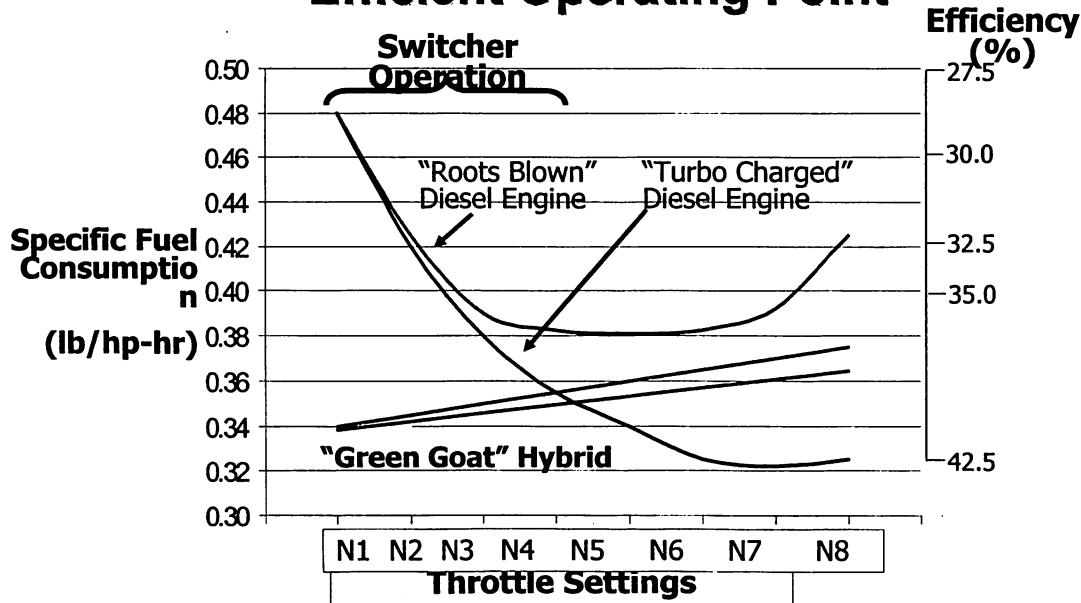
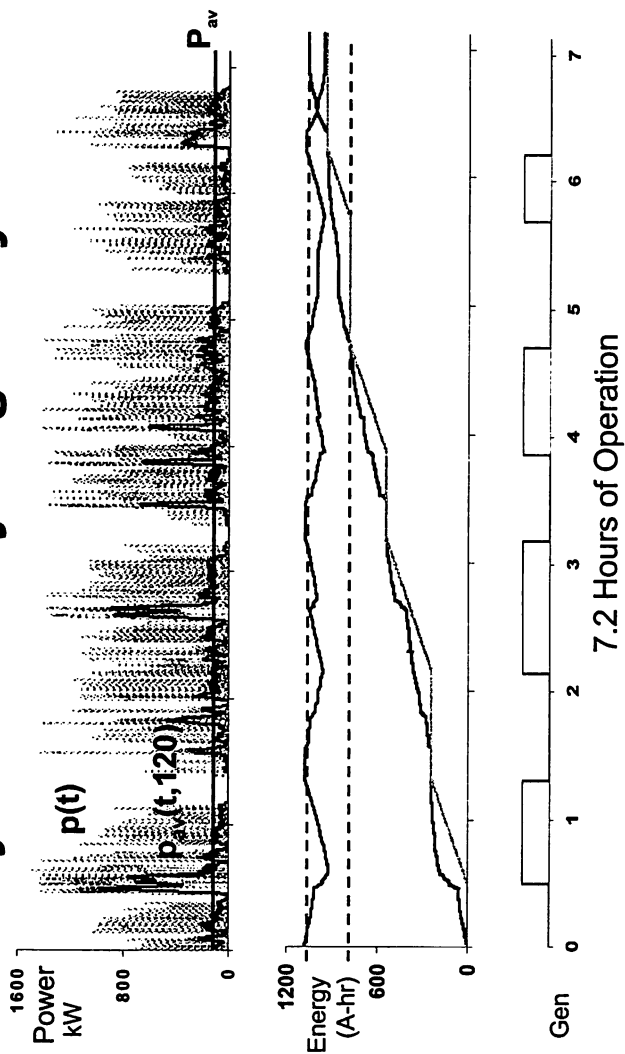


Figure 5

# Hybrid Battery/Engine Cycle



**Engine/Gen-set Operates Only When Necessary to Charge Batteries**

Figure 6

## Field Experience: CSX

### Large Class I Railroad / Medium-Heavy Duty: GG20B

- Hybrid unit operates for 16+ hours per day, available 24/7
  - Typical run (yard):
    - 40+ cars
    - 2,000-5,000 trailing tons
    - 10-20 km/h
  - 40-60% fuel savings
  - Performance equals / exceeds conventional 2,000 HP locomotives
  - Two units on 9 month demonstration lease since Jan 2005
- ▶ Local “industry” run:
    - ▶ 10-20 cars, up to 20 km, 20 km/h
    - ▶ pick up/deliver cars to/from yard & industries along on the rail line



Figure 7

## Customer Experience: Union Pacific

- **Large Class I Railroad / Medium-Heavy Duty: GG20B**
- Hybrid unit operates for 12+ hours per day; available 24/7
- Typical run (heavy):
  - 32+ cars
  - 5000+ tons
  - up to 16 km/h
  - 2 - 4 km each typical pull
- 40-60% fuel savings
- One unit on long-term lease since March 2005; orders for 20 added units



Figure 8

# Customer Experience: Canadian Pacific

- **Large Class I Railroad / Heavy Duty: GG20B**
- Hybrid unit operates for 16+ hours per day
- Typical heavy pull:
  - 91 cars, 9400 tons
  - 10 km/h (1.6 km/h on incline)
  - 30 minutes
  - The pull was achieved using a single hybrid unit; this pull typically requires two 2,000 HP conventional units
- Fuel savings of 45%
- 35% adhesion achieved with the hybrid due to RailPower's proprietary individual axle adhesion control system
- 90 day trial, 35 units then ordered

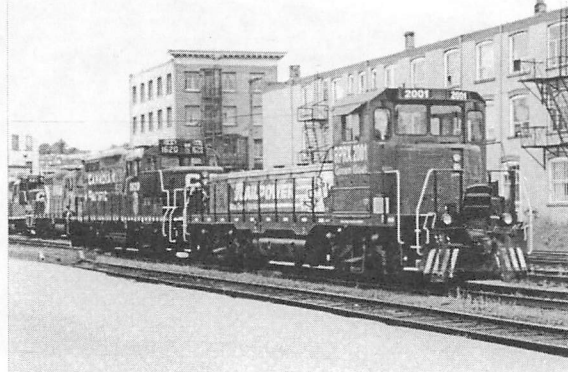


Figure 9

## Customer Experience: IDC Dist. Services

- Port (Greater Vancouver) / Medium Duty: GK10B
- Hybrid unit operates for 12-16 hours per day
- Typical run:
  - 38 intermodal double-stacked cars
  - up to 1500 tons
  - up to 16 km/h
- Unit in service since August 2004, purchased at 2004 year end



Figure 10

## Cold Weather Operations: Canadian National, Canadian Pacific, & Agrium

- Demonstrated at  $-25^{\circ}\text{C}$  to  $-35^{\circ}\text{C}$  with no performance degradation
- Some load maintained on batteries to keep warm
- Charge for starting gen-set maintained
- Fuel preheated
- Extra insulation for engine compartment
- Heavy insulated cab with electric heat



Figure 11

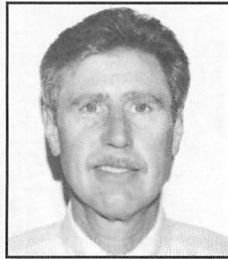
# Customer Experience: Amtrak

- **Largest U.S. Passenger Railroad / Light Duty:**
- **Green Goat Prototype**
- Hybrid unit operated for 18-20 hours per day
- Typical run:
  - 5-12 passenger cars  
(single and double stack)
  - 50-75 tons per car
  - 8-20 km/h
- 60-70% fuel savings
- Unit trialed for 30 days;  
one unit then ordered



Figure 12

**REPORT OF THE COMMITTEE  
ON DIESEL MECHANICAL MAINTENANCE  
TUESDAY, SEPTEMBER 20, 2005  
10:15 A.M.**



Chairman

**JACK KUHNS**

Vice President-Sales  
JMA Railway Supply  
Ponte Verdra Beach, FL

Vice Chairman

**DAVE RUTKOWSKI**

Chief Mechanical Officer  
Providence & Worcester RR  
Worcester, MA

**COMMITTEE MEMBERS**

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I. Bradbury	President	Peaker Services	Brighton, NJ
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D. Miller	Sr. Mgr.-Loco Engrg.	Union Pacific RR	Omaha, NE
D. Taylor	Mgr.-Cust. Support	GE Transportation Rail	Erie, PA

## PERSONAL HISTORY

### *Jack Kuhns*

In 1978, following a four-year tour of duty in the US Navy, Jack Kuhns began his railroad career with the L&N in Louisville, KY. After completing a machinist apprenticeship and supervisor training Jack transferred to the CSX facility in Corbin, KY, in 1986.

In 1988, Jack joined the supply side of the industry with the Durox Company. For ten years, he studied the industry through the eyes of gaskets and seals. Jack then joined the Hadady Corporation and con-

tinued his industry studies focusing on trucks and their components. In 2002, Jack joined JMA as Vice President of Sales. As he continues his studies of the industry he considers himself fortunate to be able to continuously broaden his knowledge in an industry as challenging and as diverse as the rail industry.

Jack and his wife, Patty, have been blessed with three children and five grandchildren and reside in Ponte Vedra Beach, FL.

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## I. CRANKCASE OVERPRESSURE TODAY - CONCENTRATING ON EMD & GE LOCOMOTIVES

*Prepared by*

*Jeff Cutright,*

*Sr. General Foreman,*

*Norfolk Southern Corp. &*

*Dick Boothe, CN RR*

### Introduction

This paper was written to address the tried and true troubleshooting practices as well as some new developments in crankcase troubleshooting. Since a "Best Practices" paper was written in 1998 discussing the details of troubleshooting an EMD locomotive engine, this paper will concentrate on GE locomotive engines. A brief discussion of the general need to have a working evacuation system and the various types available will be followed by a discussion of EMD engine systems. The rest of the paper will cover procedures one railroad uses to maintain GE locomotive engine crankcase pressure health.

Naturally, each railroad has its own practices concerning safety and troubleshooting locomotive crankcase trouble. This paper does not intend to ignore or replace those practices. Please follow all local and corporate safety and troubleshooting guidelines established at the property occupied.

The most common general safety guideline that needs to be discussed is that after crankcase explosion it is important not to open the crankcase to the atmosphere for at least two hours. Personal injury and equipment damage could result from an

explosion when the crankcase is exposed to fresh oxygen. Do not remove a crankcase cover, top deck cover, or vent the crankcase for two hours following a known or suspected crankcase explosion. Also, do not attempt to restart the engine until a thorough engine inspection has been completed and any defects found have been corrected.

### Common Evacuation Systems

Most large diesels have an evacuation system of some type in order to maintain the crankcase at a slight vacuum. Crankcase vacuum is important in order to limit oil leaks and to evacuate explosive vapors. Vacuum systems that create a vacuum stronger than what is needed will mask a potential serious engine problem that have been known to cause excessive damage to the engine and lead to road failures.

Four types of crankcase ventilation systems have been used to deliver the desired vacuum. These systems are as follows:

1. Air eductor system - Used on ALCOs where an eductor is used to pull a vacuum on the crankcase. The air from the turbocharger powers the air eductor. This was similar to the unassisted eductor used on EMD 645E3 engines in the 1970s which had an oil separator, a flexible pipe, and an eductor tube with an angled end that protruded into the exhaust stack. The system was simple and worked well, until EMD went to silencers.
2. Blower system (Fairbanks

Morse) - Some 2-stroke cycles use the scavenging air blower to draw a vacuum on the crankcase.

3. Turbo system 4-stroke cycle engines use the intake air to draw a vacuum on the crankcase.
4. Motor driven crankcase vacuum pump - Used on Colt - Pielstick and some ALCO engines, where a vacuum pump draws vapor from the crankcase through an oil separator.

Most systems will use some type of an oil separation system to help prevent pulling the oil out of the crankcase into the atmosphere. (Surface)

The domestic diesel locomotive manufacturers use the eductor system on the turbocharged engines used on the railroads of North America today. This system has been reliable and effective, but it does require some periodic maintenance. As the engine ages, the pressure in the crankcase has been known to increase. In order to offset this pressure, it is important to increase the vacuum or reduce the major contributors of the pressure. The problem could be as simple as an evacuation system failure or a leak in the seals of the engine.

### **Manometer Reading**

The manometer has been the most common tool used to measure the vacuum in the crankcase. The manometer is read by determining the total height of the water column in inches. Be aware that this device

will measure vacuum as well as pressure. Please see Figure 1 and Figure 2 as reference concerning how to read the manometer.

The left columns in both examples are connected to a crankcase with approximately three inches of vacuum. This measurement is necessary in order to verify that the locomotive measuring system was calibrated correctly. It has been found that the onboard system uses a pressure sensor that was designed to measure pressure; therefore the system will display a limited vacuum reading regardless of the actual vacuum present in the engine. One known device will display 1.5 inches of water vacuum even though the engine might have a greater actual vacuum.

### **EMD Evacuation System Review**

On EMD railroad locomotive engines, some basic evacuation system related components need to be understood. Please reference the "Best Practices" paper written in 1998 by this committee and included in published papers for that year. Included in that paper were some of the following points.

Once all local safety procedures have been implemented, the following checks can be made with the engine not running.

Check engine oil level. Excessive oil in the crankcase may cause a false pressure indication by hitting the diaphragm of the protective device causing it to trip.

Check aspirator system and eductor tube (on turbocharged engines). Check the aspirator system for

plugged screen in the lube oil separator, and plugged or damaged piping. Examine the eductor tube for carbon build up.

After a two hour cool down period examine the engine for component failures.

Remove the air box and crankcase covers. Look for the following defects that may have cause crankcase pressure:

Air box checks:

- Cracked, broken, scuffed or overheated pistons
- Cylinders with excessive scoring
- Piston rings broken or improperly installed
- Lower liner seals broken or hardened
- Any indication of carbon combustion (air box fire) which could damage seals
- Missing bolts or dowels oil pan to crankcase
- Cracks or defects in the top drain line or welds

Crankcase check:

- Inspect bearings for indications of overheat or excessive wear
- Check all p-pipes for being broken, missing or misaligned contributing to piston failure
- Examine air box drain line for cracks or defective welds
- Excessive wear at the art pin and wrist pin of the rod and piston
- Check for debris under the gear train at both ends of the engine

Top Deck Inspection:

- Loose or broken crab bolts
- Missing or loose crab retainer

plate bolts

- Loose injector crab nuts
- Leaks at the head frame or top deck covers
- Cracks in the welds in the top deck
- Improperly seated power assemblies

After these inspections have taken place and any defective parts found are repaired or replaced, the engine may be started and a top deck inspection performed looking for the previously mentioned defects. With the engine idling, check the lube oil strainer for signs of smoke, if found this could indicate a cracked piston.

After the engine has reached operating temperature apply a manometer to the engine to check crankcase pressure in the 8th notch.

If negative pressure exists and the protective device does not trip, the troubleshooting is complete.

If negative pressure exists and the protective does trip the following items should be checked:

- Check the lube oil relief valve for proper installation. If the relief valve vent has been discharging inboard instead of outboard this could hit the crankcase pressure diaphragm of the engine protector, giving a false indication of pressure.
- Check main lube oil and piston cooling pump discharge pipe to see if the O-rings were in place. If missing, a false indication could result.
- If nothing new found, replace protective device and retest.

If negative pressure cannot be achieved, the following checks



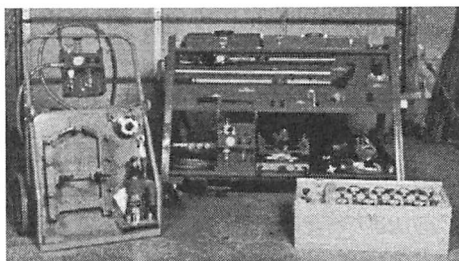
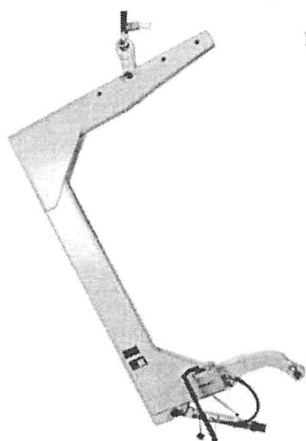
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should be made:

- Inspect the eductor and lube oil separator looking for plugging or improper orifice.
- Inspect lower liner seals for defects and wear.
- Perform a compression test of all cylinders.

These procedures will solve most crankcase pressure faults.

### GE Evacuation Systems

For GE locomotive engines, most of the same theory works as well. Naturally, the locomotive has to cool for two hours if a crankcase explosion has occurred or has been suspected.

On modern locomotives, the crankcase pressure rises as the locomotive wears. The more wear in engine, the greater the likelihood that crankcase pressure will surface as a problem. Several mechanical components of the locomotive have been identified as possible contributors to crankcase pressure. Other components have been designed to increase vacuum in the crankcase.

The following path has been described as a "Best Practice" by one railroad. Please follow any local

or corporate safety policy required on the property the locomotive occupies. If a crankcase explosion was suspected, or in the fault history, perform a crankcase inspection prior to running the engine. After any known problems have been corrected and tested, the following information has been known to correct crankcase pressure problems. This paper assumes the locomotive has been placed in an acceptable location, in safe condition, handbrake set, wheels chocked, and blue flags applied.

1. Verify the sensor reads 0.0 inches of water with the engine not running. Run the engine in the notch 8 with a manometer applied to verify the crankcase pressure sensor is accurate. Some sensors will not display a vacuum reading greater than 1.5 inches of H<sub>2</sub>O.
2. Visually inspect the crankcase, review lab reports, check oil level and clean and rebuild the crankcase evacuation system.
3. Load test in notch 8 to determine if the crankcase has at least one inch of vacuum, verified with the manometer.

#### Provides Positive Pressure

Turbo

Power assemblies

Water in oil

Overfull on oil

#### Provides Negative Pressure or Evacuation

Eductor tube

Coalescer, hoses & o-ring

Booster kit and orifice fittings

Turbo screen

4. Perform a cylinder compression check. Replace any assemblies with less than 240 psi compression.
5. Load test in notch 8 to determine if the crankcase has at least one inch of vacuum, verified with the manometer.
6. Perform valve cover pressure check and turbo bypass measurement. Repair or replace assemblies with 1 pounds per square (psi) rocker-box pressure. Replace turbo-charger when pressure changes by 1 inch water. Note: Refer to Table 1 to equate pounds per square inches of water.

Note: Oil temperature must be 200° Fahrenheit (F) and water must be 188° F. Crankcase pressure readings have been proven to be more accurate at these maximum operating temperatures.

Correct problems uncovered by the investigation. Load test the unit as required in the steps above. Intermediate load testing will be assumed in the paper. The locomotive will be hot at the end of each load test cycle and will require a cool down period between load testing and work steps. Load testing, locomotive repair and troubleshooting can stop after the eductor system has been returned to the correct configuration and the crankcase vacuum measures greater than 1 inch of water.

Verify the sensor displays an accurate reading. Next, if the oil was overfilled, correct the level, and check for oil quality and correct any issues recommended in the

associated lab report. If water was present in the oil, determine the source of the water by applying pressure to the water system and inspecting the crankcase. Free water in the crankcase will boil, creating pressure. Remove, inspect, and repair the coalescer system. This step has been determined to be critical to determine its ability to evacuate the crankcase as designed. Problems found with some eductor systems have been the boost orifice has been enlarged in order to increase the boost pressure, a hose was blocked with carbon, clamps were missing, tears or holes were in the lines and hoses. Also, it has been determined that the wrong materials have been applied to the o-ring seals. Due to the presence of the oil in this area, a fluorolastomer seal is necessary to create a long lasting repair. The latest revision concerning the coalescer calls for a single eductor tube projecting into the exhaust stack. If not previously applied, a booster kit was designed to increase the vacuum capability of the eductor system. With the eductor removed from the stack be sure the booster orifice has not been drilled larger than 3/16 inch. Figure 3 shows the eductor tube connection at the stack with the boost hose and Figure 4 shows a view of a correctly sized orifice. Some organizations have been drilling out this orifice to create the needed vacuum.

If the load test reveals that crankcase pressure is a problem, the next logical step will be to qualify the power assemblies' and turbocharger's contribution to

crankcase pressure. Worn valve guides, rings, cracked pistons or a scored liner could be some of the potential issues allowing pressure to the crankcase. Worn valve guides could be evaluated by placing a pressure gauge on and adding a quick release fitting on the valve cover as shown in Figure 5 and Figure 6.

Internal power assembly problems could be addressed by taking compression readings during bar-over. Be sure precautions have been taken to prevent the accidental starting of the locomotive during this testing. A governor stop block is required for a mechanically fuel injected (MFI) locomotive and for electrically fuel injected (EFI) locomotives unscrew and unplug the fuel pump wiring harness at the pop box. Apply compression fittings in the test cock holes of the power assembly and crank the engine for two compression pulses at each cylinder or four revolutions. Readings between 275 psi to 350 psi are normal and any cylinder with less than 240 psi reading on the gauge needs to have further investigation to determine the problem. The compression gauges have been shown in Figure 7 and Figure 8.

Several other tests can be used to qualify the power assemblies of the GE engine. The first one that comes to mind on an EFI locomotive is the on board "Pop" test. This test mimics the manual test of pulling on individual high-pressure fuel rods of every power assembly to make sure each fire. The next item to look for would be white exhaust smoke coming out the oil fill cap, indicating a

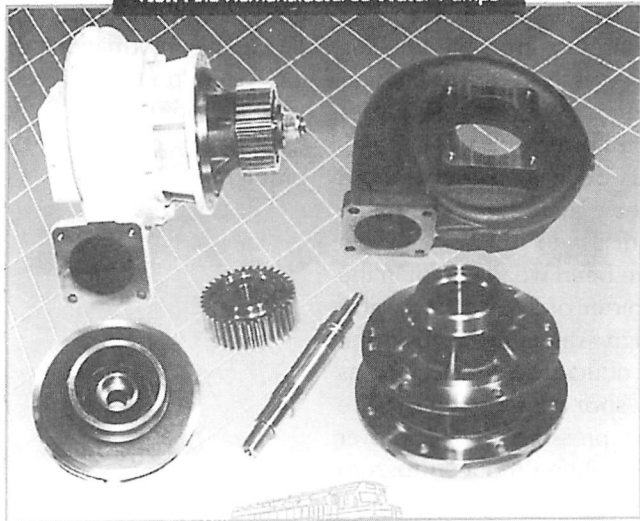
cracked piston. The "Pop" test performed while watching the oil fill cap might reveal which of the power assemblies has an issue. If the crankcase doors were removed during the compression check it might be possible to determine which of the power assemblies was by-passing compressed air by determining where a "huff" was coming from during engine rotation. This might be used to confirm the information from the compression check. If a power assembly has been determined to be suspect, another test calls for house air to be placed on the power assembly through the test cock hole. The power assembly must be at top dead center of the power stroke. If the power assembly has issues with the worn piston rings, then 90 psi house air will not be able to force the engine to bottom of its stroke.

Worn labyrinth seals in the turbocharger allow either exhaust pressure or turbocharger boost pressure to bypass to the crankcase. The turbocharger labyrinth seal in the turbocharger has been known to contribute to crankcase pressure. In order to determine the health of this seal a tester has been designed to qualify it. The tester has been shown in Figure 9 and as well as a bucket used to catch the oil that has bypassed the crankcase shown in Figure 10.

After the tester has been applied and engine has been warmed to operating temperature, this tester has been used to determine the contribution of the air or exhaust that has gotten by the labyrinth seals.

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The tester dumps the oil drain of the turbocharger to a bucket and closes off the drain/bypass oil from the turbocharger to the crankcase. A drop of more than one inch of water on the manometer indicates that the turbocharger should be removed due to worn seals. Given the size of the bucket this test needs to be completed in a timely manner. The oil and engine will be hot. By following this procedure it is possible to eliminate unnecessary turbocharger change outs. One of the issues found to be corrected by the manufacturer has been the issue of worn valve guides. There has been much speculation as to why the valve guides have been wearing, but in the second quarter of 2004 a new valve guide design was introduced in the engines produced at the factory as well as in spot replacements. The rocker box pressure of the power assembly has been reduced to zero with the new design valve guide. Figure 11 and Figure 12 show the old and new valve guide design.

It is now possible to create too much vacuum with the booster system. The booster system requires a change to reduce its effectiveness on newly overhauled locomotives. A restriction needs to be placed at the orifice and the eductor tube that projects into the exhaust stack needs to be shortened. Also, depending on how many power assemblies are replaced at one time, the crankcase pressure needs to be verified because the sensor will not measure more than 1.5 inches of vacuum. An aftermarket vendor has developed a replacement seal that can be applied

to the old style valve guide arrangement or the new valve guide. Figure 13 and Figure 14 show the after market seal design.

As can be seen by the information presented in this paper, analysis of crankcase pressure on modern locomotives requires a methodical approach. Several issues have been discussed as being possible contributors to crankcase pressure. Writing down the information as each test has been performed will help the troubleshooter change the parts that have been contributing most to the problem.

**Table 1**

Psi	in-H2O	Psi	in-H2O
0.1	2.77	1.1	30.45
0.2	5.54	1.2	33.22
0.3	8.30	1.3	35.98
0.4	11.07	1.4	38.75
0.5	13.84	1.5	41.52
0.6	16.61	1.6	44.29
0.7	19.38	1.7	47.06
0.8	22.14	1.8	49.82
0.9	24.91	1.9	52.59
1.0	27.68	2.0	55.36

Table 1 – Pounds per square inch vs. inches of water

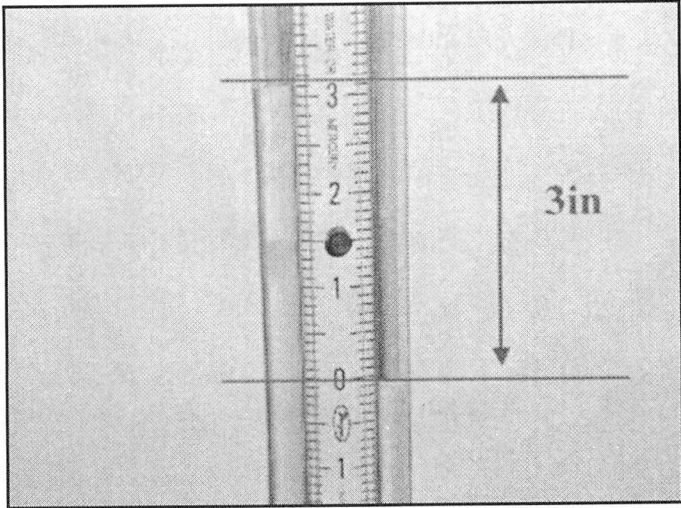
**References:**

Sadler, J. (1998) pg. 190-192. LMOA Best Practices Series - GM Engine Crankcase Pressure Troubleshooting. Proceedings of the 60<sup>th</sup> Annual Meeting.

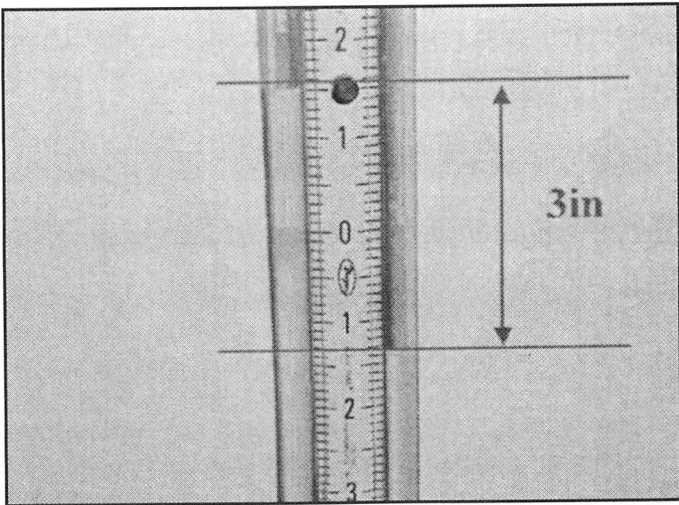
Stephens, J.A. (2004) Crankcase pressure evaluation and troubleshooting on GE Dash 8 and Dash 9 locomotives. Norfolk Southern Railroad Locomotive department instruction

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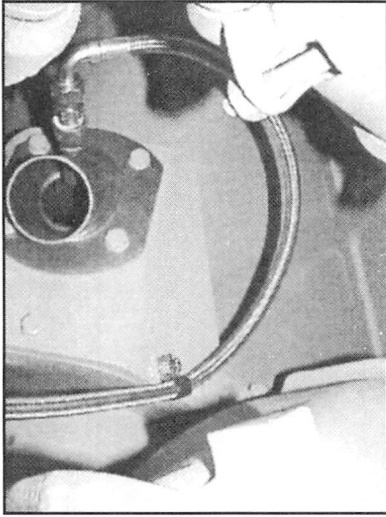
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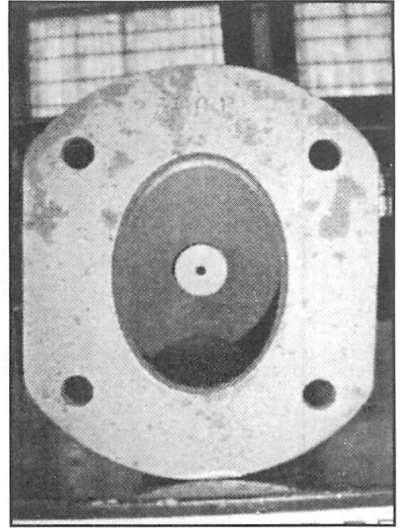
**Figure 1** - 3 inch manometer reading



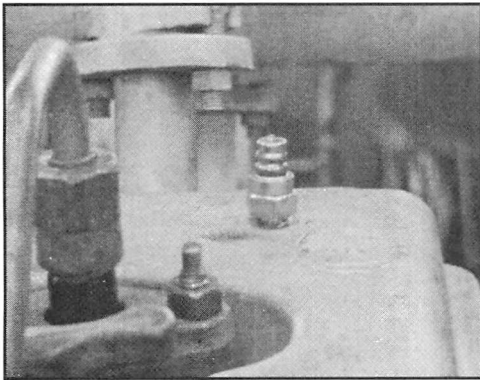
**Figure 2** - 3 inch manometer reading



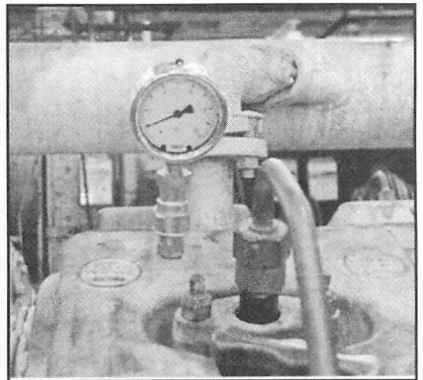
**Figure 3 -** Eductor connection @ stack complete with boost host



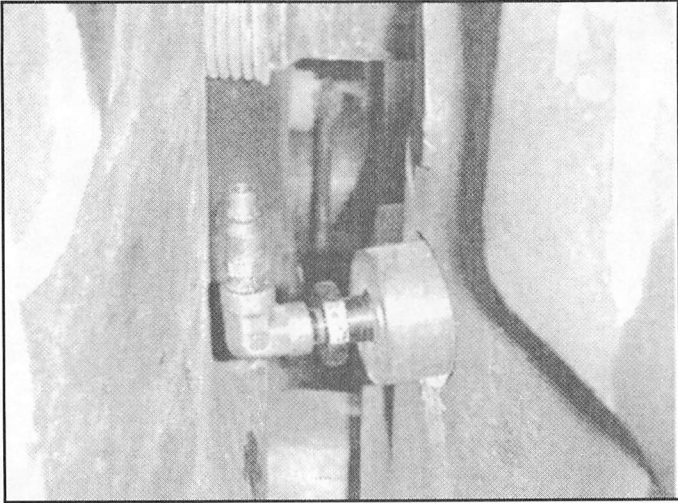
**Figure 4 -** Back side of eductor connector, note 3/16 inch orifice in the



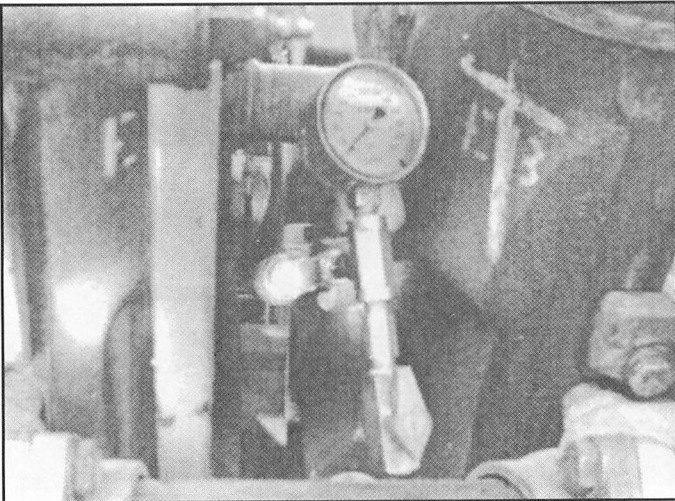
**Figure 5 -** Valve cover fitting



**Figure 6 -** Valve fitting with gauge

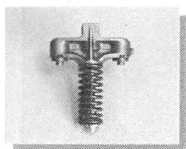


**Figure 7 - Compression adaptor**

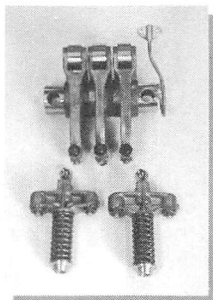


**Figure 8 - Compression adaptor with gauge**

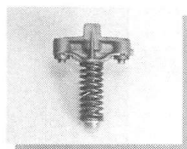
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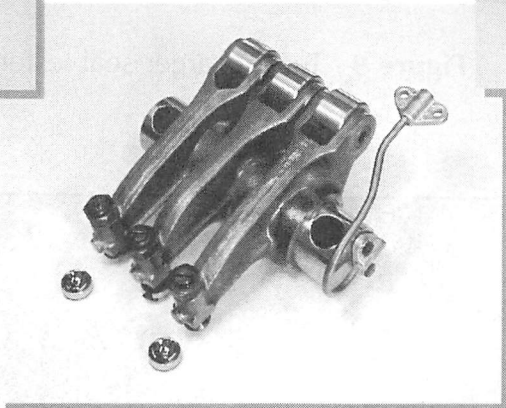
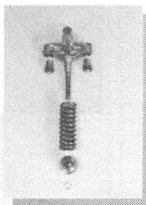
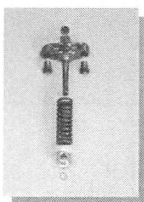
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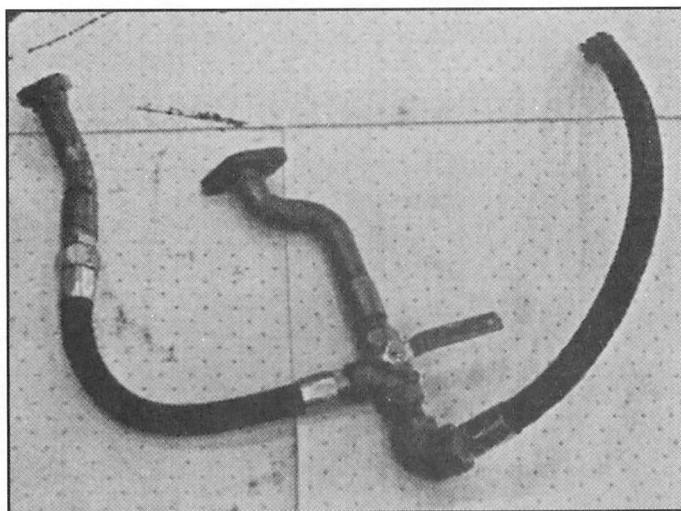
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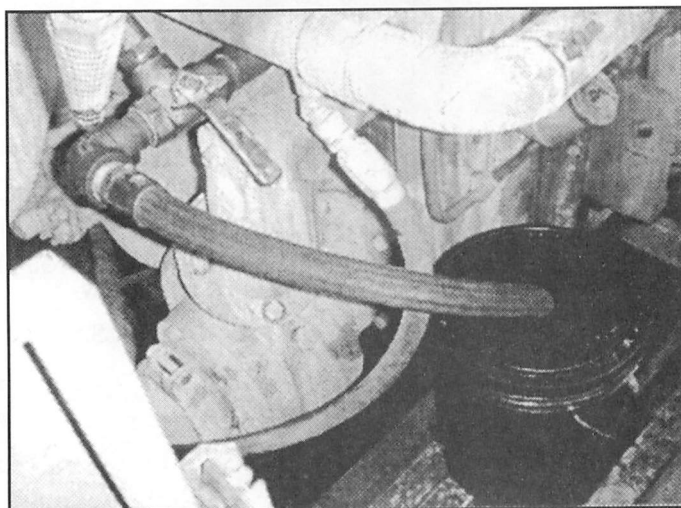
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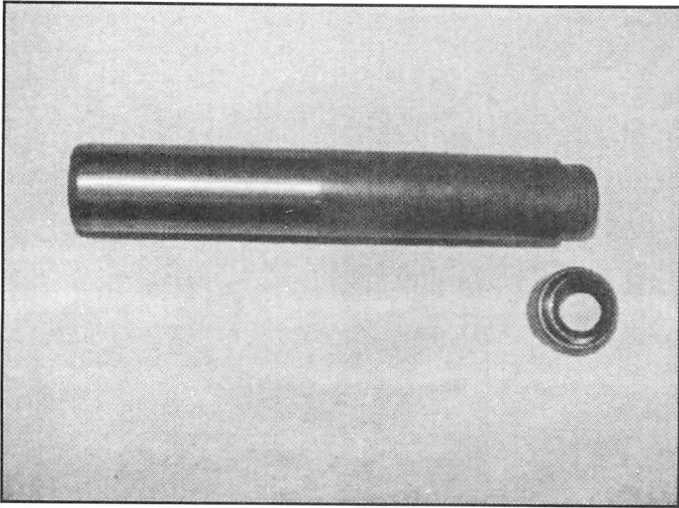




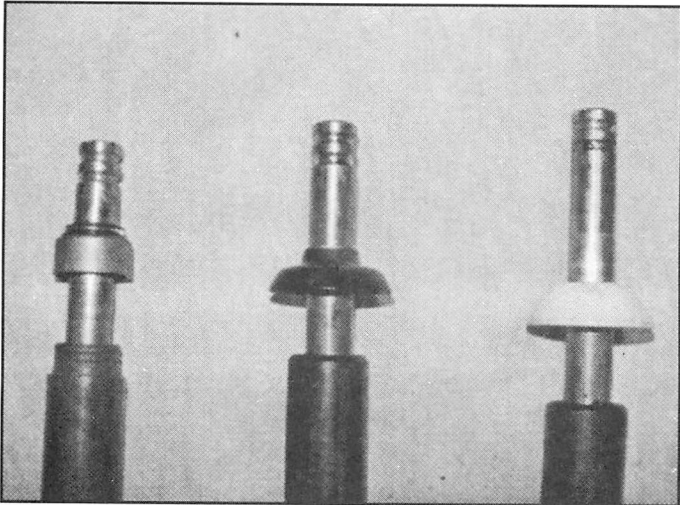
**Figure 9** - Turbocharger seal tester



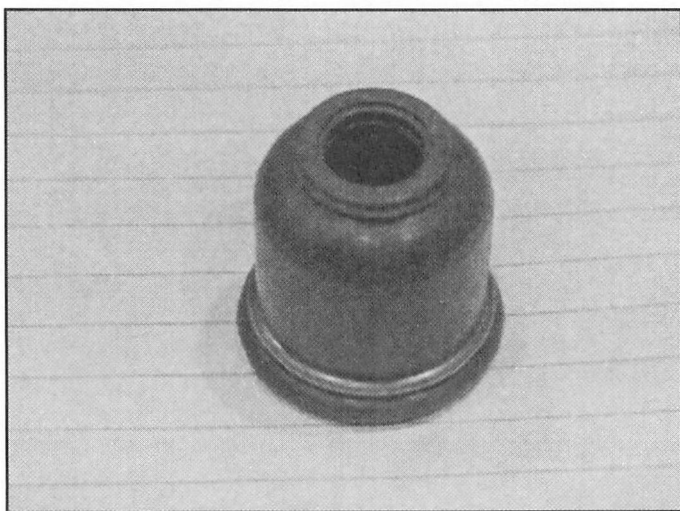
**Figure 10** - Turbocharger tester by-pass oil bucket



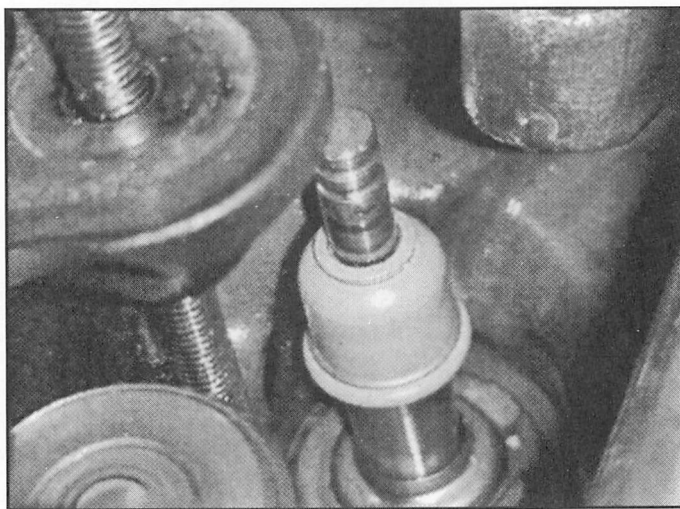
**Figure 11** - New valve guide seal design



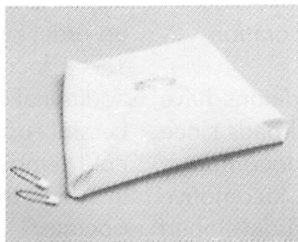
**Figure 12** - Valve guide designs



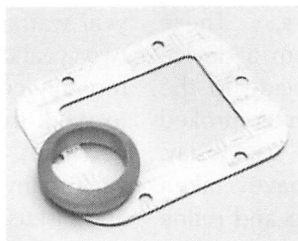
**Figure 13** - After market valve seal



**Figure 14** -  
After market design valve seal shown applied on an engine



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## II. COLD WEATHER LOCOMOTIVE OPERATIONS

*Presented by  
Bryan Graham,  
General Locomotive Supervisor  
Alaska Railroad Corporation*

Adverse weather conditions have been a challenge for railroads since the invention of the first locomotive. Over the years, many locomotive improvements have been developed for both the needs of crew members and the successful transport of commodities to customers. These improvements range from a device as simple as a wiper blade to the most complex computer controlled temperature systems in use today. Some technologies have taken decades to fully develop and refine while others have been the industry standard with little or no change since initial introduction. Although the manufacturers of today's locomotives take all of the latest industry information into consideration while designing and testing of their products, there is nothing more beneficial than customer feedback to ensure that reliability and availability issues are met. In this paper, I will cover some of the old and new technologies that have either been applied by the O.E.M. or have been developed out of the specific needs of individual railroads when considering the purchase of new or rebuilt locomotives. The focus will be on cold weather preparation/operation as this is what we at the Alaska Railroad Corporation (ARRC) deem as our greatest challenge in getting trains successfully over the road.

In the spring of 2000, the ARRC took delivery of 16 Special Duty 70 series isolated cab AC traction locomotives (SD70MAC) from Electro-Motive Division (EMD) with a follow up order of eight more in mid 2004. These locomotives had to undergo additional engineering to ensure successful operation in the extreme cold temperatures (as low as  $-60^{\circ}\text{F}$ ) in which they would be required to operate.

With the purchase of these new locomotives we also received a four year warranty. Throughout the first two years of this period we had monthly conference calls with EMD to work through concerns with our new fleet. Out of these conference calls many items were brought up and discussed. Some of these items were educational issues due to our lack of knowledge and experience with working on AC traction systems. Other concerns surfaced as time passed and the locomotives began operating in sub-zero temperatures for extended lengths of time. Many different field service engineers from EMD, SIEMENS, NEW YORK AIR BRAKE, and GRAHAM-WHITE came to Alaska to address our concerns. These information exchanges prompted modifications that were engineered and applied, resulting in the enhanced performance of our new locomotive fleet.

### **SD70MAC winterization package**

Construction was started with the underframe center sills, end plates, bottom plates and draft gear pockets all made out of CMS 10 low temperature steel. This was used to mini-

mize the chance of structural failure due to a "hard" joint or derailment in inclement weather by using a material that would resist brittleness in the extreme cold. The largest snow plow that EMD manufactures was installed on all the units to clear the rail while punching through snow drifts and small slides.

The standard summer/winter hatch application (EMD MI 1805) was incorporated (Figure 1). This consists of a winterization hatch over the #1 cooling fan with a manual summer/winter damper and an air-operated shutter in the partition between the engine and inertial filter compartment. The locomotive control computer (EM 2000) automatically opens the partition shutter at 32°F and closes at 40°F. ARRC generally changes the winterization hatch to winter mode (damper open) as soon as temperatures get below freezing and changes back to summer mode when temperature again rises above freezing. To ensure the cooling fan sequencing would not interfere with the ability to provide a steady supply of warm air to the engine compartment the EM 2000 computer was programmed so that when the shutter assembly in the inertial compartment is open the number one cooling fan is the first to turn on and the last to turn off.

### **Strip heater application**

Additional heat in the form of strip heaters is used throughout the fleet. Two additional 575w strip heaters were mounted on the interior cab sidewalls controlled by manual slide

switches for a heat supplement /option for the crews. Four 575w strip heaters are installed in the sub base to keep the KNORR computer controlled brake (CCB) equipment warm. These heaters are controlled by a relay that gets its signal through the EM 2000 computer fed by an externally mounted ambient temperature probe. The heaters are programmed to energize at -30°F. This along with additional insulation applied to the interior of all cab sub base doors was initially thought to ensure the air brake computer would function as intended (Figure 2). When the temperatures dropped below -10°F road crews started experiencing air brake heater failures that were displayed on the FIRE screens and had brake problems with CCB. A determination was made that -30°F was too cold a temperature to drop to before having the heaters turn on. The relay was eliminated from the circuit and we now run straight off the breaker. This breaker is turned off in the summer to prevent the heat from radiating into the cab.

The SIEMENS inverter cabinets also had to have additional heat applied in the form of 500w strip heaters mounted inside the compartments where the inverter computers are located. This is coupled with a blower contactor-controlled shutter assembly on the air intake side of the phase module to restrict air flow when the main traction control computer (TCC) blower is turned off. This is a critical area of the locomotive to keep maintained. An additional blower motor was installed on

the exterior of the TCC cabinet to provide sufficient cooling for the snubber resistor without having to run the main blower.<sup>1</sup> This is critical in locomotive performance because if the phase module temperature is too low (5°F or colder) the evaporation bath substance gels. Gelling can cause overheating of the semi-conductors in extremely low temperatures.

### **Transformer modification**

A "normal" SD70MAC locomotive has a phase module heating system that applies companion alternator voltage to the TCC's heating circuit when the phase modules get below 32°F. This system consists of an internal 2:1 step-up transformer and individual 240-volt (max) heating elements inside the phase modules of each TCC. However, this basic system can only be used from idle to throttle position 3. For Alaska, the internal transformer was deleted and an externally special-wound boost transformer and contactors were provided. The transformer is wound to provide boosted voltage from idle to throttle position 4 (240-volt max at TH4). At throttle positions 5-8, the transformer is switched out and the companion alternator is connected directly to the phase module heaters, and thus the phase modules can receive heat in any throttle position if necessary.

<sup>1</sup> (The main TCC blower draws air across the phase modules from one side of the locomotive, through the blower, and then blows across the snubber resistor, exhausting out the other side).

### **High idle feature**

Engine high idle feature - this additional feature is controlled by an internal temperature probe that monitors engine coolant temperatures. When the engine is running and coolant temperature drops to 130°F the engine automatically speeds up to throttle 2 R.P.M. This position is held until coolant temperature reaches 140°F when the engine goes back to idle. Engine idle is also controlled by the ambient temperature probe readings. At 13°F regardless of coolant temperature the engine goes to throttle 2 R.P.M. At -20°F the engine goes to throttle 4 R.P.M. to assist the auxiliary generator output with the load demand of the winterization package. The TH4 engine speed up stays in effect until the ambient temperature rises above -15°F. The TH2 speed stays in effect until the ambient rises above +16°F. Both of these engine speed-ups are in place whether the isolation switch is in the run or isolate position.

### **Coolant system design**

An important difference between the first build of 4000 H.P.-series SD70MAC's (built in 1999) and the new 4300 H.P. MAC's (built in 2004) is in the cooling system-specifically, the system by which the turbocharger aftercoolers get cooling water. The 4000-series have a combined water aftercooling system while the 4300s have the Tier-1 split cooling system.

EMD adopted a separate after-cooling system in the mid-1990's in order to improve fuel economy and reduce emissions. The 4000s on the

other hand have a "retro" cooling system more like that of a GP40 of the mid 1970's. Called "jacket water aftercooling" by EMD, the aftercoolers get water from the water inlet manifolds mounted inside the air-box. Thus water reaching the aftercoolers is nearly the same temperature as the water going to the cylinder liners. This was applied by EMD to simplify cold-weather operation in Alaska.

By the time the 4300's were built, new locomotives were required to meet EPA Tier-1 emission standards. Among other things, this required that the aftercoolers be supplied with the coldest water as possible. Figure 3 shows a diagram of the Tier-1 System. It was extracted (with major modifications) from the EMD SD70MAC Service Manual.

Inspection will show two fairly separate cooling circuits - one of the engine (sometimes termed "jacket water") and one of the aftercoolers. The forward half of the radiator hatch and #1 fan is dedicated to the jacket water circuit, the rear half of the hatch and #3 fan is for the aftercooler circuit and #2 fan cools both circuits. The final results of this is a system that keeps the jackets water near 180°F and the aftercooler water near 100°F for best efficiency and best emissions.

Because of the separate aftercooling, EMD was very concerned about cold weather operation in Alaska. With -40°F to -60°F air entering the turbo, and very little heat applied in the compression process, aftercooler freezing seemed like a real possibility. The units were shipped from

Canada with 100% water and water treatment, but EMD recommended that 50/50 glycol/water mix be applied before winter in Alaska arrived. We also started the preliminary plans to stock and mix ethyl glycol and to be able to capture drained coolant on units being worked.

Having to utilize glycol instead of conditioned water for cooling became a challenge in itself. Recovery tanks and a pumping/filtering process to return good used coolant back into the locomotive would have to be drawn up and installed under the ramp area of the locomotive shop, occupying much needed space. However, a new employee with the railroad who was a former design engineer with EMD felt that maybe EMD was just being overly cautious. After all, the Tier-1 cooling system incorporates a linking valve to automatically couple together the two cooling circuits in very high or very low ambient conditions. Thus, it was thought that the EM2000 control system would cycle the linking valve to keep the aftercooler water from getting too cold.

Testing in September & December 2004 confirmed that the cooling system had plenty of margin, especially with the Th4/600rpm cold weather speed up. The September testing showed that with the linking valve under manual control & open, the aftercooler water circuit temperature would be 15°F cooler than the jacket water temperature and the jacket water would be at least 166°F over ambient at the TH4 cold weather speed up. December testing showed that the EM2000 control

system would cycle the linking valve so that the aftercooler temperature would be maintained between 105°F and 85°F.

Based on these results, we chose to stick with the standard water and treatment we use all year long. Although we haven't run a test in the coldest temperatures Alaska can throw at us, neither did we end up with any frozen aftercoolers in our fleet!

### **Auto-start system (AESS)**

The first 16 locomotives received were not equipped with AESS. This was remedied during the winter of 2002 when EMD was contracted to install its Auto-start package. This package was welcomed as we saw reduced fuel costs and reduced engine idle time. However, it was not long before some major concerns had arose. Locomotives were dumping their water out of the Guru automatic drain valve and into the engine sump area. The coolant then filled up the retention tank and overflowed onto the ground. This presented two problems. First, we had a mess to clean up as any fuel and lubricant that was present in the retention tank at the time was now in the ground. Secondly, we had a locomotive that had to be brought back into the shop for unplanned maintenance. The problem was linked to the Guru automatic drain valve prematurely opening. This valve was properly applied in the lowest possible position of the coolant system to ensure complete evacuation of all coolant when activated. The oversight was that with

the AESS enabled and when the diesel engine was in automatic shut down mode, hot water stopped circulating through the piping where the Guru was applied. AESS still monitored coolant temperature as one of its parameters for start-up or shut-down, but it was monitoring engine block coolant temperature, not the coolant temperature next to the Guru valve. After finding out what the root cause was we quickly disabled all the newly installed auto-starts.

It was not long until we had a new modification from EMD consisting of a drain pan that diverted the coolant through the main frame and onto the ground in case of unintended discharge by the Guru valve. EMD also issued a new temperature probe modification that installed another sensor in the coolant piping next to the Guru valve. This will enable EM2000 to monitor both engine block coolant and sump coolant temperatures at the same time, and initiate the auto-start sequence if the coolant temperatures fall below acceptable parameters. We finished this modification this spring and are in the process of re-activating all of our AESS systems on the MAC fleet.

As a final note, on our 4300 series locomotives the Guru automatic drain valve was not applied by EMD, as they expected us to use 50/50 glycol and thus they saw no reason to automatically drain glycol into the retention tank. We will be installing Gurus this fall so that we can enable our EMD Auto-start system in the winter.

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### **Radar function**

Having a properly functioning radar ensures that power and dynamic braking operate as intended. Radars that are covered with snow and ice accumulations can cause false readings resulting in interruption of these functions. SD70MAC locomotives come standard equipped with a radar blow down controlled by a magnet valve in the short hood. This blow down is on a 30 second timer that in most cases is sufficient enough to keep the radar face clear of debris. In deep snow operation this can present a problem because there is insufficient air to keep the radar face clear. Snow build up behind the plow and underframe can completely seal off the radar to the extent that it can no longer function. A simple modification can be applied to the end of the air supply line to assist in keeping this equipment functioning properly. As a rule when deep snow conditions are encountered we bring the locomotive consist into the shop for snow and ice removal. Special attention is paid to the radar assembly. When boarding trains at outlying line points road crews have learned to broom away excess snow to help ensure successful train movement.

### **Dryer air**

Clean air is always a concern in cold weather. All SD70MAC locomotives are equipped with Graham-White model 994 air driers with electrical heaters. These driers have proven to be exceptional in their performance. We are almost done with

our five year COT&S air dates on the original order of SD70MAC's and have noticed that the valve portions are dry and clean internally without evidence of corrosion. Main reservoir drain valves are pneumatically operated with thermostatic control heaters applied. Air compressor lube oil heating is provided by using an engine water heat exchanger in the compressor sump.

### **Fuel system**

The fuel system is standard set up incorporating 60,000 BTU Young heat exchanger with automatic AMOT thermostat control. We also use a blend of #1 & #2 diesel fuel during winter operation. While this does reduce horse power, a blended fuel coupled with the heat exchanger prevents fuel from gelling.

### **Walkway design**

Walkways along both sides of the long hood were constructed out of open grating. This was designed to let snow migrate through with out buildup on the tread surface (Figure 4) to eliminate trip, slip and fall hazards for train crews and mechanical forces.

### **Bell operation**

All the MAC locomotives came with air operated bells when first delivered. During the first winter we had numerous freeze-up problems with the actuator assembly. This was rectified by retrofitting the fleet with the Graham-White E-bell. This modification has completely eliminated our bell problems and eliminated terminal delays due to malfunctioning

safety equipment. While reviewing our specification for the manufacture and purchase of the new 4300 series locomotives were incorporated the installation of the E-bell at the EMD London, Ontario plant.

### **Electric cabinet blower**

Typically, EMD electrical cabinets are pressurized with filtered air drawn from the traction motor air duct. This can pose a problem because while operating in winter mode, and drawing air down across the engine, the air is drawn into the traction motor blower and tends to be sooty and smoky. Hence, if the door seals on the high voltage cabinets are leaky the locomotive cab can become a danger to crew members. Both SD70MAC orders addressed this problem by incorporating a separate Electrical Cabinet Blower (ECB). Located on the conductor's side walkway just left of the cab, it is always on and powered by the companion alternator. This blower draws air from the room underneath the dynamic brake hatch, which circuitously gets air from the dynamic brake air inlets and across the blower motor thus minimizing snow ingestion.

The downside of the ECB system is that the cooling air to the EMD main electrical cabinet is not warmed at all. In the depth of winter, this constant saturation of sub zero air has adverse effects on the power chassis causing various cold ambient shut-downs of the computer controlled systems. We have also found that when the ambient air temperature drops below -35°F it is necessary to

have mechanical forces as well as road crews turn off the ECB circuit breaker. This oversight has yet to be addressed. We are in the process of engineering a solution to eliminate this particular failure mode so that the switch-off will be automatic.

### **Conclusion**

Having up front engineering done on a new or rebuilt locomotive fleet is beneficial to both the manufacturer and the customer. With careful planning and testing most questions and concerns can be answered. However, there will almost always be issues that arise related to oversights not included in the specification. We hope this paper which has covered some of the problems that have been successfully met on the Alaska Railroad Corporation will benefit other carriers operating in inclement weather locations.

### **References**

Electro-Motive Division  
MI 1805

Electro-Motive Division  
EMD SD70MAC-T1 Service Manual

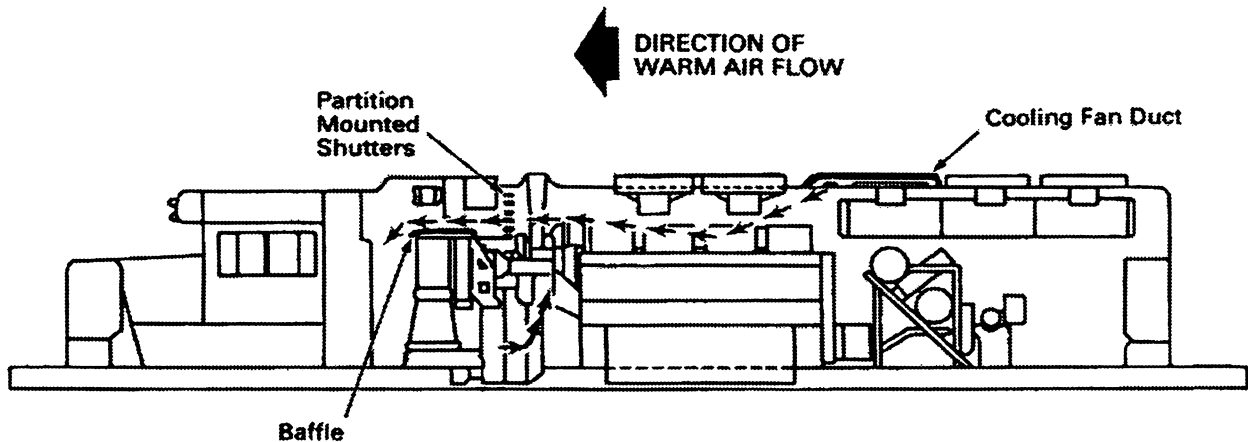


Figure 1 - Typical Winterization Systems

(From EMD MI 1805)

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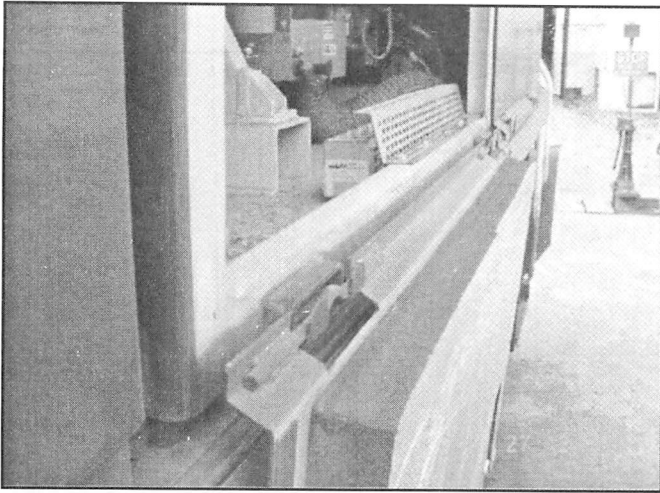


Figure 2 -

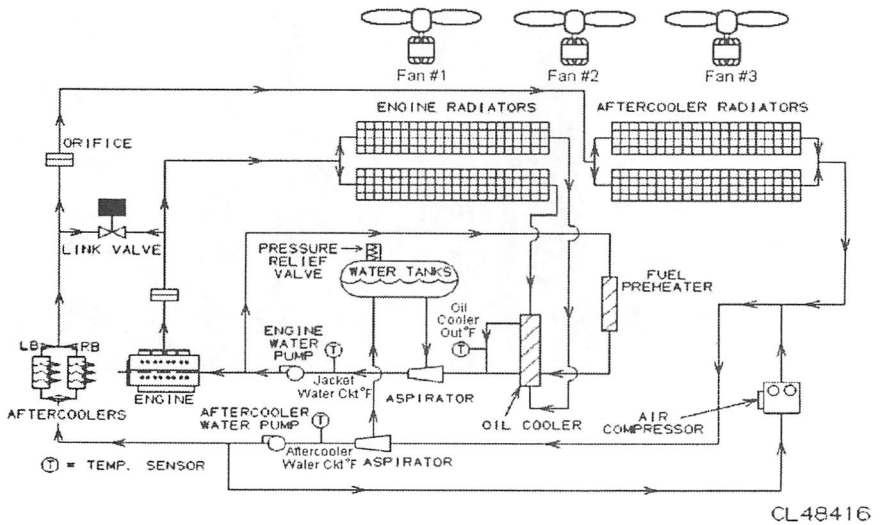


Figure 3 - Cooling System Diagram (SD70MAC-T1)  
 (Adapted from EMD SD70MAC-T1 Service Manual)

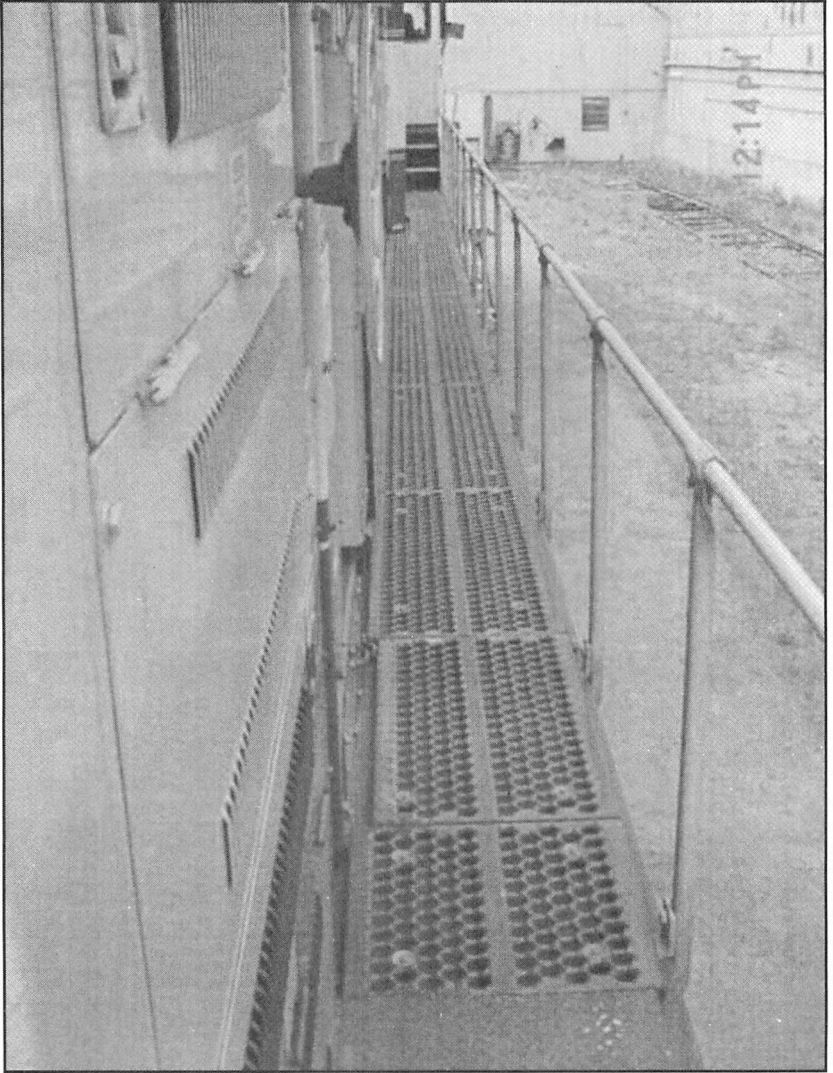
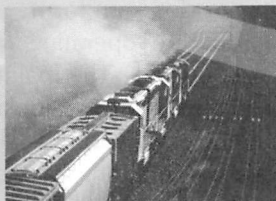


Figure 4 - Walkway design

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### III. IMPORTANCE OF COOLING SYSTEM HEALTH, EPA COMPLIANCE IMPACT

*Presented by:*

*Dan Agler,*

*Kansas City Southern Rwy*

The often-neglected cooling system on our locomotives takes on a new and critical role when it comes to EPA compliance. The cooling system provides uniform cooling throughout the operating range of the diesel engine. The maintenance and selection of proper coolant solutions are necessary for efficient cooling system operation. Failure to recognize the importance of these factors can result in increased maintenance cost, unnecessary down time, increased fuel consumption, increased emissions, and EPA penalties.

In the good old days we would often be able to add raw water to the cooling system to get by. We would be able to run locomotives with fan temps not set at factory settings just so they worked. Attention to aftercoolers consisted of did they leak and if not they were OK.

Well the good old days are gone!

Effective January 1, 2000, under the Clean Air Act as Amended 1990 (40 CFR Parts 85, 89, and 92), the United States Environmental Protection Agency (USEPA) promulgated locomotive exhaust stack emission regulations. Locomotive exhaust stack emissions must now be measured and regulated for Oxides of Nitrogen (NO<sub>x</sub>), Hydrocarbons (HC), Carbon Monoxide (CO), Particulate Matter

(PM), and Smoke emissions.

#### **EPA three tier compliance program**

- Tier 0 (lowest emission standard): locomotives with manufacture dates 1973 through 2001, or which had their diesel engine re-manufactured after January 1, 2002. All locomotives built prior to 1973 are not covered by USEPA regulations. Applicability is based on locomotive manufacture date, rather than the diesel engine manufacture and/or re-manufacture date. Engines, to be used in the aforementioned regulated locomotive model years, must carry a certification label, which indicates compliance with emission standards and identifies the engine model/family.
- Tier 1 (medium emission standard): Applies to newly manufactured locomotives, during 2002 through 2004, and any subsequent re-manufactured diesel engines for these locomotives thereafter.
- Tier 2 (highest emission standard): Applies to newly manufactured locomotives, manufactured during 2005 and later and any subsequent re-manufactured diesel engines for these locomotives thereafter.

*To comply with these regulations both manufacturers have improved their cooling systems. They now operate the diesel in a much tighter range of operating temperatures, and have increased the amount and quality of aftercooling. The chart in Table*

1 depicts the effect this and other items have on emissions.

### Strategies utilized to reduce emission

One of the most effective means of controlling NO<sub>x</sub> emission is by reducing the air box temperatures. For example, reducing air box temperature by 10 degrees F results in 2% reduction in NO<sub>x</sub> without incurring any fuel consumption penalty. Given the need to comply with the regulations and the desire to not have a fuel penalty or even be able to reduce fuel consumption, it becomes critical that the cooling system work properly, and to do so it must be maintained. To start with, the proper engine coolant must be used.

### Engine coolant

#### Description

- Coolant is circulated throughout the engine to provide the means for heat transfer from the engine components. Water, corrosion inhibitor and, in some applications, antifreeze are used in coolant solutions.
- Because the function of the coolant is so necessary to the operating efficiency of the engine, it is important that the selection of a coolant solution be carefully considered. Failure to meet any one of the following requirements will inevitably result in costly system damage.

**A coolant suitable for use in engine cooling systems must meet four basic requirements:**

- It must adequately transfer heat

energy through the cooling system.

- It must not form scale or sludge deposits in the cooling system.
- It must not cause corrosion within the cooling system.
- It must not deteriorate any of the cooling system seal materials.

These requirements are normally satisfied by combining suitable water with a reliable corrosion inhibitor. Certain operating conditions may dictate the use of antifreeze-coolant. In this case the basic requirements can be satisfied with a combination of suitable water and an ethylene-glycol type antifreeze which contains an adequate corrosion inhibitor.

Failure to meet these requirements will result in poor fuel consumption, failure of EPA compliance and premature component failure.

Next we need to use the proper Inhibitor.

#### Types include:

- Chromate
- Borate-Nitrite
- Silicate-Nitrite

#### Types of antifreeze include:

- Ethylene-Glycol with De-ionized water
- Methoxy Propanol.

Then the components of the system require maintenance at prescribed intervals. As examples, I've highlighted the cooling system maintenance items for the following engines required for compliance.

**Emissions-related maintenance****645E****Six-month intervals**

- Visually inspect crankcase, blower duct mounting flanges, and air box for air leaks; repair as necessary. (EMM)

**One year intervals**

- Inspect radiator air passages; clean if necessary. (LSM) and (M 1549)
- Check proper operation of radiator shutter system. (LSM) and (MI1756)
- Check engine and cooling fan temperature switches for proper operation and settings. (LSM)
- Perform self-load test after engine work, and before releasing unit, confirm the following:
  - Proper loading at each throttle notch
  - Jacket cooling water temperature is within specified range
  - Check engine speeds and governor balance point. *Tests must indicate that the horsepower is within specifications. (LSM and EMM)*

**645 Turbo****90 day interval**

- Check air box drains for flow; clean if necessary.

**Six-month intervals**

- Visually inspect crankcase, aftercooler duct mounting flanges, and air box for air leaks; repair as necessary. (EMM)

**One year intervals**

- Inspect radiator air passages; clean if necessary. (LSM) and (MI 549)

- Check air pressure drop across aftercoolers; clean aftercooler cores if necessary. (EMM)
- Check proper operation of radiator shutter system. (LSM) and (MI 1756)

On locomotives equipped with mechanical temperature switches, check temperature switch function and settings. (LSM)

- Perform self-load test after engine work, and before releasing unit, confirm the following:
  - Proper loading at each throttle notch.
  - Jacket cooling water temperature is within specified range.
  - Check engine speeds and governor balance point. Tests indicate that the horsepower is within specification. (LSM and EMM)

**Two year intervals**

Depending on manufacturer maintenance requirements, following applies:

- Aftercoolers require replacement or:
- Check air pressure drop across aftercoolers, clean aftercooler if necessary. (EMM)

**710****90 day interval**

- Check air box drains for flow; clean if necessary.

**Six-month intervals**

- Visually inspect crankcase, aftercooler duct mounting flanges, and air box for air leaks; repair as necessary.
- Check EMDEC active and inactive fault codes (if equipped). Correct any system failures. Clear fault codes. (EMM LSM).

EMDEC Troubleshooting Guide.

### One year intervals

- Inspect radiator air passages; clean if necessary. (LSM and MI 549)
- Note: Operation in areas and in periods of airborne seeds and leaves can require more frequent cleaning.
- Check air pressure drop across aftercoolers; clean aftercooler cores if necessary. (EMM) Check proper operation of radiator shutter system. LSM and MI 1756 for lubricant specifications.
- On locomotives equipped with separate circuit aftercooling, check linking valve function. Repair as necessary. (LSM)
- Perform self-load test after engine work, and before releasing unit, confirm the following: Proper loading at each throttle notch. Jacket cooling water and (if equipped with separate loop aftercooling) aftercooler water inlet temperatures are within specified ranges. For MUI applications, check engine speeds and governor balance point. For EUI applications, use hand-held diagnostic reader or PC to confirm injector response times.
- Tests indicate that the horse power is within specification, LSM, EMM, and EMDEC Troubleshooting Guide.

## 710 Tier II

### Daily

#### Cab and control systems

- Check operation of Functionally Integrated Railway Electronics

(FIRE)

- Check locomotive computer display panel for messages, and check archived messages.

#### Engine (running)

With engine idling and at operating temperature:

- Inspect engine room for fuel, oil, air box, or water leaks. Also check for unusual noises or smoke.
- Check cooling system water level.

### Electrical equipment and systems

- Check locomotive support systems and cooling fans for unusual noises.

#### Every 184 days

#### Cab and control systems

- Check EMDEC for active and inactive fault codes: Correct any system faults.
- Check fault codes.
- Test functional operation of locomotive computer and display.
- Verify screen display of all menu driven features. Correct any system failures.
- Perform/review system diagnostics on display screen. Correct any system defects.
- Perform all locomotive self-test functions.
- Download and review archive and running totals as required.
- Inspect, check, and test all alarms, automatic controls, and protective devices.

#### Engine (running)

- With engine idling and at operating temperature:
- Inspect crankcase, aftercooler

duct mounting flanges, and air box for air leaks. Repair if necessary.

- Inspect lines, connections, and equipment for fuel, oil, water, air, or exhaust gas leaks.
- Load test engine in each throttle position and verify the following:
  - EMDEC signals via FIRE screen.
  - Engine parameters are within specified ranges.
  - Injector response times are in specified range.
  - Crankcase pressure is tracking properly with engine rpm.

#### **Engine (stopped)**

- Inspect air box drains for proper drainage. Clean drains if necessary.
- Inspect air box for oil or water leaks.
- Check cooling system inhibitor concentration. (MI 1748)

#### **Electrical equipment and systems**

- Check tightness of all mechanical and electrical connections.
- Check AC system for grounds.
- Check low voltage DC system for grounds.
- Check electrical locker ventilation. Take manometer readings at electrical locker.

#### **Mechanical equipment and systems**

##### **Every year**

##### **Cab and control systems**

##### **Engine (running)**

- Perform load test after engine

work and confirm the following:

- Proper loading at each throttle position.
- Jacket and aftercooling water inlet temperatures are within specified ranges.
- Check air pressure drop across aftercoolers. Clean aftercooler cores if necessary.

#### **Engine (stopped)**

#### **Electrical equipment and systems**

- Inspect electrical locker, check for loose plugs and connections. Check also for signs of overheating.
- Inspect all fan and blower motor fuses.
- Check operation of cooling fans and blowers.

#### **Mechanical equipment and systems**

- Inspect radiator air passages. Clean if necessary. Operation in areas and in periods of airborne seed and leaves can require more frequent cleaning. (MI 549)
- Check for proper operation of radiator shutter system.
- Lubricate radiator shutter linkages and cylinders.
- Clean radiator inlet header tank screens. The presence of metal chips at first cleaning or after engine parts have been replaced is normal. (MI 549, MI 550).
- Service engine coolant. (MI 1748)
- Inspect and test cooling system pressure cap and filler neck. Replace cap/neck if necessary.

- Replace guru automatic water drain valve cartridge (if applicable). (MI 20001)

#### **Every two years**

- Engine (stopped)
- Replace coolant pressure sensors.
- Replace cooling system pressure cap.

#### **Every 3 years or**

#### **10,000 megawatt hours**

(whichever event occurs first)

#### **Every three years**

#### **Engine (stopped)**

- Replace water pumps.
- Replace crankcase pressure sensor.

#### **Mechanical equipment and systems**

• Check temperature differential between lube oil and cooling water into engine during scheduled load test.

- Clean oil cooler if necessary. (MI 927, MI 928)
- Replace flexible coupling seals in cooling and lube oil piping.
- Replace and recondition cooling system automatic drain valve (if applicable). (MI 582)
- Replace shutter magnet valves. (MI 4707)
- Replace or recondition shutter air cylinders.

#### **Every six years or**

#### **28,000 megawatt hours**

(whichever event occurs first)

#### **Engine**

- Clean or replace aftercooler cores.

- Replace all EMDEC temperature sensors.
- Replace manifold air pressure (MAP) sensor.

#### **Electrical equipment and systems**

- Replace radiator cooling fan assemblies. (MI 4104)
- Replace dust bin/electrical locker filter blower motor.

#### **Mechanical equipment and systems**

- Replace fuel preheater.
- Replace fuel check valves.
- Replace turbocharger-to-filter air duct.
- Replace or recondition all magnet valves.

#### **Emission Critical Components on 7FDL diesel engines**

##### **Engine Cooling System**

The radiator heat exchangers (core) are emission critical components.

The cooling water system is designed to maintain a nearly constant engine operating temperature throughout the load range of the engine, even with wide variations in outside temperature. The split cooling system provides additional cooling for the turbocharger/air intercoolers at higher load conditions: a lower turbocharger temperatures decreases the amount of harmful emissions out of the exhaust stack and decreases fuel consumption.

- A pressurized, split-cooling, dry-radiator system is used. The amount of heat rejected from the engine and other components to the cooling

water is controlled by the radiator fan speed and the routing of the cooling water through the cooling system. The rate of heat transfer from the water to atmosphere is dependent on atmospheric temperature and pressure.

- For the cooling water system to operate properly, the “mechanically bonded” radiators need to be clean and in good operating condition. To determine if the radiators are in good working condition or if they need to be cleaned, perform a Mechanical Heat Run to measure the water temperature leaving the subcooler. If the heat run results indicate radiator cleaning, proceed to appropriate section of GE publication Section 3.2 for details.

Note: GE recommends performing a mechanical heat run annually to ensure proper engine cooling system operation.

Note: Mechanical Heat Run can only be performed on locomotives with split cooling.

The radiators are used to transfer heat from various cooling loops in the engine, turbocharger intercoolers, and oil cooler to the ambient air heat sink.

### **Intercooler**

The left and right intercooler assemblies are emission critical components.

Refer to publication MI-95100 (GEK-76434), Engine Air Inlet System, for maintenance information on the intercooler.

### **GE Tier “0” 7FDL EFI Engine Annual Maintenance**

Engine cooling system (determine if engine cooling system is performing as expected).

#### **Intercooler**

Replace at 26,000 motoring MWHRS.

#### **Turbo**

Replace at 26,000 motoring MWHRS.

### **GE Tier “0” 7FDLMFI Engine Annual Maintenance**

Radiator (determine if radiator cleaning procedure is necessary).

#### **Intercooler**

Replace at 26,000 motoring MWHRS.

#### **Turbo**

Replace at 26,000 motoring MWHRS.

### **GE Tier “1” 7FDL EFI Engine Annual Maintenance**

Engine cooling system (determine if engine cooling system is performing as expected).

#### **Intercooler**

Replace at 26,000 motoring MWHRS.

#### **Turbo**

Replace at 26,000 motoring MWHRS.

### **GE Tier “2” 7HHDL Engine Intercooler**

Qualify or Replace at 33,750 motoring MWHRS.

#### **Turbo**

Qualify or Replace at 33,750 motoring MWHRS.

*Failure to do this maintenance in a proper manner will increase the*

*chances of the unit not passing during the EPA testing required, as outlined below.*

### **Testing Requirements**

- USEPA levied two different types of locomotive in-use testing programs.
- The first applies to locomotive manufacturers and locomotive diesel engine re-manufacturers (including engine component re-manufacturers)
- Supplier/vendor to provide the required USEPA Tier 0-emission certification as applicable.
- The second applies to Railroads. "Railroad Annual In-use testing program." Railroads are required to track power assembly change-outs and monitor for triggering an EPA rebuilt locomotive engine.

### **Exemption**

- Locomotives owned by small railroads that have never been certified.

### **Definition Small Railroad**

- Small "line haul" railroad is 1500 employees.
- "Short line" railroad is 500 employees.

### **Class I railroad annual in-use testing program**

- Beginning January 1, 2005, all Class I Railroads are required to randomly test 0.15% (0.0015) of the locomotive fleet, or 1 locomotive engine per every 650 locomotives. This number will be generated from using the previous year fleet count, including all leased locomotives.
- Testing will be spread evenly over all engine families and locomotive

models. All tests will be focused on units within 50% to 75% of their useful life.

- Beginning December 31, 2015, for Class I railroads with more than 500 locomotives in their fleet, testing frequency will be reduced to 0.10 percent (0.0010).
- Locomotives tested during the previous year shall be excluded from subsequent testing years. Locomotives shall be randomly selected for testing, and never excluded because of visible smoke, a history of durability problems, or other evidence of mal-maintenance.

### **Testing and reporting requirements**

- Sampling and analysis will be conducted according to the Federal Test Procedure as outlined under 40 CFR, Part 86, Subpart "D" & "N".
- Testing will include on-site sampling and analysis by a qualified contracted service provider.
- Engines must be tested in the locomotive chassis, with the engine warmed to operating temperature.
- Locomotive smoke emissions will be tested in idle through each throttle notch, including analysis of emissions during acceleration between throttle notches.
- Locomotive NO<sub>x</sub>, HC, CO, and PM will be tested with the engine at idle and operating under steady load conditions (load box or self-load) for throttle notch #1 through throttle notch #7. The engine will be operated at steady state for a minimum duration of six (6) minutes before sample/analysis is conducted. For throttle notch #8, the engine will

operated at steady state for a minimum duration of fifteen (15) minutes.

### Compliance actions required

- Closely track and document the following:

- Track and database all locomotives by unit number model year, horsepower, and engine serial number (including historical engine serial numbers). For these locomotives, further track and database accumulated: road mileage, MW hours, and power assembly change-out, and engine replacements. Power assembly documentation must track: change-out dates, assembly locations, serial numbers, location of service, and USEPA certifications of replacement parts.

- All re-manufactured diesel engines, which fall within the applicable dates, must be retrofitted with appropriate emission control equipment purchased from a certified vendor, and carry that vendor's certified compliance label.

\*Note: Minimum useful life defined as 750,000 miles or 10 years; therefore, 50% equates to 375,000 miles or 5.0 years.

Re-manufactured diesel engines are defined as "having all power assemblies replaced within a 5-year period."

**The most difficult part about this is going to be education of our maintenance personnel and ourselves. For years when the cooling system was performing below specification it would still be good "enough to make it." And even today it will run, but it will not comply with the EPA regulations!**

**Should a unit fail in its testing the price is severe and can be personal. Below is a copy of the penalty schedule.**

### EPA Penalty

40 CFR 92.1106 (a)(1) says that violations of 92.1103 (a)(1), (a)(4), or (a)(5) (Manufacturer or remanufacturer of new locomotives or new locomotive engines into service without a certificate of conformity), are subject to a civil penalty of no more than \$25,000 per violation.

92.1106 (a)(3) states that a separate violation is counted as each locomotive with respect to introducing a new or remanufactured locomotive into service without a certificate of conformity.

92.211 (b)(1) states that the manufacturer or remanufacturer must provide in boldface type on the first page of the written maintenance instructions notice that maintenance, replacement, or repair of the emissions control devices and systems may be performed by any locomotive or locomotive engine repair establishment or individual.

92.21 (b)(2) prohibits manufacturers and remanufacturers from providing maintenance instructions that place conditions on the locomotive owner to use only brand name parts or specify only certain service providers unless, as specified 91,211 (b)(3), the manufacturer and remanufacturer demonstrates to EPA that the parts or service provider are the only way the engine will function

properly and meet the emission requirements. 92.1106 (a)(1) would cover penalties for violations of this section, which would be no more than \$25,000 for each violation.

92.1103 (a)(2)(iv) states that failure to establish or maintain records is prohibited, in which case the civil penalty is no more than \$25,000 per day of violation.

92.1103 (a)(3)(i) For a person to remove or render inoperative a device or element of design installed on or in a locomotive or locomotive engine in compliance with regulations under this part, or to set any adjustable parameters to a setting outside of the range specified by the manufacturer or remanufacturer, as approved in the application for certification by the Administrator is subject to a civil penalty of not more than \$2,500 for each violation.

92.1103 (a)(3)(ii) For a person to manufacture, remanufacture, sell or offer to sell, or install, a part or component intended for use with, or as part of, a locomotive or locomotive engine, where a principal effect of the part or component is to bypass, defeat, or tender inoperative a device or element of design installed on or in a locomotive or locomotive engine in compliance with regulations based under this part, and where the person knows or should know that the part or component is being offered for sale or installed for this use or put to such use, is subject to a civil penalty of not more than \$2,500 for each violation.

92.1104 General enforcement provisions. (1)(i) Every manufacturer or remanufacturer of new locomotives and/or new locomotive engines and other persons subject to the requirements of this part must establish and maintain records, perform tests, make reports and provide information the Administrator may reasonably require to determine whether the manufacturer or remanufacturer or other person has acted or is acting in compliance with this part or to otherwise carry out the provisions of this part, and must, upon request of an office or employee duly designated by the administrator, permit the officer or employee at reasonable times to have access to and copy such records.

### Conclusion

*In conclusion, we as an industry will have to be more vigilant on how we maintain our locomotive cooling systems, and what we use for coolant. The reward for doing this is a locomotive that is*

- Better running
- More fuel efficient
- Lower exhaust emissions
- Longer component life and
- Helps with a cleaner environment and thus helps to improve our image to the public as well as the regulators!

### References

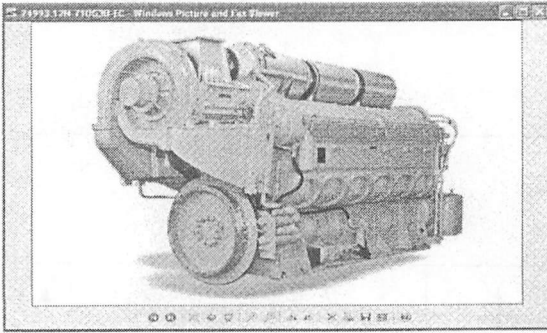
(40 CFR Parts 85, 89, and 92  
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#125E585 Section 10-2 Cooling  
System  
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GE GEK 76637  
GE GEK 7637a  
GE GEK 76636  
GE GEK 76677  
GE GEK 76731  
GE SMI 08000C  
GE SMI 90010G  
SMI 08000D  
KCS Locomotive Emissions rev 5-16-  
2003

Emission parameter	Key driver	Control method	Impact
NOx ↓	Combustion ↓ temperature	Timing retard ↓ Lower Airbox temperature Air fuel ratio Injection rate	BSFC ↑ Heat Rejection Particulate/Smoke Higher Exhaust temp
Particulate ↓ CO Smoke	Combustion ↑ temperature Injection timing(BOI) Combustion chamber Geometry	Injection pressure ↑ Air fuel ratio Optimized combustion chamber	NOx ↑ Parasitic Load
Hydrocarbon (HC) ↓	End of Injection quality Sac Volume	Rapid end of Injection Reduced sac volume	

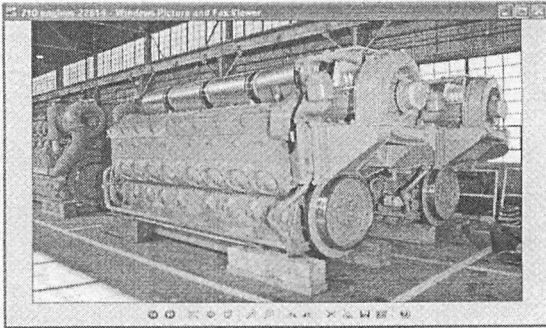
Table 1

# EMD



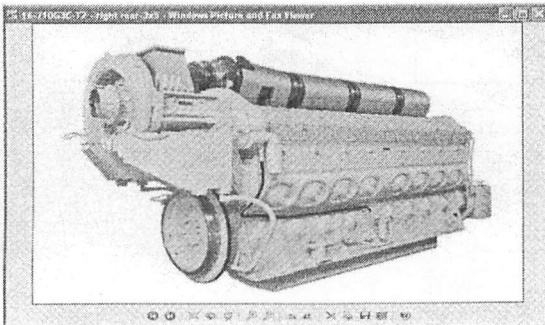
Tier 0

Four Pass  
Aftercooler



Tier 1

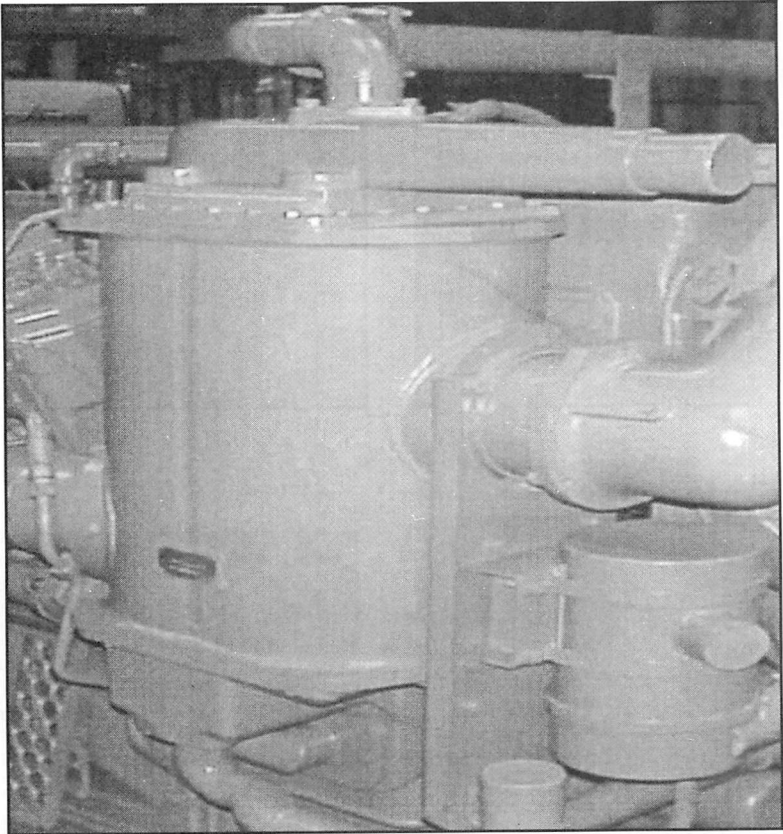
Four Pass  
Aftercooler  
Separately  
Cooled



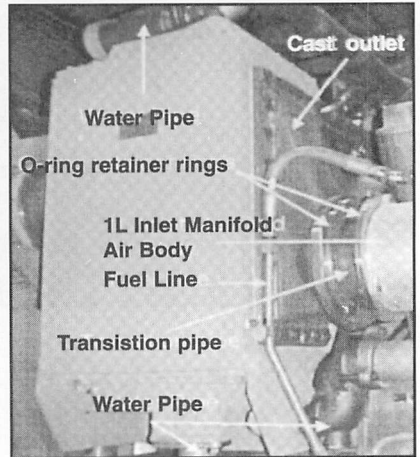
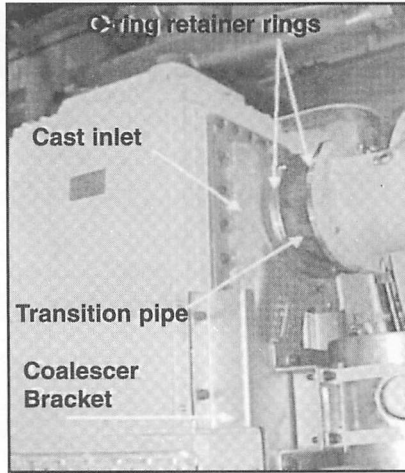
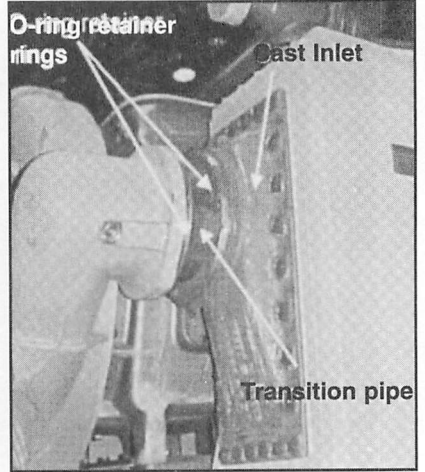
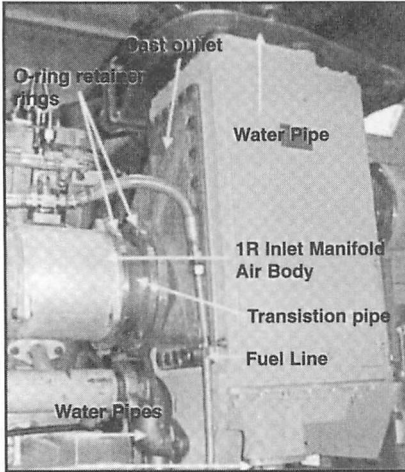
Tier 2

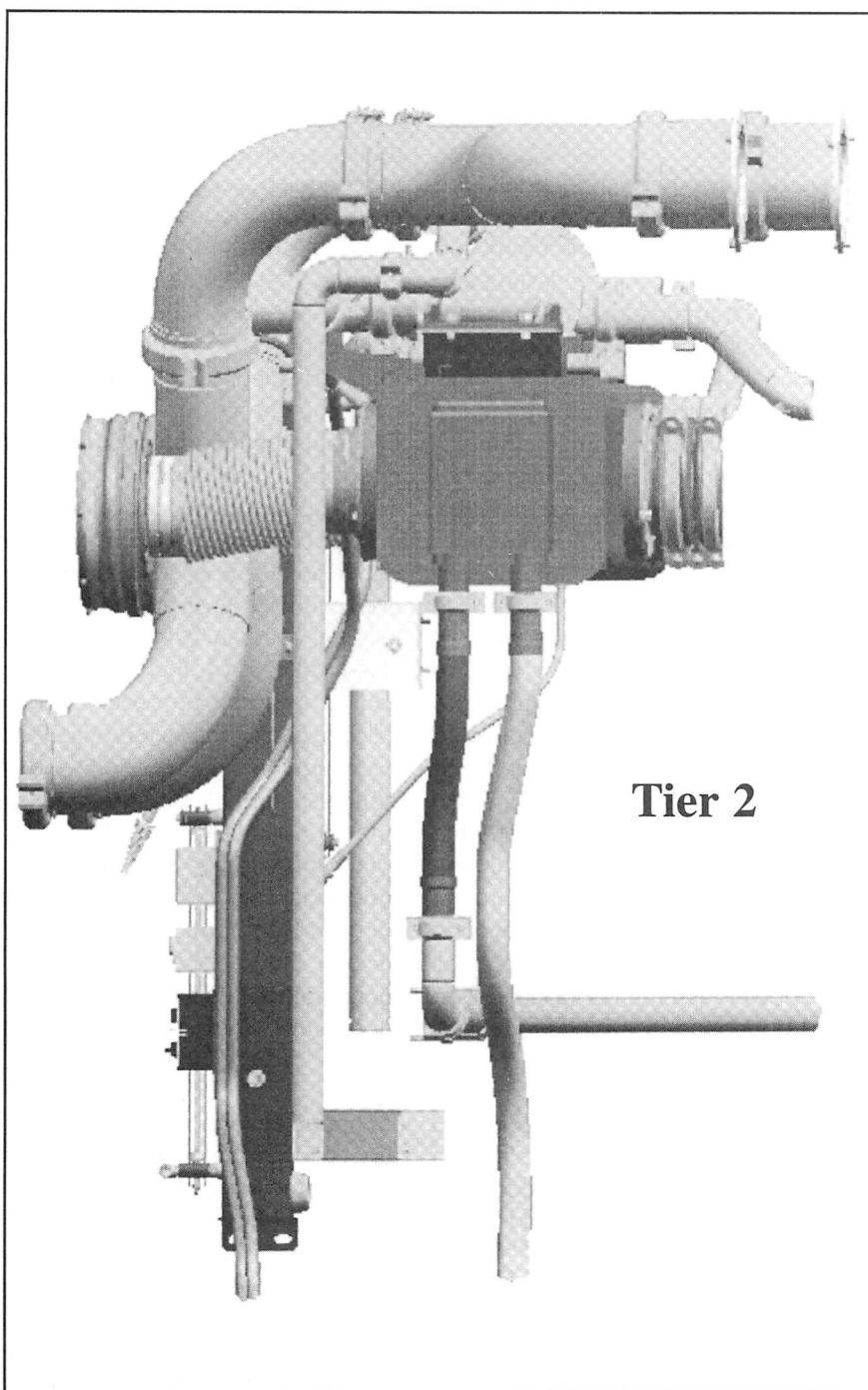
Four Pass  
Separate Loop  
Aftercooling

## Tier 0



# Tier 1





**Tier 2**

#### IV. OVERHAUL EXTENSION

*Presented by:  
David K. Miller,  
Sr. Mgr. Loco. Engrg.,  
Union Pacific Railroad*

Locomotive overhauls should be the cornerstone of a railroad's maintenance strategy. Actions taken during an overhaul can have lasting and profound ramifications on locomotive reliability as well as financial performance. Fundamentally, decisions regarding overhauls should be made using real world performance measures and good engineering judgement to result in the optimal economic performance.

In the most basic sense, an overhaul is the renewal of the locomotive or the power plant. The scope, or systems and equipment that are addressed during an overhaul, varies significantly from railroad to railroad. Most railroads also have varied levels of overhaul as within their own organizations the definition of what an overhaul is even varies within the industry. The Environmental Protection Agency (EPA) defines an overhaul as the replacement of all the power assemblies (a.k.a power packs) within a 5-year window. They use this event to drive emissions upgrade requirement. The overhaul event is usually an expensive and time-consuming event in the life of a locomotive where key components are replaced and/or reconditioned to avoid failure.

Locomotive overhauls tend to be driven by engine overhauls. The wear rates and performance of the locomotive engine is commonly the

system that drives a need for an overhaul. This degradation of the engine can manifest itself in two common forms. One mode is the elevated failure rate of internal engine components. This causes numerous unscheduled repair events, driving up the cost of ownership. The other mode is a catastrophic failure of the engine that requires extensive repair, i.e. crankshaft or block failures that result in the need of a repair so extensive it is essentially an overhaul. The goal of performing an overhaul on locomotives is to circumvent these failure modes by avoiding the failures altogether.

The scope of the overhaul varies significantly amongst railroads; and even within a given railroad several levels of overhaul exist. Some typical classifications of locomotive overhaul scopes can be summarized as follows: full locomotive rebuilds, unit exchange programs, full engine rebuilds, partial engine rebuilds, opportunistic replacements.

Full locomotive rebuilds are the most extensive and expensive forms of refurbishment. They typically include the replacement of all the major components and systems on a locomotive. They are time consuming and require large, flexible budgets.

Unit exchange engine programs are typically described as replacement of the engine with another that was refurbished and qualified offsite. The engine rebuild is done off site, usually by a vendor or contractor and is shipped to the locomotive. These programs tend to have faster cycle times and high levels of relia-

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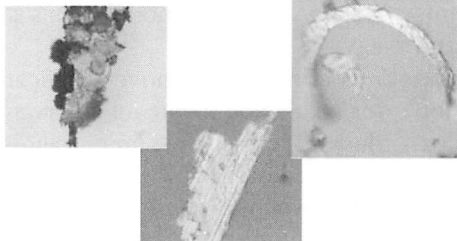
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bility. Many of the enhancements that are incorporated into new engine production are also fitted into unit exchange engines. These programs also require functional core material and can have logistical issues due to transportation and production problems.

Full engine rebuild programs refer to engine overhauls that are done on site and can be characterized as a replacement and/or qualification of all the major engine components. Typically all the power assemblies, pumps, bearings are replaced and the camshafts, gearing, engine block and crankshaft are qualified. This type of program tends to be similar to the unit exchange engine replacements, without the involvement of a vendor for the engine rebuild. This eliminates the problems that could be incurred with supplier logistics, but this type of program requires significant investment in manpower and facilities.

Partial rebuild programs are essentially power assembly and other engine component replacements with the exception of block and crankshaft work. The crankshaft and block are given a visual inspection but are not removed for qualification. Other engine component changes can take place with the engine still in place on the locomotive.

Overhaul planning should take place at least one year in advance of the event. The major considerations that need to be taken into account are funding needs, capacity constraints, supplier constraints, OEM recommendations, EPA require-

ments, contractual obligations and individual railroad needs and experiences.

Overhaul strategy dictates maintenance strategy and vice versa. The traditional "planned overhaul and maintenance strategy" typically consists of performing an overhaul event at a periodic interval. This approach provides fixed predictable costs and tries to offset failure risk with fixed schedules for component replacement. A typical locomotive may experience three overhaul events in its lifecycle and maintain a relatively low level of risk between overhaul events. Figure 1 shows a typical model of this strategy.

Another traditional approach can be characterized as 'run-to-failure' strategy. This approach has longer unpredictable intervals between overhaul events and periods of higher failure risk between these events. Locomotives that have a strategy similar to this have fewer overhaul events but suffer lower reliability levels throughout their useful life. Figure 2 shows a typical model of this strategy.

The basic economic justification for extending overhaul intervals is derived from the time value of money. Essentially what is being saved when an overhaul is extended is the interest that would have been paid on the funds to perform the overhaul. For example, if an overhaul has an expected expenditure of \$150,000, for every year the overhaul is extended would save \$9,000 to \$12,00 by deferring the expense. If the increased risk causes more failures that result in a cost greater than

what is being saved, the overhaul interval should not be extended. If the risk of failure does not increase to the point where the failure cost is greater than what is being saved, the overhaul interval could be extended. Better management of the failure costs and understanding the failure risks may allow the extension of overhaul intervals, which would decrease the lifecycle cost of the asset.

At Union Pacific, the realities of managing a large fleet provide ample opportunity to extend overhaul intervals. Surveying our fleet it was determined that we were regularly running locomotives beyond their OEM recommended overhaul criteria as well as beyond our internal recommended limits. Most of the engines that fell into this population had acceptable levels of reliability. Failures that did result in overhaul were preventable. It was our feeling from looking at some of our past practices that it would be possible to extend overhauls without having a negative impact on locomotive reliability.

Based on our past experiences with extending overhauls and analysis of the risks involved, we believed that it would be possible to have the 'Ideal Overhaul Model' that had longer periods between overhaul events and relatively low levels of risk of failure between those overhaul events. One of the key aspects to accomplishing a risk based overhaul strategy is to incorporate changes into the everyday maintenance strategy that complement and specifically address the issues that

hinder performance between overhaul events. Assessing, understanding and managing failure risk is the key to controlling locomotive failure liability, and thus overall lifecycle cost.

To develop an understanding of the failure risk involved, UP embarked on a program to extend overhaul intervals without impacting reliability. The basic premise of the program was to assess and understand the failure mechanisms that cause the failure risks to increase and determine what running maintenance changes need to take place to manage the failure risk to lower levels. Union Pacific worked with an outside contractor to manage the study. The project consisted of a failure and wear analysis to determine the cause of risk of failure at various stages of the locomotive's life.

The evaluation consisted of taking 120 total engines, 30 engines at each interval of 100%, 116%, and 124% of the recommended overhaul criteria. To date, the engines in the 100-116% categories have been completed. The engines were run through a normal unit exchange program and the key qualification measurements were recorded and compared to expected wear levels. The locomotive repair histories were reviewed with respect to teardown results to determine if there were practical explanations for engines that showed exceptional or unusual wear. For each of the key measurements, rates of wear were calculated and were incorporated into a risk model to determine if the expected wear at higher age levels would pose

a notable increase in failure risk. If the risk level was increased beyond an acceptable level, a contingency plan would have to be developed to address that particular issue.

The results of our study did show several components that required us to develop a contingency plan to address elevated levels of failure risk. One particular problem required a locomotive design change. The solution to the rest of the issues was an interim maintenance event that would address several specific issues with either detailed inspections or proactive replacement of key components. This event allows us to buy enough time to make it to the next overhaul event without sacrificing reliability.

From the study we also gained significant insight to how maintenance practices can have a profound effect on the ability to stretch overhaul cycles. A significant portion of the OEM recommended maintenance did have positive effect on failure risk.

Maintenance throughout the engine lifecycle has a significant impact on the ability to successfully get to and go beyond traditional overhaul models. A good example of this is the cleaning of port carbon on GE locomotives. If this task is not performed, it will significantly affect power assembly reliability.

Another issue that was identified was the importance to quickly and accurately identify root causes of failures. If minor water and fuel leaks are not found and expeditiously corrected they can lead to substantial engine damage. Several engines

were found to have bearing wear rates that were greater than the norm. Many of these engines had significant oil quality events in their histories that contributed to the excessive wear rates.

Another issue that needs to be addressed in this program is dealing with overhaul and replacement of non-engine systems in the absence of a traditional overhaul event. The reliability of these components needs to be evaluated in a similar manner to determine what their individual failure risks are and what can be done from a maintenance standpoint to address additional failure risk.

In conclusion, extending overhaul intervals is possible. To be successful, failure risk must be understood and managed. The running repair strategy will likely have to be modified to complement the overhaul strategy. In turn, these changes will lower the overall lifecycle cost of the locomotive.

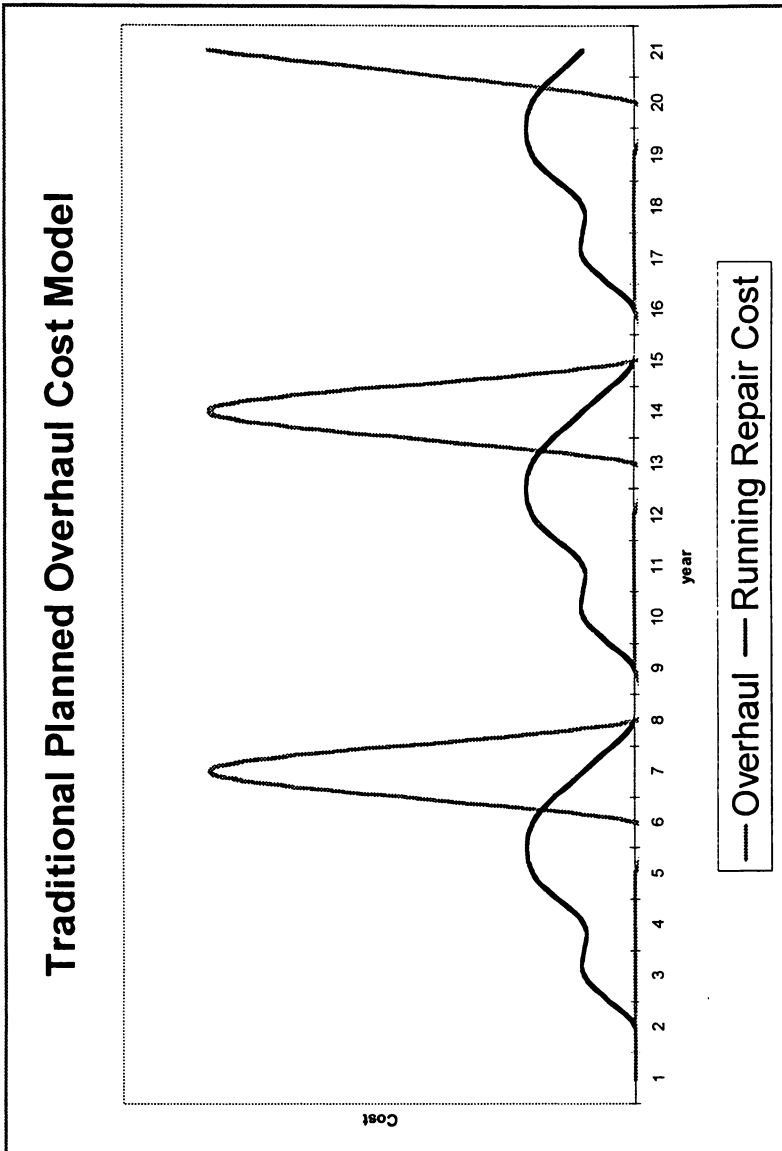


Figure 1

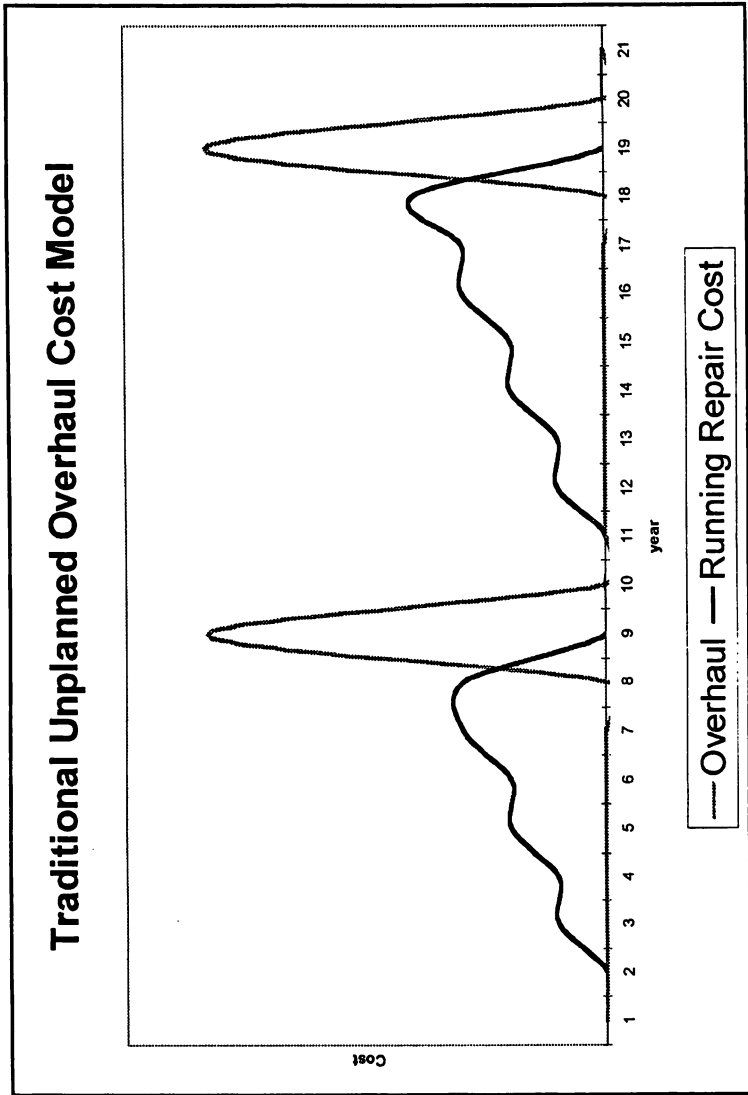
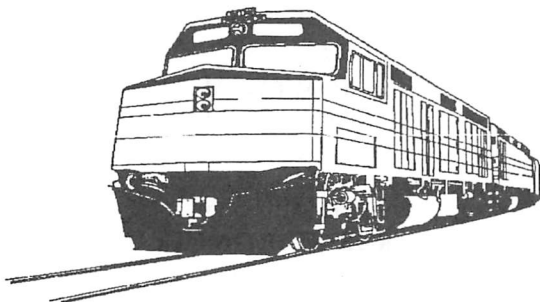


Figure 2

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ON FUEL, LUBRICANTS AND ENVIRONMENTAL  
TUESDAY, SEPTEMBER 20, 2005  
2:00 P.M.**



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## PERSONAL HISTORY

### *Thomas Pyziak*

Thomas J. Pyziak, Chairman of Fuel, Lubricants and Environmental Committee, was born in Chicago on August 10, 1954. Tom is a graduate of Gordon Technical High School in Chicago. He attended and graduated from St. Norbert in DePere, Wisconsin in 1976 with a Bachelor of Science degree.

Tom began his career as a lab technician with Motor Oils Refining Company in McCook, Illinois which is a re-refiner of petroleum lubricants. He learned all aspects of manufacturing from plant operation to quality control and research and development.

Tom transferred to marketing as a Technical Sales Representative and subsequently became an

Industrial Sales Rep. He was given railroad/sales responsibility in 1984, handling product development, marketing/sales and oil waste removal sales. In 1989, this portion of the operation was sold to Breslube which two years later was acquired by Safety-Kleen Systems. Tom's current position is National Account Manager Railroads, handling all aspects of railroad engine oil development, sales/marketing with added technical responsibilities to the OEM's, GM, Ford and Chrysler.

Tom's hobbies include gardening, Chicago softball and auto racing. He is married. His wife's name is Katie and they reside in Palatine, Illinois.

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## I. ENGINE OIL 202: REFINED BASE OILS AND THEIR IMPORTANCE IN LUBRICATION

*Presented by:*

*Fred W. Girshick, Infineum USA, L.P.*

### **Abstract**

This paper reviews the functions, properties, composition, origins, and manufacture of lubricant base stocks. Base stocks are the refined mineral oils that are the major components of all lubricating oils. The major modern refinery processes will be explained, as well as current base stock naming conventions, measurements and typical targets, and the "Group" definitions published by the American Petroleum Institute (API). The types of base stocks used in railroad oils, and how they changed in response to increased engine and service severity, are discussed. This is a follow up to last year's paper, "Engine Oil 101: Additives and Viscosity," and completes the discussion of engine oil components.

### **Functions of engine oil**

The primary function of engine oil is to separate moving parts that would otherwise rub against each other and wear out. The main properties that provide this function are viscosity and the response of viscosity to temperature. In addition, good lubricants have a property called "lubricity" or "slipperiness." This is the property that makes oil a better lubricant than water or water-based fluids. Another important, but often overlooked, function of engine lubri-

cating oil is cooling. A good lubricant will be able to absorb large amounts of heat without degrading. The lubricating oil is required to prevent destructive processes that occur in an engine, such as oxidation, wear, friction, rust, and corrosion. A properly formulated engine lubricating oil can help maintain the engine's designed operating condition, increase longevity, and reduce maintenance costs.

### **Composition of engine oil**

Engine oils can contain many components, which are classified in four categories: base stock, pour point depressant, viscosity modifier, and performance additives. Performance additives, also known as the detergent-inhibitor (DI) package, can include detergents, dispersants, anti-oxidants, anti-wear, rust and corrosion inhibitors, friction modifiers, and anti-foamants. Last year's paper reviewed all the most common components except base stocks, which are covered here.

### **Overview of base stocks**

Base stocks are the distilled and refined mineral oil streams derived from crude oil. They can be anywhere from 60% to 99+% of the total lubricating oil. Modern generation railroad oils are typically 80 to 90% base stock, as shown in Figure 1.

The designation "mineral oil" reflects their origins - they are refined from crude oil which has been pumped from oil-bearing rock. The word "petroleum" comes from two Greek words, "petra" and "oleum"

which mean rock-oil. Although they are found in minerals (rocks), base stocks are not made from the same materials as minerals.

In contrast to mineral oils, lubricants derived from animal and vegetable sources are used in other industries, but not railroad engine oils. Synthetic oils are a designation for oils manufactured from chemical reactions, as opposed to traditional refinery processes. The precise meaning, structure, and properties of synthetics will be discussed in detail later.

Besides being the vast majority component in engine lubricating oils, another way to demonstrate the importance of base stocks is to show their effect on engine performance. Figure 2 shows the degree of oxidation, as measured by viscosity increase, in the GE Oxidation Test for the same non-commercial additive system blended into four different base stocks. The GE Oxidation Test is one of the approval tests for railroad oils. Changing the base stock can have a significant effect on the performance of the same additive system. As discussed in last year's paper, it is the final blended oil - the combination of additives and base stock - which must be approved for railroad service, so it is possible for the additives to "make up" for weaker base stocks.

Another property affected by base stock is soot-dispersancy. Figure 3 shows the amount of viscosity thickening caused by diesel engine soot using the same additive system in three different base stocks. Again, base stock can have a signifi-

cant effect on performance.

In a later section, we will review the tests conducted on all approved railroad engine oils to ensure acceptable performance when changing base stocks.

The major lubricant properties affected by base stocks are: viscometrics, oxidation stability, soot-handling ability, foaming, and volatility (evaporation).

Base stocks are composed of thousands of different kinds of hydrocarbon molecules. These can be grouped into various categories, each with its own nomenclature and properties. Before we examine these categories, it is worth reviewing the chemistry and terminology of hydrocarbon molecules.

### **Chemistry of hydrocarbons**

Organic chemistry is the chemistry of carbon compounds. Although just one of more than 100 known elements, carbon forms more compounds than all the others combined. There are literally millions of different substances containing carbon. This is due to carbon's unique ability to bond to itself and other elements to form chains, branches, rings, and even more complicated three-dimensional shapes.

Carbon prefers to form four chemical bonds. Each of these can be to other carbon atoms or to atoms of other elements. The four bonds of carbon form a tetrahedron, which is a pyramid with a three-sided base (Figure 4), contrasted with the Pyramids in Egypt, which have four-sided bases. Because of the tetrahedral shape of each carbon atom, car-

bon compounds form complicated three-dimensional structures. It will be important to consider the three-dimensional configuration of carbon compounds, as the geometry of the molecule can be just as important as its chemistry.

The chemical shorthand used to discuss carbon compounds is shown in Figure 5a. The molecule pentane is represented by the formula  $C_5H_{12}$ . The name pentane derives from the Greek word "penta-" meaning five, as in The Pentagon - a five sided building. This formula shows there are five carbon atoms and 12 hydrogen atoms in the molecule, and is useful when calculating molecular weights or balancing a chemical equation.

Of equal interest is the structural formula shown in Figure 5b. This shows how the individual atoms are bonded to each other. In this case, the five carbons form a straight chain; the carbons on the ends have three hydrogens each and the carbons in the middle have two hydrogens each. Each carbon atom is bonded to four other atoms, which is the preferred configuration for carbon.

The structure shown in Figure 5b is a two-dimensional representation of the correct three-dimensional structure in Figure 5c. A form of chemical shorthand is shown in Figure 5d, where the same pentane molecule is shown with only the carbons and without the hydrogens. Figure 5e takes this shorthand one more step and omits the letter "C" representing carbon. Only a line drawing remains. This representa-

tion shows the "backbone" of the molecule with the details omitted. It is understood that there is a carbon atom at each vertex and each carbon has its maximum number of hydrogens. This representation will usually show all the salient features needed to evaluate a molecule's potential for lubricant service.

A simple linear carbon chain in Figure 6a. Each carbon is bonded to four other atoms; the bonding spaces where carbon isn't bonded to another carbon are filled with hydrogen. Since the molecule contains only carbon and hydrogen, it is called a hydrocarbon. It is called a saturated molecule, since all the possible bonding sites are full, just as a saturated solution is completely full.

A similar molecule is shown in Figure 6b, but with the difference that two of the spaces formerly filled by hydrogen are empty. In order to maintain four bonds per carbon, a double bond has formed, in the place indicated, and the two carbons in the double bond each "claim" to have four bonds. The molecule would really prefer to fill those spaces, and is relatively unstable as a result. Molecules containing double bonds will be more reactive towards other chemical species - for example, oxidation - than the saturated molecules.

If carbon atoms form a six-sided ring (a hexagon) with three double bonds, a particularly symmetrical and stable structure occurs, as shown in Figure 7a. Because the double bonds can re-position around the hexagon, the three double bond are shown as a circle

(Figure 7b). The simplest aromatic, shown in Figure 7, is benzene.

### Molecule names

This section will examine the names of the different types of hydrocarbon molecules, followed by a discussion of which types are good lubricants and why.

The first class of hydrocarbons is Saturates. These are molecules where all of the four possible bonding positions at every carbon atom are occupied. We can further subdivide saturates based on the geometry of the molecules. Figure 8a shows a straight chain saturate molecule, in this case with six carbons. The same six carbons can form a branched chain saturate molecule, as shown in Figure 8b. Figures 8a and 8b differ only in the geometric configuration of the atoms. They are called "isomers," from the words "iso" (same) and "mer" (unit) and there are refinery processes, called isomerization, capable of converting one isomer into another. Saturated molecules with no rings are called paraffins or paraffinic.

Figure 8c shows carbons in a six membered ring. This molecule is also saturated, as indicated by the absence of double lines. Saturated molecules with ring structures are called naphthenes or naphthenic.

In contrast to the saturates, Figure 8d shows an unsaturated molecule with a single double bond. Molecules with a double bond are called olefins, and typically don't occur in fresh lubricants although they can be created by degradation during use. Figure 8e shows the six

membered ring with three alternating double bonds, benzene. Compounds containing this structure are called aromatics because the substances in which they were originally detected had strong smells. These are unsaturated molecules.

### Desirable lubricant properties

The ideal base stock molecule will have excellent resistance to oxidation, high viscosity index, and low pour point.

### Oxidation resistance

Oxidation is destruction of molecules by exposure to oxygen at elevated temperatures. (*n.b.*, Technically, oxidation can occur without oxygen, but we don't need to consider those cases). Oxidation is initiated by radicals, which are molecular fragments with an unpaired electron. Electrons are stable when paired, so the radicals are very unstable and reactive. The radicals will attack and "pull apart" the base stock molecules to "steal" an electron. In doing so, a radical can create two or more new radicals and cause a chain reaction of ever-increasing degradation. In an engine, the initial radicals are formed from the combustion of fuel, and get into the lubricating oil through the thin film on the cylinder wall and *via* blow-by past the piston rings.

The best base stock molecules are those that can resist attack by radicals by having strong carbon-carbon and carbon-hydrogen bonds. These are generally the saturated hydrocarbons, although there is considerable range of stability within

each class of molecule. The straight chain saturated paraffins have the best oxidation stability. The branched chain saturated paraffins are more unsusceptible to oxidation because the carbon-hydrogen bond at the branch point is weaker than the carbon-hydrogen bonds in the straight "backbone" chain.

The naphthenics - saturated molecules with a ring structure - are more susceptible still due to the presence of the ring. The carbon where a side chain attaches to the ring is bonded to three carbons, which weakens the bond to the remaining hydrogen.

The least stable molecules towards oxidation are the aromatics. In this case, due to the double bonds in the ring, the ring itself is quite stable. But the presence of the ring weakens the carbon-hydrogen bonds in the side chains, particularly on the first carbon removed from the ring.

### Viscosity index

Viscosity Index is a measure of viscosity-temperature dependence, and is defined by ASTM D 2270. The higher the viscosity index, the less the change of viscosity with temperature. All other things being equal, a high viscosity index is beneficial. Viscosity index is determined by the physical geometry of the molecules more than by their chemical properties. A flexible molecule will have a higher viscosity index than a rigid molecule. A flexible molecule can coil into a small volume at low temperatures and expand into a large volume at high temperatures.

At the low temperature, smaller volume molecules will tend not to "bump into" each other as much and not resist flow as much, and therefore not thicken as much. At the high temperature, the larger volume molecules will tend to "bump into" each other, which impedes flow - cause resistance to flow - which is a higher viscosity, and the oil will not "thin out" as much.

The straight chain paraffins will have the highest viscosity index because they are the most flexible, followed by the branched chain paraffins. Paraffinic base stocks tend to be manufactured with viscosity indices in the range 95 - 110. The naphthenes and aromatics, both with ring structures, are the least flexible molecules and have the lowest viscosity index, particularly those with multiple fused rings. The exact value of viscosity index will depend on the nature of the side chains. Naphthenic base stocks tend to be manufactured around 60 viscosity index.

### Pour point

Pour point, or low temperature properties in general, are also determined by the physical geometry of the molecules. In this case, a very regular molecule that can "fit together" or crystallize will have poor low temperature properties. The straight chain paraffins are the most regular, crystalline molecules and have the worst low temperature properties. The branched chain paraffins are significantly better. The naphthenics have the best low temperature properties and are often used when that

is a critical requirement. The low temperature properties of the aromatics depend on the length and structure of their side chains. Pour point is measured by ASTM D 97.

### **Desirable base stock molecules**

This section will categorize the different types of molecules with respect to their performance as engine lubricants.

Figure 9 shows various classes of hydrocarbon molecules - those with only hydrogen and carbon - and elevates their performance as lubricants. Figure 9a shows a straight chain, saturated, paraffin molecule. This type of molecule will have a very high viscosity index because it is flexible, and very good oxidation stability because it is saturated, but a high pour point (poor low temperature properties) because the very regular structure allows it to "fit together" and crystallize at low temperatures.

Figure 9b shows a branched chain, saturated, paraffin molecule. This molecule will have a high (but not very high) viscosity index because it is relatively flexible, good oxidation stability because it is saturated, and a reasonable pour point (low temperature properties) because the side chains interfere with wax crystal formation at low temperatures. These are generally considered to have the best overall balance of properties for lubricant molecules.

Figure 9c shows a saturated ring, naphthenic molecule. This molecule will have a medium viscosity index because the ring limits molecular

flexibility, medium oxidation stability because the presence of the ring weakens the carbon-hydrogen bonds, and low pour point (very good low temperature properties) because the ring structure cannot crystallize very well.

Figure 9d shows an unsaturated aromatic ring molecule. The viscosity index and pour point of aromatics depend on the number of rings and the structure of the side chains. The oxidation stability is very poor because, although the aromatic ring itself is relatively stable, its presence lowers the strength of the carbon-hydrogen bond immediately adjacent, making it more susceptible to chemical attack.

Figure 10c shows a molecule containing nitrogen, which is a mild pro-oxidant. The oxidation performance of the nitrogen compounds are sometimes important in industrial oils, but their contribution is completely overwhelmed by the fuel combustion products in engine oil applications.

### **Base stock refining**

Mineral oil base stocks are derived from crude oils through processing in refineries. A modern lubricant refinery is shown in Figure 11. As the name suggests, refining is the process of improvement, just as a refined person is somehow better than an unrefined person. Base stock refining is the process of taking crude oil as a starting material and transforming it into a finished product that is suitable to make lubricants. By first examining the composition of crude oil, we can deter-

mine the processes required to change it into good lubricants.

### **Crude oil**

Crude oil was formed over millions of years from the decomposition of primarily plant, and some animal, materials. The molecules and structures present in crude oil are a result of the specific material decomposed, the time, temperature, and pressure of decomposition, and probably many other factors. The goal of the base stock refiner is to take the specific mixture of molecules in the crude oil and make it suitable for use in lubricants.

Crude oil contains tens or hundreds of thousands of different kinds of molecules. Crude oils vary in viscosity from lighter than water to heavier than asphalt; in color from golden amber to green, brown, red, or black; and in pour point from less than  $-20^{\circ}\text{C}$  ( $-4^{\circ}\text{F}$ ) to more than  $+40^{\circ}\text{C}$  ( $104^{\circ}\text{F}$ ). Likewise, they vary in their suitability as raw material for lubricant manufacture. Availability of a particular crude will be affected by its location, ease of pumping and transmission, modes of transportation to the refinery (pipeline or ship), its suitability for other purposes (supply vs. demand), and sometimes by political considerations. Some crude oils are not suitable to manufacture lubricants at all, and some refineries only manufacture fuels. Even in the crudes most suitable for base stock production, lubricants represent less than 10% of the total so economics of other products, notably fuels, may determine crude oil selection for a refinery.

The refinery considers both the physical and chemical properties of the crude oil molecules and determines the best strategy for manufacturing good quality lubricants from the given raw material. In general, base stock refining consists of selecting streams with the correct physical properties of viscosity, volatility, and pour point and then further selecting for the desired chemical properties of oxidation stability, sulfur and nitrogen content. The next sections will describe the individual refinery processes available, followed by sections showing how these processes are combined into a total refinery processing scheme.

### **Distillation**

Lubricants must have the correct viscosity for the given application and temperature range. Crude oil contains molecules from gases methane and propane, to light liquids such as gasoline and diesel fuel, to heavier liquids suitable for lubricants, to semi-solids like wax and asphalt. The process used to separate these streams is distillation.

Distillation separates the streams based on their boiling point. This is the same principle used to separate or concentrate mixtures of alcohol and water to manufacture different "proof" liquors, based on the different boiling points of alcohol and water. Distillation of lubricant base stocks is more complicated because of the greater number of components in the mixture, the higher boiling point of those components. Lubricant distillation is accomplished in two steps: atmos-

pheric and vacuum distillation.

Atmospheric distillation, as the name implies, is conducted at atmospheric pressure and is a continuous flow operation. The crude oil is introduced into a tall column called an atmospheric pipestill (Figure 12). The pipestill contains "plates" stacked at intervals along its height. The plates have "caps" which allow liquid and vapor to pass from one plate to the next. The column is kept under a temperature differential, with the bottom hotter than the top. If a molecule finds itself lower in the column than its boiling point, it will vaporize and migrate up through the caps until it is on a plate lower than its boiling point. There, it will condense back to liquid. Conversely, if a molecule is higher in the column than its boiling point, as a liquid it will drip down until the plate temperature causes it to vaporize and migrate upwards. In this way, each molecule will seek its own level based on boiling point. Piping in the side of the column extracts each separated stream.

The streams at the very top are gases which are used to make liquefied propane (LP), compressed natural gas (CNG), butane, and as chemical feed stocks. Next lower will be streams suitable for gasoline blending, kerosene, and jet fuel. Next will be diesel fuel and heating oil. The heavier material, called "atmospheric residuum," is sent for vacuum distillation.

Vacuum distillation is a method to distill materials at lower temperatures than required for atmospheric distillation. The materials heavier

than diesel fuel boil at temperatures so high that they would decompose before they could be distilled. Applying a high vacuum reduces the temperatures required for distillation. This is the same principle that requires increased cooking times at high altitudes because the boiling point of water is lower at the lower atmospheric pressure. It is the opposite of a pressure cooker, which increases the boiling point of water by applying a higher pressure, and reduces cooking times.

Other than the presence of a vacuum, the distillation is the same. The streams removed from the vacuum pipestill are called vacuum gas oil (VGO), or "lube oil distillate," or just "distillate." The heaviest material, which cannot be distilled at these temperatures even under vacuum, is called vacuum residuum or "vacuum bottoms" and will be sent to a deasphalting unit.

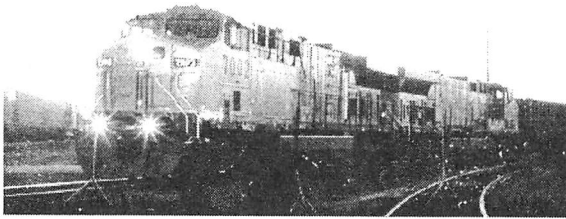
Distillation selects molecules of the correct viscosity because of a high, but not perfect, correlation between viscosity and boiling point. Distillation can also be used to modify volatility, or the propensity to evaporate. Volatility is caused by evaporation of the lightest molecules in the lubricant mixture, and can be controlled by adjusting the width of the "cuts." Each of the side streams from the pipestill is a mixture of a larger number of individual components. This is illustrated schematically as Figure 13a which shows a distribution of boiling points resulting from combining several side streams. The refiner has the option of making a narrower "cut," shown as Figure

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13b. This distribution has the same midpoint, so it will be the same viscosity, but is narrower. This means it will have less of the lighter materials and will have a lower volatility. In order to maintain the same viscosity (same midpoint), the heavier ends must be trimmed as well. Base stocks made from these distillates are called "narrow cut" base stock. The disadvantage of narrow cutting is the reduction in yield by eliminating the tails of the distribution. Narrow cut base stocks are needed for very light passenger car engine oils and automatic transmission fluids. The base stocks used for railroad service are high enough in viscosity that volatility is rarely an issue. Volatility is often measured as the percent of material that evaporates below 371°C (700°F), by ASTM D 5480.

A property related to volatility is flash point. Flash point, measured by ASTM D 92 or D 93, is the minimum temperature at which the vapors will be ignited by an open flame. Flash point is important for safety, handling, and transportation.

### Quality upgrading processes

The distillates are streams selected to have the desired physical properties of viscosity and volatility. However, they are still mixtures of materials with both good and bad chemical stability, viscosity index, and pour point. The next step is to increase the proportion of "good" (chemically stable, high VI) molecules and reduce the proportion of "bad" (chemically unstable, low VI) molecules. The two main technolo-

gies used to do this are separation and conversion.

Separation technology removes the "bad" lubricant molecules. The remaining mixture has a higher proportion of "good" molecules and is thus improved. The removed material is used in other parts of the refinery or in other products, for which it is suitable. The main separation technology is solvent extraction.

Conversion technology chemically changes "bad" molecules into "good" molecules. The major conversion technology is hydrocracking.

### Solvent extraction

In solvent extraction, molecules are separated based on their solubility, or polarity. Polar molecules prefer to dissolve in other polar molecules and non-polar molecules prefer to dissolve in other non-polar molecules. Referring back to Figures 9 and 10, we can see a correlation between the suitability of molecules for lubricants and their polarity.

Straight chain and branched chain saturates - paraffins - are good lube molecules and have very low polarities due to (a) the low polarity of the carbon-hydrogen bond and (b) their molecule symmetry which cancels what little polarity each bond has. Naphthenic molecules are worse lubricant molecules and slightly more polar because the ring structure partially cancels the symmetry of the paraffins. The aromatics are poor lubricant molecules and also more polar because of the extra electrons in the aromatic cloud. The sulfur and nitrogen compounds are polar because of the presence of the

non-hydrocarbon atom and because most of them contain an aromatic ring.

Solvent extraction is shown, conceptually, in Figure 14. In practice, solvent extraction is a continuous flow process. A stream of the correct viscosity from the crude oil, called distillate - is mixed with a polar solvent. The more polar molecules (the poor lubricants) preferentially dissolve in the polar solvent and get separated from the better (non-polar) lubricant molecules. Commonly used solvents include phenol, furfural, N-methyl pyrrolidone (NMP) and mixtures. Some of the specific processes are patented and trademarked by individual companies.

The extraction solvents are small molecules that can be separated from the aromatic portion of the distillate by evaporation. They are then re-cycled to the extraction unit. The stream containing the aromatic portion is called the extract and is used for applications requiring very high solubility such as printing inks and rubber process oils. The stream now enriched in non-aromatic molecules is called the raffinate.

Variables that affect the quality of the raffinate include crude source, solvent, solvent-distillate ratio, temperature, and residence time. In some cases, the raffinate has sufficient quality to use directly as base stock, but more commonly, the raffinate requires further refining.

### Hydrocracking

Hydrocracking is the common conversion technology. "Cracking"

means breaking chemical bonds. "Hydro-" indicates reaction with hydrogen. "Hydrocracking" is the simultaneous breaking of chemical bonds and reaction with hydrogen. Catalysts are designed specifically to enhance the desired reactions while suppressing undesirable reactions. The hydrogen is generated from the gasoline production part of the refinery, where it is removed from lighter fractions to improve octane number. The term hydrocracking is usually used to indicate a relatively high severity operation; hydrofinishing or hydrofining indicate low severity processes; and hydrotreatment can be either. There are also trademarked names for individual company's processes.

A schematic example of hydrocracking is shown in Figure 15m where a multiple-ring aromatic (Figure 15a) is converted into a naphthenic molecule with several paraffinic side chains (Figure 15b). One of the original aromatic rings has been broken open, and the other two saturated. Figure 15c shows the same molecule subjected to a higher severity - perhaps higher temperature and hydrogen pressure. In this case, all three rings have been broken open and fully saturated. Figure 15c shows the molecule in a way to emphasize its origin as the molecule in Figure 15a; Figure 15d shows the same molecule uncoiled to show that it is an excellent branched chain paraffin.

Hydrotreatment, either hydrocracking (severe) or hydrofinishing (mild) can remove sulfur and nitrogen, as shown in Figure 16. The

bonds to the sulfur or nitrogen are broken and replaced with hydrogen. Sulfur is combined with hydrogen to form hydrogen sulfide ( $H_2S$ ) and nitrogen becomes ammonia ( $NH_3$ ), both of which are gases removed at the top of the reactor.

Hydrocracking can form small molecules, and these will have to be removed by another distillation step. Hydrocracking can also create waxy molecules with poor low temperature properties. These will be removed during the dewaxing stage. The main factors affecting hydrocracked base stock quality are temperature, hydrogen pressure, type of catalyst, catalyst-distillate ratio, and residence time.

### **Deasphalting**

Vacuum residuum is the bottom stream from the vacuum pipestill. It is too heavy for further distillation, even at reduced pressures, and contains large molecules called asphaltenes. Asphaltenes are unsuitable for lubricants, but very useful for other purposes such as road paving and roofing tiles. Separating asphalt from the vacuum residuum both improves the quality of the "resid" and produces a valuable by-product.

Solvent de-asphalting is analogous to solvent extraction: a separation based on solubility. A common solvent for deasphalting is liquid propane. Once the asphalt has been removed, the "deasphalted distillate" is sent for solvent extraction of hydrocracking, and will eventually become the heaviest grade of base stock, called bright stock.

### **Dewaxing**

Wax is another term for paraffin molecules with predominantly straight chains (Figure 9a). Although these molecules have the desirable properties of high viscosity index and chemical inertness, their very regular shape allows them to crystallize into large structures (wax) which impede the flow of lubricant in an engine, particularly at lower temperatures. Such clogging can lead to engine failure through lubricant starvation. There are three technologies to remove wax; solvent dewaxing, catalytic dewaxing, and catalytic isodewaxing.

### **Solvent dewaxing**

Solvent dewaxing is a separation technology that uses the very wax-crystallization property of wax to effect its separation. A schematic is in Figure 17. Waxy raffinate is dissolved in a solvent, commonly methyl ethyl ketone (MEK) or methyl isobutyl ketone (MIBK). The mixture is chilled and the straight chain paraffins crystallize on the surface, where they can be skimmed off. Rotary filters are used in a continuous process. The removed wax is used to make candles, crayons, milk cartons, and other products, compensating for the loss of base stock material.

### **Catalytic dewaxing**

Another way to remove wax is to break apart the long chain linear molecules into smaller pieces that have lower boiling points and can be removed with distillation. This can be thought of as a selective form of

cracking - breaking bonds. Catalysts are available that promote this particular reaction. A method to attack selectively only the straight chain molecules is to place the catalyst in a structure with tube-like porosity (Figure 18). Only the long straight chain molecules can fit into the tubes and only they react with the catalyst. Figure 18 shows how branched chain and cyclic molecules cannot fit into the tubes. A disadvantage of catalytic dewaxing is the loss of base stock material without recovery of the valuable wax.

### **Catalytic Iso-dewaxing**

An improvement that avoids the disadvantages of catalytic dewaxing is catalytic isodewaxing. Similar in concept to catalytic dewaxing, catalytic isodewaxing uses a different catalyst that, instead of breaking the straight chain molecules, re-arranges them. It takes pieces off the ends of the molecules and moves them to the middle, converting straight chain saturates into branched chain saturates. This way, there is no loss of material.

### **Refinery schemes**

The several processes discussed above are the basic building blocks to compose a refinery scheme. There are many variations, and we will examine only the most fundamental.

Figure 19 shows a typical solvent extraction refinery scheme. Atmospheric distillation is followed by vacuum distillation, solvent extraction, hydrofinishing, and dewaxing. Hydrofinishing is a rela-

tively mild hydrotreatment that removed some of the sulfur and nitrogen compounds not removed by solvent extraction, and may saturate some of the aromatic molecules. Inclusion of this step allows reducing the severity of the solvent extraction step and increases yield. A chart showing typical properties of solvent extracted base stocks is Table 1.

Figure 20 shows a typical hydrocracking refinery scheme. Atmospheric distillation is followed by vacuum distillation, hydrocracking, and catalytic dewaxing. The light materials formed during hydrocracking and catalytic dewaxing are removed by further atmospheric and vacuum distillation. A chart showing typical properties of hydrocracked base stocks is Table 2.

### **Re-refining**

Re-refining is the name given to a refinery process that takes used oil as the starting material instead of crude oil. It is a method to re-cycle and re-use discarded oil that would otherwise be burned as fuel. Used oil contains a certain amount of oxidation by-products, wear particles, fuel, water, and other contaminants, but is mostly refined base stock. Re-refining is completely analogous to crude refining, except the particular composition and properties of used oil are considered when developing the scheme. Basically, atmospheric distillation is replaced by two steps: dehydration to remove water, and stripping, to remove fuel. These are actually atmospheric and mild vacuum distillation processes, but with

conditions optimized to remove water and fuel, rather than to separate crude oil fractions. Next, vacuum distillation removes additives and wear metals. Typically, thin film evaporators are used instead of vacuum towers, to avoid fouling of the hot surfaces. At this point, the streams may be sent to either solvent extraction or hydrocracking units for final processing.

### Synthetics

In contrast to crude refining, synthesis builds up "good" lubricant molecules by combining small molecules using chemical reactions. The small molecules - the building blocks - are originally derived from crude oil so these too are of mineral origin, although the term "synthetic" is usually used as an antonym for "mineral oil." There are many possible types of synthetic base stocks, each derived from different basic chemical starting materials and each resulting in base stocks with a particular combination of properties. In principle, any chemical reaction can be used to make a synthetic base stock. The most common synthetic base stock is poly alpha olefin (PAO), which will be reviewed in this paper. Other commercial synthetic base stocks, beyond the scope of this paper, include isomerates, gas-to-liquids (GTL), diesters, polyol esters, polyalkene glycols (PAG), polybutenes, dialkyl benzenes (DAB), phosphate esters, silicones, and silicates.

#### **Poly alpha olefin (PAO)**

The most common synthetic

base stock is shown schematically in Figure 21, starting with the small simple molecule, ethylene. Ethylene, or ethene, is a two-carbon molecule with a double bond. Double bonds are reactive and can add to each other to create larger molecules. In Figure 21a, five ethylene molecules join together to form decene, a ten-carbon molecule with a double bond. The name decene comes from "deca" meaning ten and "ene" that designates a double bond. Since the double bond is between the first and second carbons, this is called 1-decene or  $\alpha$ -decene ("alpha-decene") using the first letter of the Greek alphabet, alpha, to designate the first position. A molecule with a double bond is called an olefin, so 1-decene is also called an alpha-olefine.

Since 1-decene has a double bond, it can join together the same way ethylene did. Figure 21b shows three 1-decene molecules joined together to form a 3-carbon branched chain saturated hydrocarbon. When the decene molecules first join together, the resultant molecule has a double bond, but it is then saturated by reaction with hydrogen. The prefix "poly" means "many," so this type of synthetic base stock is called a poly-alpha-olefin, or PAO. The viscosity of the PAO is controlled by how many decenes are allowed to combine. The 30-carbon molecule shown here has a viscosity of about 4 mm<sup>2</sup>/s at 100°C. The 40-carbon molecule made by combining four decenes has a viscosity around 6 mm<sup>2</sup>/s at 100°C, and the 50-carbon molecule made by com-

binning five decenes has a viscosity around 8 mm<sup>2</sup>/s at 100°C, and so forth. Poly (a-decene can be manufactured with up to 50 decene units, at which point it has a viscosity around 100 mm<sup>2</sup>/s at 100°C. PAO's are oftentimes by appending the viscosity at 100°C to the acronym PAO, such as PAO 4, PAO 6, PAO 8, etc.

It is possible to make PAO from olefin other than a-decene (10 carbons), for example a-hexene (six carbons), a-octene (eight carbons), or a-dodecene (12 carbons); however, poly (a-decene) is the most common PAO. A chart showing typical properties of some PAO's is Table 3.

### Base stock names

Although each refining company may have its own brand names, base stocks are commonly named in ways to indicate their viscosity, since that is the most important property of a lubricant. Viscosity is fluid's resistance to flow, and depends very strongly on temperature. Kinematic viscosity, which is viscosity divided by density, is easier to measure. The SI unit of kinematic viscosity is the millimeter squared per second (mm<sup>2</sup>/s). Using familiar liquids to establish a scale of viscosity, water is about 1 mm<sup>2</sup>/s at room temperature; olive oil is about 100 mm<sup>2</sup>/s at room temperature; and honey is about 10,000 mm<sup>2</sup>/s at room temperature.

An older, historical unit of kinematic viscosity is the Saybolt Universal Second (SUS). This was the number of seconds it took a fluid to drain out of a particular apparatus. Viscosity in SUS is approximately

equal to 4.6 times the viscosity in mm<sup>2</sup>/s. A full conversion table can be found in ASTM D 2161.

Solvent extracted base stocks are almost universally named as "Solvent xxx Neutral," where xxx is the viscosity in SUS at 100°F. This can be abbreviated as SxxxN, SNxxx, xxxSN, or other combination. Sometimes they're just called "neutrals" without the word "solvent." S100N, S150N, and S600N are common grades. Railroad oils use base stocks near the viscosity of the S600N grade; the other grades are used for other products, such as passenger car engine oil, or for on-highway trucks, etc.

Bright stock is the heaviest grade of base stock, equivalent to about S2500N. They are typically named as, for example, "150 Bright Stock" where 150 is its viscosity in SUS at 210°F (note the change in temperature), but often just called Bright Stock because a refinery probably only makes one grade.

Hydrocracked base stocks can be named as their equivalent "neutral number" (without the word "solvent") or by their nominal viscosity in mm<sup>2</sup>/s at 100°C (again, a change of temperature), with or without some indication that they are hydrocracked. For example, 600N, HC600, HC12 are all possible means for the same base stock.

Base stocks are sometimes named by their nominal Viscosity Index (a measure of viscosity-temperature dependence), that being an important property. The prefixes MVI, HVI, VHVI, and XHVI have been used to indicate, respectively,

Medium Viscosity Index, High Viscosity Index, Very High Viscosity Index, and eXtra High Viscosity Index. MVI usually indicates a naphthenic base stock and HVI a paraffinic base stock, but there are no industry standards for use of these terms.

Poly-alpha-olefin base stocks are usually named as "PAO xx" where "xx" is either the viscosity in mm<sup>2</sup>/s at 100°C or some number containing the same information, for example PAO 4 or PAO 164 are both trade names for 4 mm<sup>2</sup>/s poly-alpha-olefin.

Table 4 shows approximate base stock grade equivalent viscosities at four temperatures.

#### **API base oil classification**

The American Petroleum Institute publishes a classification system for base stocks. Although directed primarily at passenger car and on-highway heavy duty engine oils, the nomenclature of the API system is rapidly becoming a term of commerce in other industries. The American Petroleum Institute is a trade association of oil companies, and represents the interests of base stock manufacturers. As the number, complexity, and cost of approving passenger car and heavy duty engine oils (on-highway trucks) increased, the API wanted to find a way to reduce the cost of approving lubricants. Under the previous rules, the same additive system used in different base stocks had to be tested repeatedly. The API noted there were known correlations and trends in base stock performance, and

designed a system to allow reduced testing when blending a proven additive system into a different base stock. Companies submitted data to an API Technical Panel to document the trends of base stock performance. Base stock trends were only accepted as valid if data were submitted from at least two oil companies using at least three additive supplier's technologies.

A method to classify base stocks were developed, to allow the promulgation of rules for reduced testing. At first the API thought base stock could be described by reference to the three refinery processes noted above: solvent extraction, hydrocracking, and synthesis, and proposed a classification with these three groups. It was found that this system was deficient because a base stock purchaser would not always know what process was used for its manufacture and because there was variation in the composition and quality within each refining process. The API therefore developed a system based on chemical analysis, comprising five groups. The API system refers to base oil rather than base stock. Base stock is a single manufactured stream, sold as individual component; base oil is the specific mixture of base stocks used in the product in question and can be a single base stock or a mixture.

The API base oil groups are characterized by Viscosity Index, saturates, and sulfur content. Viscosity Index is measured by ASTM D 2270. Saturates are measured by ASTM D2007, which also reports aromatics and polars. Sulfur may be measured

by ASTM D 1552, D 2622, D 3120, D 4294, or D 4927. The API base oil groups are shown in Table 5.

API Group I base oils have viscosity index between 80 and 120, and either less than 90% saturates, greater than or equal to 0.03% sulfur, or both. This generally describes base stocks manufactured with solvent extraction technology.

API Group II base oils have viscosity index between 80 and 120, and both greater than or equal to 90% saturates and less than 0.03% sulfur. This generally describes base stocks manufactured with hydrocracking technology.

API Group III base oils have the same chemical requirements as Group II, but have viscosity index greater than 120. These base stocks are generally manufactured using more severe hydrocracking conditions.

API Group IV base oils are defined as poly-alpha-olefins. Although these are, in fact, synthetic base stocks, the API system does not use the term "synthetic" as part of the classification.

API Group V base oils are all those that don't fit into another category and synthetics other than PAO. Group V includes both low viscosity index (less than 80) naphthenics, synthetic esters, and others.

Base on this system, API publishes a set of rules to allow reduced testing of a proven additive system in a new base oil. For example, the data submitted to API documents that Group II base oils are better for soot-dispersancy test in Group I base oils. Therefore, if an additive system

passed their soot-dispersancy test in a Group I base stock, it can be assumed it will pass in a Group II base stock and the test does not have to be re-run. Conversely, it was found that one of the diesel deposit tests responds better to Group I base oils than to Group II base oils. Therefore, an additive system that has passed that test in a Group II base oil does not have to be re-run when changing to a Group I base oil.

Many companies use their own terminology to describe their base stocks. Terms such as "Group 1 1/2" and "Group II plus" are being used in advertising and marketing, but have no standing in the API system.

### **Railroad requirements for base stocks**

The process of approving lubricants for use in railroad applications ensures the combination of additives and base stock meets the required quality level. The railroad approval system does not allow for reduced testing based on base oil groups. A new additive must be proven through rigorous field testing under severe conditions. This is necessarily done in a particular base stock or base oil. Once the additive system has been fully approved, it may be used in different base oils only if the exact combination meets certain chemical and physical requirements and passes bench tests for friction, oxidation, and silver corrosion performance.

Before about 1976, when railroad oils met the quality levels LMOA Generations 1 through 4, naphthenic base stocks were widely

used. The increased severity of railroad operations and new engine designs that led to GE Generation 4 Long Life and LMOA Generation 5 prompted a move to paraffinic base stocks. Current industry trends include further increases in severity through increases power utilization, extending oil drain intervals, and changes in engine design to meet new emissions requirements, Tier II and beyond. These trends are prompting increasing consideration of hydrocracked (API Group II) base stocks for railroad service.

Currently, the base oil mixture used for railroad applications is limited to a maximum of 10 mass percent bright stock, due to the deterioration of oxidation stability above that level. This was reduced from 15 mass percent maximum a few years ago. In addition, the base oil mixture for railroad oils must contain a minimum of five to 10 percent aromatics, to assist seal compatibility. Therefore, 100% hydrocracked (API Group II) base oils may not be used; hydrocracked base oils may make up the majority but must be blended to meet the aromatics minimum.

### Conclusions

Base stocks are complicated mixtures of molecules that critically contribute to the overall performance of lubricants. Physical properties, such as viscosity, viscosity index, and pour point, are just as important as chemical properties, such as saturates and sulfur content. Unfortunately, the exact chemical mechanisms of lubricant performance are not understood well

enough to be predicted from physical and chemical analyses of the base stock. This is an active area of research. Performance testing of the finished blended product is still required to ensure engine protection in service.

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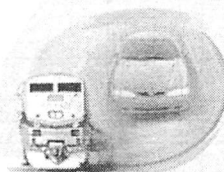
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Table 1

## Typical Base Stock Properties (Solvent Extracted)

Property	Units	Light	Medium	Heavy	Bright Stock
Name		S100N	S150N	S600N	150 Bright Stock
Viscosity at 100°C	mm <sup>2</sup> /s	4	5	12	32
Viscosity at 40°C	mm <sup>2</sup> /s	20	30	110	490
Viscosity Index		95	95	95	95
Pour Point	°C	-18	-18	-9	-18
Volatility	% off at 371°C	20	15	0	0
Flash Point	°C	200	210	250	280
Saturates	mass %	75	75	70	60
Sulfur	mass %	0.3	0.3	0.4	0.7

Table 2

## Typical Base Stock Properties (Hydrocracked)

Property	Units	Light	Medium	Heavy
Name		HC100	HC220	HC600
Viscosity at 100°C	mm <sup>2</sup> /s	4	6.5	12
Viscosity at 40°C	mm <sup>2</sup> /s	20	42	110
Viscosity Index		100	100	100
Pour Point	°C	-18	-18	-18
Volatility	% off at 371°C	16	2	0
Flash Point	°C	200	220	250
Saturates	mass %	95	95	95
Sulfur	mass %	0.01	0.01	0.01

Table 3

## Typical Base Stock Properties (PAO)

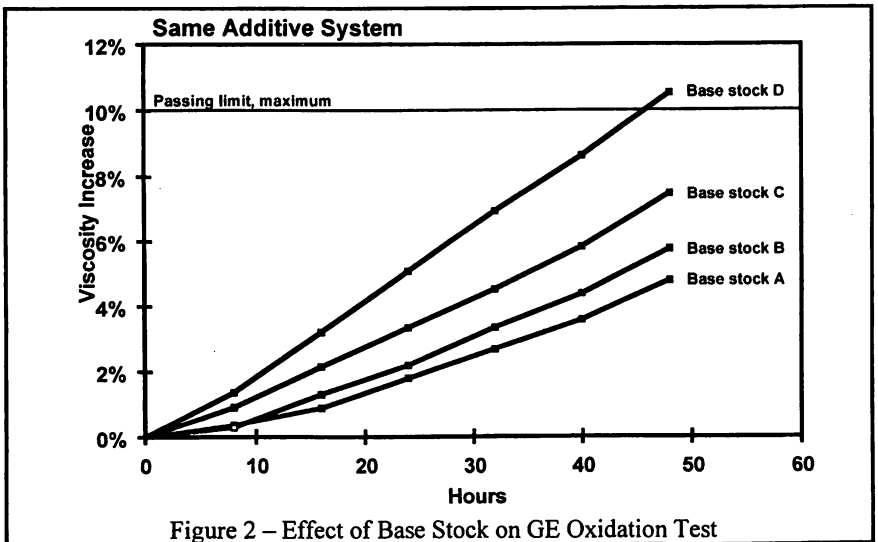
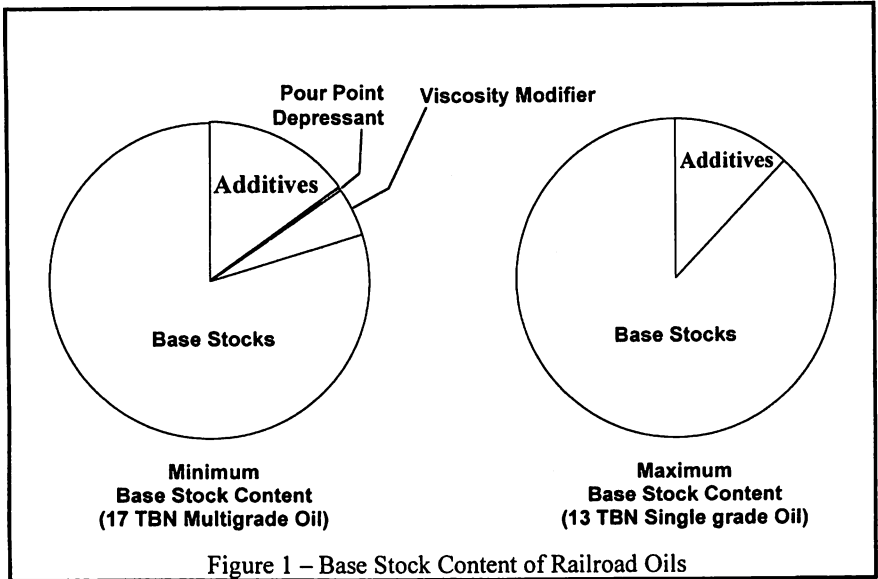
Property	Units	Light	Medium	Heavy	Very Heavy
Name		PAO 4	PAO 6	PAO 10	PAO 100
Viscosity at 100°C	mm <sup>2</sup> /s	4	6	10	100
Viscosity at 40°C	mm <sup>2</sup> /s	18	30	65	1400
Viscosity Index		130	135	130	165
Pour Point	°C	-63	-63	-51	-20
Volatility	% off at 371°C	1	0	0	0
Flash Point	°C	200	240	270	288
Saturates	mass %	96	96	96	96
Sulfur	mass %	0	0	0	0

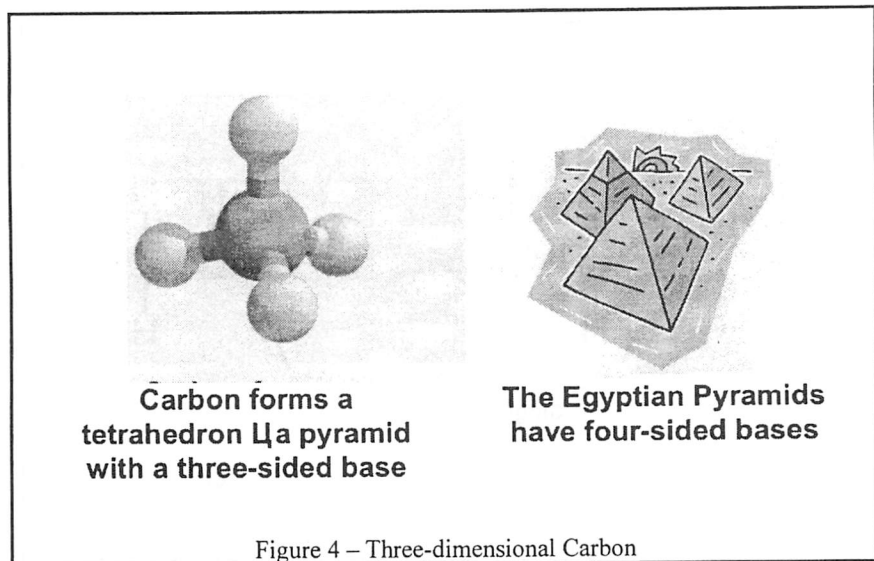
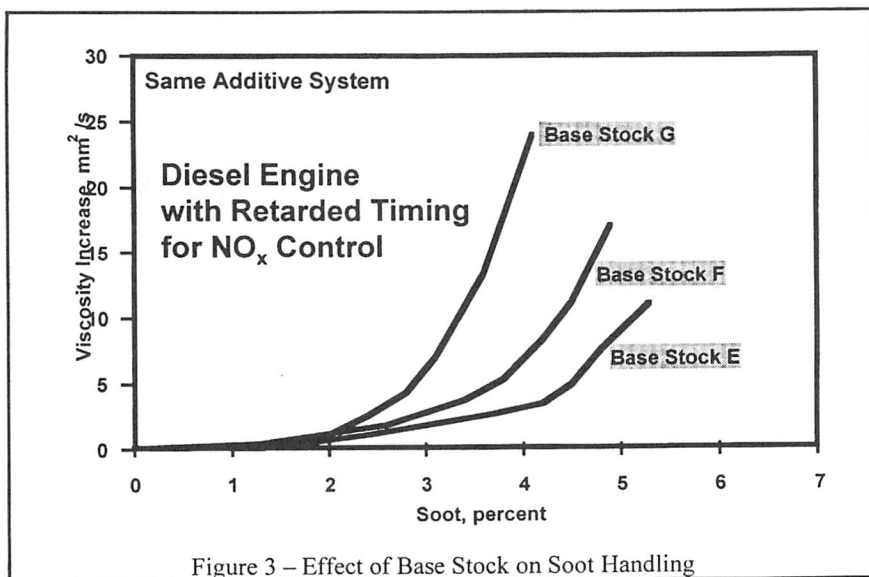
**Table 4**  
**Approximate Base Stock Grade Equivalents**

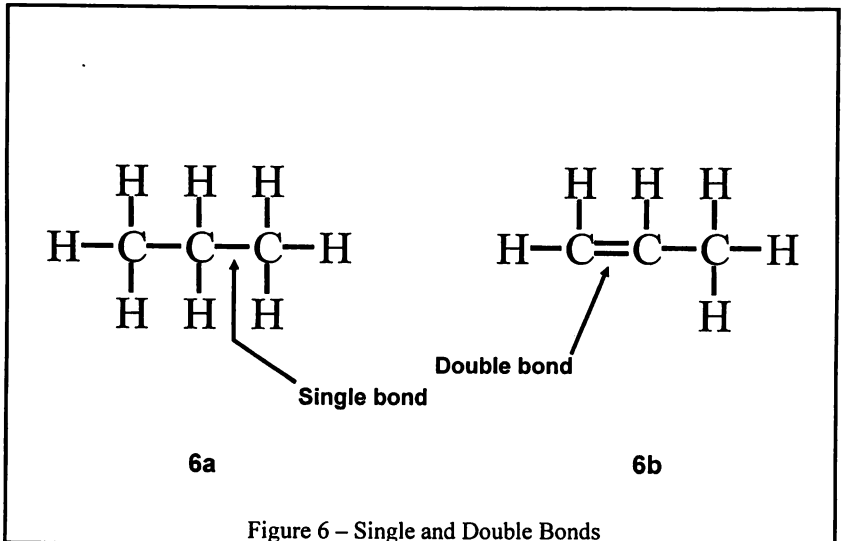
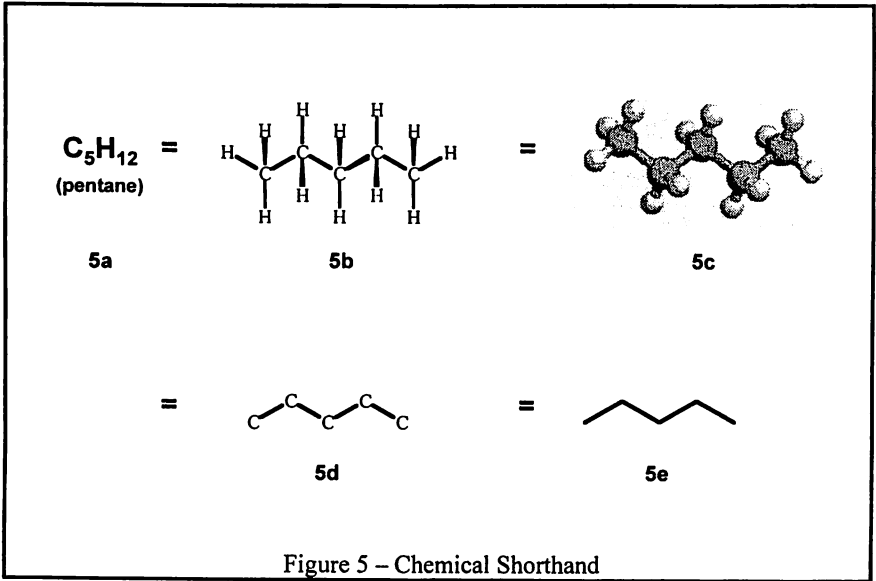
Grade	SUS at 100°F	SUS at 210°F	mm <sup>2</sup> /s at 100°C	mm <sup>2</sup> /s at 40°C
S 75N	75	37	3.1	13
S100N	105	40	4.1	20
S150N	155	43	5.1	30
S325N	330	55	8.5	65
S600N	590	68	12.1	115
150 Bright Stock	2500	150	31.5	500

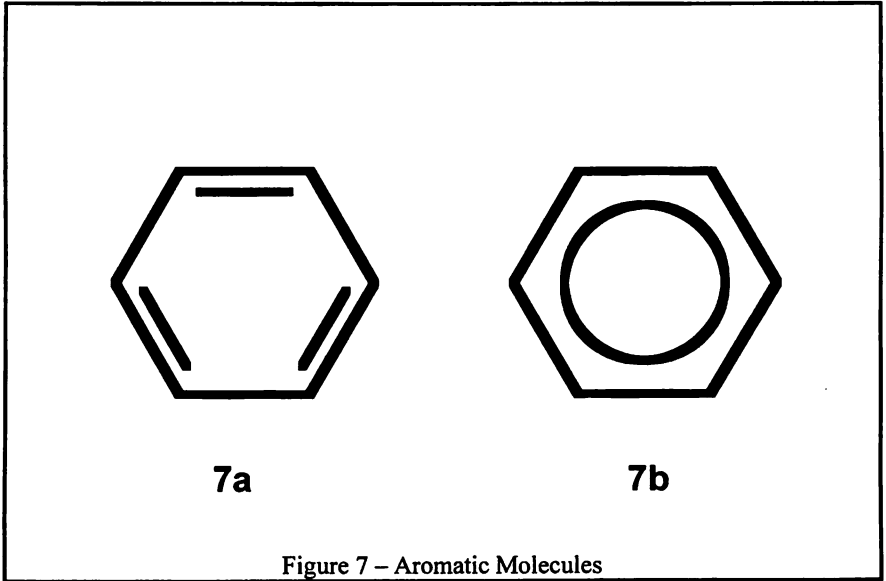
**Table 5**  
**API Base Oil Groups**


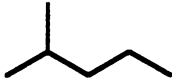



Group	Viscosity Index	Saturates	Sulfur	Other
I	80 – 120	<90%	and/or $\geq 0.03\%$	13
II	80 – 120	$\geq 90\%$	and $< 0.03\%$	20
III	>120	$\geq 90\%$	$< 0.03\%$	30
IV				Poly Alpha Olefin (PAO)
V				Everything Else









Type	Structure	Chemical Name
<b>8a. Straight Chain (paraffinic)</b>		<b>n-hexane (normal hexane)</b>
<b>8b. Branched Chain (paraffinic)</b>		<b>iso-hexane</b>
<b>8c. Ring (naphthenic)</b>		<b>cyclo-hexane</b>
<b>8d. Double Bond (olefin)</b>		<b>1-hexene</b>
<b>8e. Ring with Multiple Double Bonds (aromatic)</b>		<b>benzene</b>

**Figure 8 – Molecule Names**


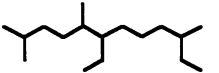
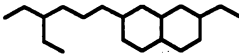
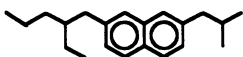
	Type	Structure	Properties
	<b>X Saturates</b>		
	<b>└ Paraffins</b>		
9a	<b>X Straight chain</b>		<b>Very high VI</b> <b>Good oxidation</b> <b>High pour point</b>
9b	<b>X Branched chain</b>		<b>High VI</b> <b>Good oxidation</b> <b>Medium pour point</b>
9c	<b>└ Naphthenes</b>		<b>Medium VI</b> <b>Poor oxidation</b> <b>Low pour point</b>
9d	<b>X Aromatics</b>		<b>VI and pour point depend on chain lengths</b> <b>Very poor oxidation</b>

Figure 9 – Hydrocarbon Lube Molecules

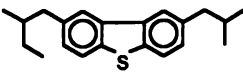
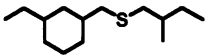
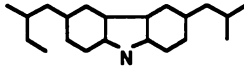
	Type	Structure	Properties
	<b>X Sulfur</b>		
10a	<b>└ Dibenzothiophene</b>		<b>Antioxidant</b>
10b	<b>└ Dialkylsulfide</b>		<b>Corrosive</b>
10c	<b>X Nitrogen</b>		
	<b>└ Alkylhydrocarbazole</b>		<b>Mild pro-oxidant</b>

Figure 10 – Polar Lube Molecules



Figure 11 – Lubricants Refinery (courtesy Emerson Refining Company)

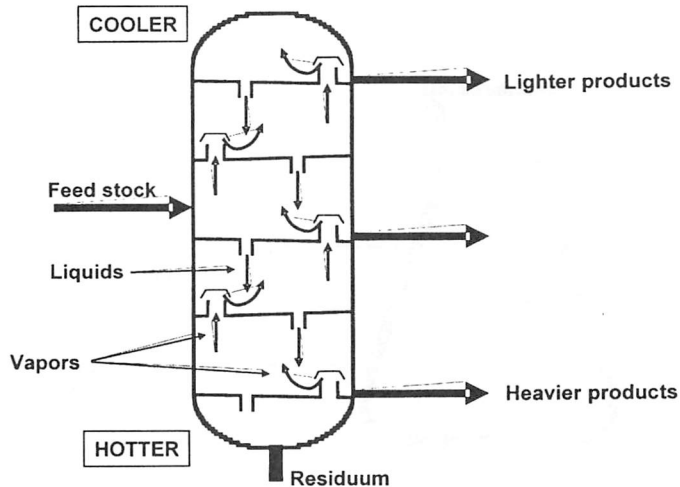
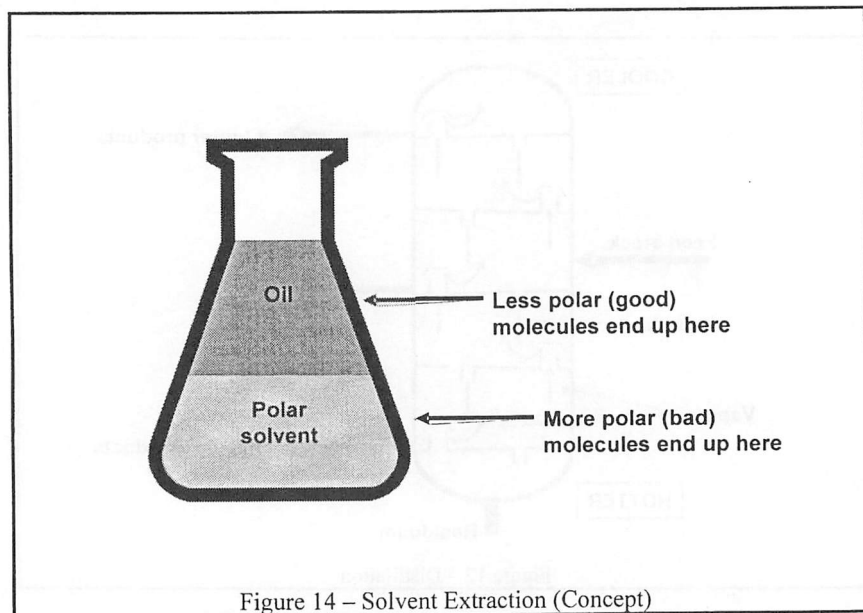
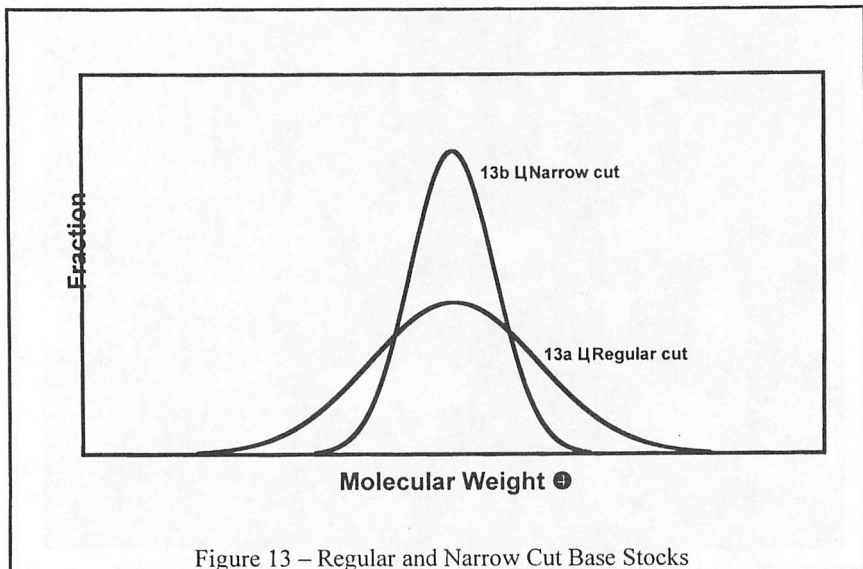


Figure 12 – Distillation



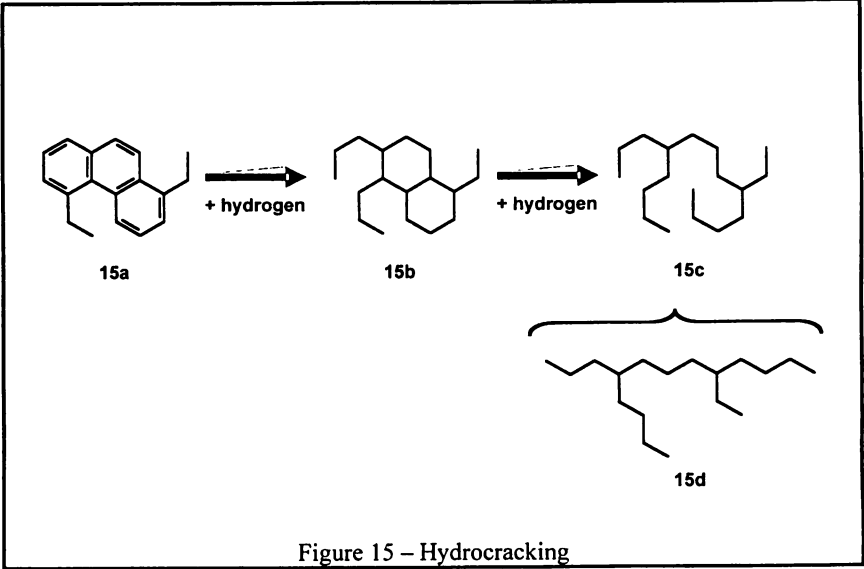


Figure 15 – Hydrocracking

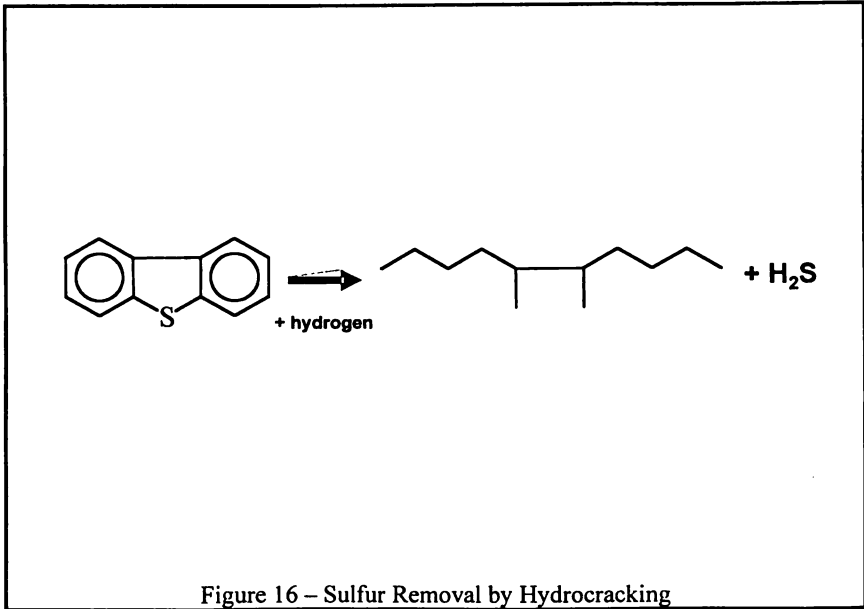
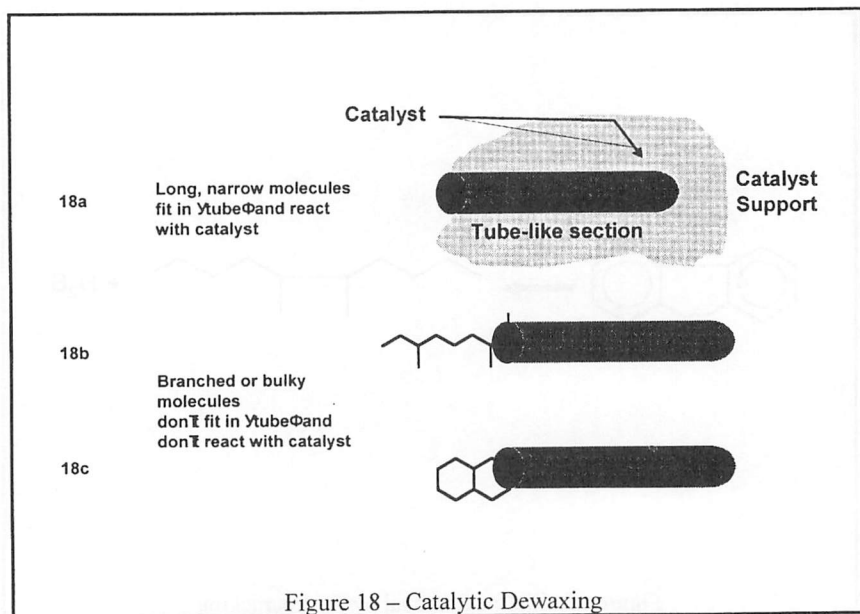
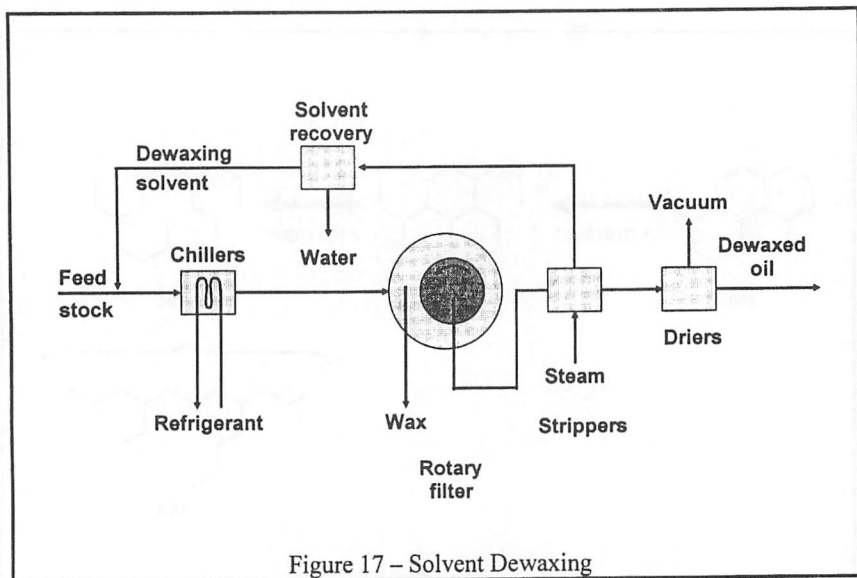
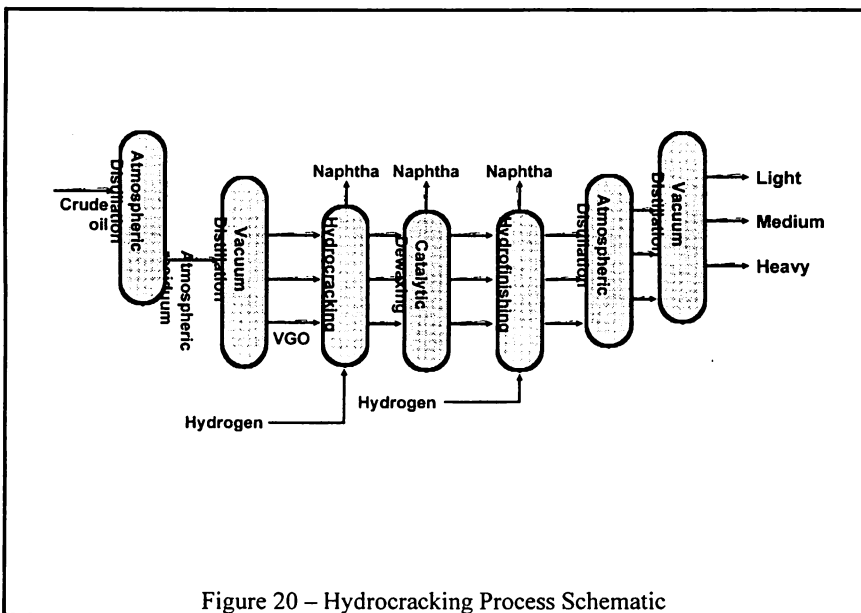
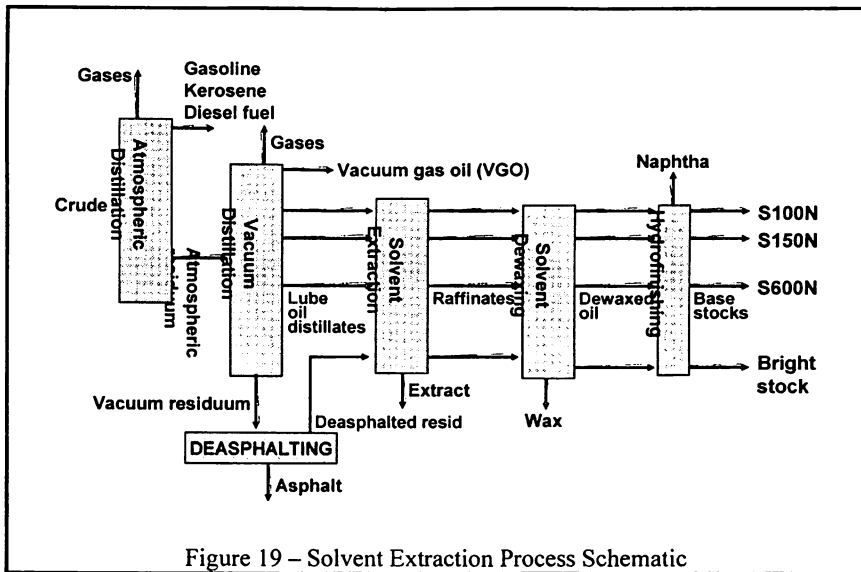
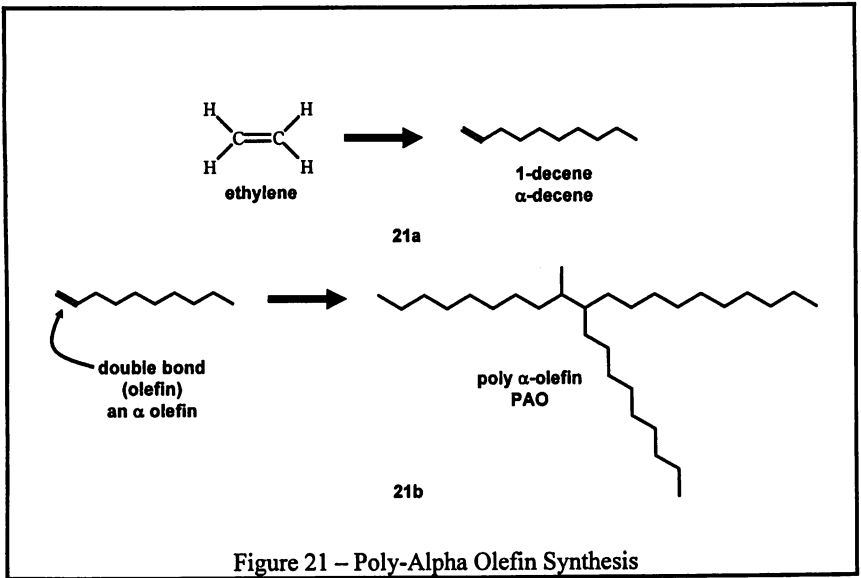
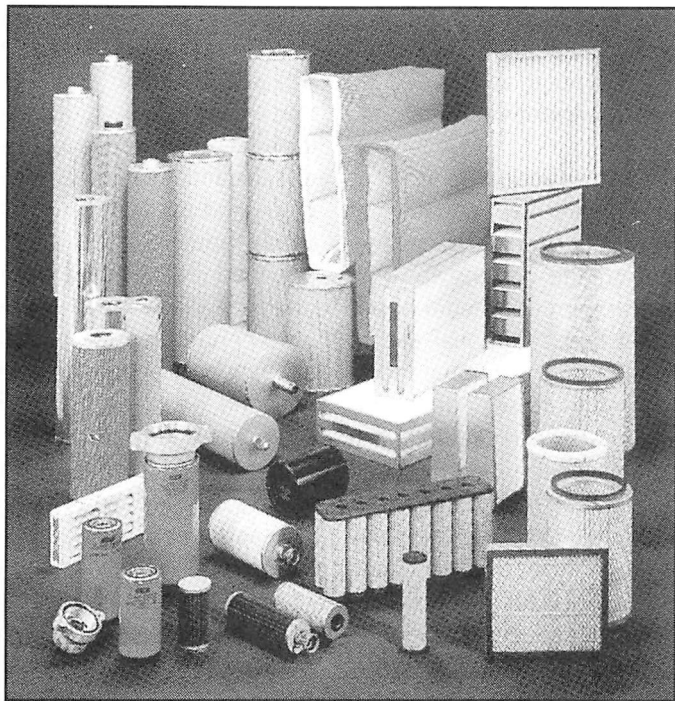


Figure 16 – Sulfur Removal by Hydrocracking









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## II. BIODIESEL - A POTENTIAL FUEL SOURCE FOR LOCOMOTIVES

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BNSF Railway*

*Leighton Haley, Norfolk Southern  
Corporation*

*Dennis McAndrew, GE Rail*

### Introduction

Diesel engines are capable of burning a variety of materials as fuel but current engine designs are optimized for use with petroleum based No. 2 diesel fuel. Potential use of fuels other than conventional No. 2 diesel naturally raises questions regarding costs associated with engine maintenance, engine performance and long-term reliability of the equipment. With present-day concerns regarding the cost and availability of diesel fuel and the negative environmental effects of burning fossil fuels, greater attention is being given to alternative fuels that can minimize or solve these issues. One alternative being investigated is renewable sources derived from plants and animals - commonly referred to as biofuel. Both plants and animals contain fats and oils that, once extracted, can be chemically treated to produce fuels with physical properties similar to petroleum-based diesel fuel.

The 1972 oil embargo brought to the public eye the dependency on foreign oil. However, in subsequent years as fuel costs decreased, public awareness and resolve waned. Concerns over greenhouse gas emissions and global warming has refocused attention on the negative

effects of burning fossil fuels. In the US there has been a slow but steady move toward alternative fuels since enactment of the Clean Air Act of 1990 and subsequent regulations requiring reduced exhaust emissions and a lower sulfur content of diesel fuel. Europe's development of bio-fuels has been more aggressive due to substantial subsidies for non-food crops and tax incentives that significantly reduced assessment values or provided exemptions from normal taxes on diesel fuel. These factors have contributed to European biofuel being cost competitive with diesel fuel and have resulted in biodiesel production on an industrial scale since 1992. While most of the world's efforts have centered on car, bus and truck usage, development for off-road use has lagged behind.

Following is an overview of bio-fuels and biodiesels, a typical production process, properties of the fuels produced, advantages and concerns regarding its use along with some information on costs and incentives for promoting its use.

### Biofuels - What are they?

Biofuel is a generic term that refers to a family of fuels produced from animal and plant sources. Biodiesel is a subgroup of biofuel that meets specific requirements and is more suitable for use in diesel engines. Although the terms tend to be used interchangeably there are significant differences in the materials referenced. Biofuel can refer to any fuel derived from biological matter, i.e. vegetable oil, animal fats, waste oils, etc. Using raw biofuel

(i.e. vegetable oil) in diesel engines can produce negative effects such as reduced bearing life, lubricant thickening, injector deposits, poor injector spray patterns, polymerization of the oil in the ring belt area contributing to reduced engine life along with other problems.

Biofuels are the starting materials for biodiesel production. Triacylglycerols (triglycerides) that are extracted from plants and animals are reacted and purified to produce biodiesel. Triglycerides that are solid at room temperature are often referred to as "fats" and those, which are liquid as "oils." In addition, sources that are high in fatty acid content, such as recycled cooking oils, can be used in the production of biofuel.

The triglyceride molecules can be viewed as composed of a three-carbon backbone alcohol (glyceride) with three fatty acids attached. Diagram 1 shows the structure of a triglyceride molecule and the structure of a fatty acid that may be incorporated in the triglyceride.

$R_1, R_2, R_3$  represent carbon chains varying in length from 8 to 22 atoms—the chains most often are not identical.

These triglycerides in themselves are not normally a suitable fuel source for compression ignition engines as the viscosity and other properties produce short and long-term problems. However, triglycerides can be chemically altered by a process called transesterification where one alcohol (the glycerol backbone) is displaced by another alcohol (typically methanol). The

resulting products from this reversible reaction are glycerol and fatty acid methyl esters (FAME). The fatty acid methyl esters produced are the source material for biodiesel. Diagram 2 shows a generalized chemical reaction for the production of fatty acid methyl esters that compose biofuels.

The basic route involved in the production of FAME is to combine an excess of a short chain alcohol with a plant oil or animal fat in the presence of heat, a catalyst and mixing. This reaction produces the mono-alkyl esters and the byproduct glycerol – commonly referred to as glycerin. Once the reaction is complete, the product is purified by separation from the byproducts and excess reactants.

The length of the fatty acid carbon chain and the amount of saturation or unsaturation does vary with and within the source. These differences affect the physical and chemical properties, which in turn affect their performance. For example, the cloud point varies with the amount of saturation in the molecule, the more saturated, the higher the cloud point; also, the greater the amount of unsaturation, the greater the tendency toward oxidation instability.

Table 1 shows some common fats and oils used in biofuel production along with the percentages of the various fatty acids contained in each. Currently, the feedstock used for the majority of biofuel production in the United States comes from soybean oil. Soybean oil is available in sufficient quantities at reasonable cost and the production process is

fairly simple. The alcohol predominately used in this process is methanol ( $\text{CH}_3\text{OH}$ ). Although it is possible to use other alcohols, price, availability and performance generally dictate which one is used. Diagram 3 shows a typical reaction and products obtained from the transesterification of soybean oil.

In this example three separate fatty acid methyl esters are formed from one soybean oil triglyceride, one methyl oleate and two methyl linoleate. The difference between these FAMES is the number of double bonds (the amount of unsaturation) in the methyl linoleate. Other FAMES can be produced from soybean oil (see Table 1) but the above represents a "typical" soybean oil triglyceride. The amount of unsaturation affects the properties of the fuel produced and varies based on the source material used.

Purification of the product can be as simple as gravity separation of the glycerol and catalyst followed by water washing to remove any soaps, alcohol, glycerol and catalyst that remains or as complicated as distillation of the product after washing. Which methods is used can affect the properties of the end product. For example, distillation can remove natural antioxidants leaving the final product more susceptible to oxidation.

Although the reaction process is fairly simple, the quality of the starting materials and the final purification processes can have a dramatic affect on the properties of the final product.

### **Biodiesel - What it is:**

Biodiesel is a biofuel with some limitations on its properties and is registered as a fuel or fuel additive with the US Environmental Protection Agency. In many instances, the two terms are incorrectly used interchangeably, but The American Society for Testing and Materials International (ASTM) defines biodiesels as 'a fuel comprised of mono-alkyl esters of long chain fatty acids derived from vegetable oils or animal fats, designated B100.' The biodiesel described by ASTM must meet the specifications of ASTM D 6751; otherwise the fuel may not meet the requirements of current medium speed diesel engines.

Biodiesel is similar to conventional petroleum-based diesel fuel but does have some significantly different properties. These properties can vary based on the raw material source or even the region where the raw material came from. The main source for biodiesel in the US is soybean oil but in Europe rapeseed oil is primarily used. Since the starting materials have diverse chemical compositions, the resulting fuels will have properties somewhat different that affect parameters from cloud point to storage stability. Therefore, European experience with biodiesel is not necessarily directly applicable to what may be experienced in the United States.

Biodiesel can be used neat or blended at varying concentrations with No. 2 diesel, No. 1 diesel, kerosene, Jet A, heating oil or any other distillate fuel. The most com-

mon blends are with No. 2 diesel fuel. Current consumption of petrodiesel dwarfs present and near future production capabilities of biodiesel, therefore, realistically biodiesel use would be mainly as an extender - it will be blended with petrodiesel. Typical blends consist of 1 to 20 percent biodiesel. When blended, the resulting fuel should meet the requirements of ASTM D 975 while the bio portion must still meet the D 6751 requirements. As will be seen later, there are some notable differences between the specification for B100 (D 6751) and No. 2 diesel (D 975). Biodiesel blends are dilutions of the B100 product and are given the B designation followed by the percentage of B100 in the product. For example, a B5 product would identify a biodiesel that is 5% B100 biodiesel and 95% No. 2 diesel. A product comprised of 20% B100 biodiesel and 80% No. 2 diesel would be a B20 product.

B5 and lower blends generally meet the properties listed in ASTM D 975, which defines the properties of conventional No. 2 diesel fuel. B20 or higher blends also meet the properties listed in ASTM D 975 with the possible exception of viscosity and distillation, depending mostly on the diesel fuel with which it is blended. OEMs and railroads specify fuels that meet ASTM D975 as a minimum.

### **Biodiesel specifications**

ASTM standards are recognized in the United States and by EPA and govern most government entities,

including states with the responsibility of insuring fuel quality. ASTM has developed D 6751 as the US standard for biodiesel fuel. The corresponding standard in Europe is EN 14214 and is very similar except EN 14214 contains a limit on the iodine value that would exclude biodiesel derived from several important vegetable oils including soybean oil. The iodine value shows the amount of unsaturation in the fuel. The greater the amounts of unsaturation, the less oxidatively stable the fuel.

The definition of biodiesel contained ASTM D 6751, along with the physical and chemical properties, eliminates "biofuels" that have incorrectly been called biodiesel in the past. Raw vegetable oil or animal feed stock, partially reacted oils or fats, coal slurries, or any other "biologically derived methyl esters or fuels not meeting the definition and specifications are not biodiesels.

The latest ASTM specification for biodiesel (B100) is D 6751-03a. This specification is intended to ensure the quality of biodiesel B100 and that used as a blending stock. The standard lists two grades of B100 biodiesel, S15 and S500. The S15 and S500 specifications differ only by their sulfur content; the S15 product has a sulfur maximum of 15 ppm and the S500 product has a maximum sulfur content of 500 ppm.

A comparison of the ASTM biodiesel specification (ASTM D 6751-03) and the comparable specification for No. 2 diesel fuel is shown in Table 2. You will note there are several parameters (acid number, free and total glycerin and phospho-

rous content) that are unique to the biodiesel specification. These parameters and their respective ASTM procedures recognize the unique characteristics of the biodiesel and the potential hazards if manufacturing is not performed correctly. A brief discussion of each parameter is also provided in Appendix A.

At this time there are no ASTM specifications for biodiesel blends. However, within ASTM committee D02.E0 (the committee charged with overseeing standards for Burner, Diesel, Non-Aviation Gas Turbine, and Marine Fuels), there is an effort underway to develop a B20 standard. Work Item WK6286, dated 11/04/2004, is listed in the ASTM internet site, [www.astm.org](http://www.astm.org). A Work Item is used to describe a new standard under development by an ASTM committee.

The WK6286 specification will cover three B20 grades of fuel blends collectively designated as B20. The three grades are Grade B20 (S15) a fuel with a maximum of 15 ppm sulfur, Grade B20 (S500) a fuel with a maximum of 500 ppm sulfur and (S5000) a fuel with a maximum of 5000 ppm sulfur. The biodiesel component of the blend shall conform to the requirements of ASTM D 6751 prior to blending. The remainder of the fuel shall be of a middle distillate grade fuel conforming to ASTM D 975.

Once a biodiesel is blended at 20%, it is very difficult to determine the quality of the B100 product used in the mix. Today, without a specific standard for the B20 blend, most users of B20 can only insist from

their supplier that the B100 material used in the product meet the ASTM D 6751 specification and that the middle distillate diesel fuel oil meet the ASTM D 975 specification.

### **Advantages of biodiesel**

Biodiesel is a fuel produced from domestic, renewable materials thus reducing our dependence on foreign oil. Development of this industry would improve and strengthen the rural and agricultural economy as well as improve the US balance of trade. The infrastructure already in place for moving petroleum products can incorporate biodiesel with no major changes in equipment or procedures. Biodiesel is generally better for the environment since it is made from renewable or waste resources, is biodegradable, nontoxic and, in most instances, has lower emissions compared to petroleum diesel. It is less toxic than common table salt and biodegrades approximately four times as fast as petrodiesel.

### **Health and safety**

Biodiesel exhaust emissions have been shown to have decreased levels of polycyclic aromatic hydrocarbons (PAH) and nitrated PAH compounds to petrodiesel. PAHs have been identified as potential cancer causing compounds. In addition, breathing diesel exhaust particulate matter is also a health hazard. Since use of biodiesel, either neat or blended, reduces the levels of most emissions, there is less risk for employees working in and around running equipment. However, as

the level of biodiesel in the blend is reduced, the health and safety benefits will also be reduced.

The flash point of biodiesel is much higher than the 52°C to 66°C (125°F to 150°F) range seen for petroleum diesel. Depending on the source material, the flash point can range from 130°C to 188°C (266°F to 370°F). The elevated flash point provides an extra margin of safety in case of fuel spills and handling.

### **Renewable resource**

Petroleum-based diesel for all practical purposes is not a renewable resource and an ever shrinking amount is available. As availability decreases and demand increases, costs will dramatically increase. One way of countering this trend is to reduce dependence on petroleum and utilize fuels that are derived from renewable sources. Biodiesel can help move us in that direction as it is produced from animal fats and plant oils that can be cultivated or grown specifically for this purpose. However, current and the foreseeable future production capabilities of biodiesel fall way short of supplying the domestic demand to replace even 10% of our present diesel needs.

### **Increased cetane**

The cetane number of diesel fuel is a rating comparing a fuel's ease of combustion in a standard engine with that of a mixture of cetane and heptamethylnonane. The cetane number is the percentage by volume of cetane in the mixture that provides the same combustion charac-

teristics as the fuel being tested. The higher number, the easier the fuel is to ignite and the more uniform the energy release early in the thermo cycle. Conversely, low cetane numbers indicate a fuel that is more difficult to ignite, resulting in a delay of the onset of ignition. This delay allows more fuel to be injected before auto ignition resulting in a sharp peak in the cylinder pressure as the energy is released. This translates into difficulty in starting, engine knock or combustion roughness and excess white smoke during warm-up.

ASTM specifies petrodiesel fuel to have a minimum cetane number of 40 to provide adequate starting. The methyl esters of biodiesel contain oxygen atoms in their molecules along with some double bonds (unsaturation) between carbon atoms. The presence of the oxygen and double bonds in biodiesel increases the ease of ignition and therefore the cetane number of the biodiesel.

### **Higher fuel lubricity**

Standard industry tests for lubricity indicate a significant improvement in lubricity with neat biodiesel or when blended with petrodiesel. The National Biodiesel Board reports that even when blended at levels of less than one percent, an improvement of up to 65% can be seen. This translates into reduced wear for moving components in the fuel delivery system. Incorporating low level blends of biodiesel may help reduce potential lubricity problems associated with low sulfur diesel fuel.

### Emissions

Biodiesel fuels have been shown to reduce particulate matter (PM) hydrocarbon (HC), and carbon monoxide (CO) in gas emissions from modern diesel engines. The reduction of PM, HC, and CO is a result of improved combustion believed due to the higher content of oxygen in the fuel. Biofuels contain approximately 11% oxygen in their molecular structures. The presence of the oxygen helps the fuel to burn more completely. The amount of emissions reduction observed depends on the feedstock, engine type and the engine's oil consumption. In contrast, No. 2 diesel fuel basically contains no oxygen.

Although most exhaust emissions are reduced with the use of biodiesel over conventional diesel, the NO<sub>x</sub> emissions actually increase in many engines. Since biodiesel does not contain nitrogen, the phenomenon is not related to the fuel nitrogen content. The increase of NO<sub>x</sub> produced can vary as high as 15%, depending on the source of the biodiesel. Soybean based biodiesel produces the highest NO<sub>x</sub> increase. The 15% variability in NO<sub>x</sub> production is not uncommon within No. 2 diesel fuels meeting ASTM D 975.

A slight engine timing retard (1 to 5 degrees) can bring B100 NO<sub>x</sub> to reduced levels and even baseline diesel levels. However, retarding timing in an EPA certified engine without recertification with EPA is considered tampering and re-timing modern diesel engines is generally not a user-serviceable item.

### Tax incentives

Presently, there are no general federal incentives for using biodiesel. There are a couple of federally mandated programs (the Energy Conservation and Reauthorization Act of 1998 and Executive order 13149 - Greening the Government Through Federal Fleet and Transportation Efficiencies) that encourage use of alternative fuels such as biodiesel and some biodiesel bonds. However, these are basically small pilot programs directed at limited government fleets and are not applicable to the railroad industry. Biodiesel is not exempt from federal excise taxes and it is not exempt from state and local taxes. While there are no federal incentives for the railroad industry or general consumer to use biodiesel, there are very recent tax incentives for the producers of biodiesel. The American Jobs Creation Act of 2004 has provisions that afford income tax credits to the producers of biodiesel and other alternative fuels. The hope is that these credits will be passed on to the consumers, making the alternative fuels more cost competitive and thereby increasing their use.

### Disadvantages of biodiesel

The following is a discussion of the potentially negative characteristics of B100 biodiesel. Many of these characteristics would be lessened/diluted through the use of biodiesel blends. Still an understanding of the characteristics of the neat product lend insight into the significant differences in biodiesel and

No. 2 diesel, and therefore areas you may want to monitor should you consider use of B1000 or a biodiesel blend.

### **Cold flow properties:**

Earlier discussion indicated biodiesel, in general, has a much higher cloud point than petrodiesel. Similarly, the pour point and Cold Filter Plug Point (CFPP), two other commonly used measurements to define cold weather performance of a fuel, are also much higher for biodiesel than conventional diesel fuel.

The cloud point of B100 can be as low as  $-1^{\circ}\text{C}$  ( $30^{\circ}\text{F}$ ) for biodiesel derived from vegetable oil to as high as  $27^{\circ}\text{C}$  ( $80^{\circ}\text{F}$ ) or higher for animal fats or frying oils that are highly saturated. In comparison, typical pipeline cloud point specifications for fungible No. 2 diesel fuel is  $-9^{\circ}\text{C}$  ( $15^{\circ}\text{F}$ ) maximum.

Because of its high cloud point, use of B100 on a North American railroad in anywhere but the very south would require above and in-ground fuel systems (piping, pumping equipment and vehicles) be protected with insulation, agitation, heating systems or other measures if temperatures fall regularly below the cloud point of the fuel.

Cold flow additives (wax crystal modifiers) can be added to diesel fuel to lower the cloud point, pour point and CFPP. These additives lower the wax, pour and CFPP by modifying the wax crystal growth. B100 found in the United States cannot be effectively managed with current cold flow additives like some

petrodiesel or European rapeseed oil-based biodiesel. The U.S. oil contains too high a level of saturated compounds for most additives to be effective.

Blending biodiesel with petroleum distillate moderates cold flow problems by dilution. The blend makes the use of cold flow improver practical, since the cold flow improvers are effective in the petroleum portion of the blend. An accurate estimate of how a biodiesel blend such as B20 will perform in the winter months will require mixing the biodiesel with the winter diesel typically delivered in your area and testing the mixture.

Another alternate to achieve suitable winter characteristic in a biodiesel blend is to make the blend with No. 1 diesel, jet A or kerosene instead of No. 2 diesel. All of these materials typically have lower cloud point, pour point and CFPP than No. 2 biodiesel and can produce biodiesel blends with more favorable winter characteristics than No. 2 diesel - biodiesel blends.

No. 1 diesel, jet A or kerosene are typically more expensive and have lower BTU value than No. 2 diesel, adding both a cost penalty and energy penalty to their use. In addition, these alternatives may raise cylinder firing pressures resulting in increased bearing loadings and potential for damage. For these reasons most refiners prefer to achieve better winter characteristics through the use of less expensive cold weather additives.

### **Biodiesel solvency:**

The methyl esters that comprise biodiesel have better solvency than conventional diesel. As a result biodiesel may loosen and/or dissolve sediments left by conventional diesel in the fuel tanks and fueling systems. The result can be unexpected and contribute to premature plugging of wayside and locomotive fuel filters. Although this is shown as a disadvantage, once the cleanup is completed it becomes an advantage as the fuel system maintains the cleanliness.

The biodiesel solvency properties coupled with some of the fuels oxidation byproducts can also have a negative affect on the construction materials of the fuel filters. To maintain trouble free operation after initial clean-up, the filters should be constructed using materials suitable for use with biodiesel.

### **Biodiesel compatibility:**

B100 may soften and degrade certain types of rubber compounds found in hoses, gaskets, seals, and elastomers, glues and plastics (i.e. buna N, nitrile and natural rubber, polyethylene and polypropylene). Degradation of the elastomers may shorten the life of seals and gaskets causing leakage and failures. Some of the typical plastics, polyethylene and polypropylene, cannot be used for storing biodiesel because, over time the biodiesel will permeate the plastic. Materials such as Teflon, Viton, fluorinated plastics and Nylon have been found compatible with biodiesel. Use of elastomers that are less compatible with biodiesel can-

not be excluded, as they are generally lower cost.

B100 is not compatible with some metals. Biodiesel will form high sediment levels if contacted for long periods of time with copper or copper-containing metals (brass, bronze) or with lead, tin or zinc (i.e. galvanized surfaces). These sediment levels may cause filter plugging. Diesel systems should not use the copper-bearing metals or galvanized surfaces; however, many accessory items in the diesel fuel distribution can contain such items. Affected equipment, e.g. copper core heaters, should be replaced with aluminum, carbon steel or stainless steel.

Although compatibility issues are greater with B100, blending with petrodiesel only reduces the effects; it does not eliminate the problems. This requires the users of biodiesel to verify that the materials in contact with biodiesel are suitable for the intended use and life.

### **Energy content (versus No. 2 diesel) Fuel consumption:**

Biodiesel contains about 8% less energy per gallon than a typical No. 2 diesel; 12.6% less energy per pound. The difference in these two measurements is caused by the slightly higher density of biodiesel over diesel fuel. All biodiesels, regardless of the feedstock, provide about the same amount of energy. The lower heating values for typical fuels are:

	Btu/lb	Btu/gal
Typical Diesel No. 2	18,300	129,050
Biodiesel (B20)	18,033	128,455
Biodiesel (B100)	16,000	118,170

Fuel consumption would be expected to increase with the use of biodiesel because of its lower energy content. The amount of increase with B20 fuel is estimated to be about 2%. This increase only accounts for the change in energy content of the fuel. There is an additional expected increase in specific fuel consumption of approximately 1.5% attributed to the difference in combustion characteristics. These differences are not insignificant for a large consumer of fuel like a railroad and should be considered in the pricing and use of the biodiesel blend. Typical yearly fuel consumption for one locomotive is between 300,000 to 400,000 gallons a year. Table 3 shows the fuel consumption and projected cost difference for No. 2 diesel compared to that of B20. Table 4 shows the calculations using higher heating values.

### **Stability:**

Stability with respect to fuel generally refers to two issues: long-term stability or aging and stability at elevated temperature and/or pressure as the fuel is recirculated through an engine's fuel system. Long-term storage stability is commonly referred to as oxidative stability while thermal stability refers to the stability at elevated temperatures.

Aging of biodiesel fuel can lead to high acid numbers, increased viscosity and the formation of gums and sediments that clog filters. The points of unsaturation on the biodiesel molecule can react with oxygen; therefore, biofuels derived from more saturated fatty acids

would be expectedly more stable. The fatty acids from soybean oil are highly unsaturated and would expectedly have poor stability. Periodic monitoring of acid number and viscosity of stored biodiesel can provide some idea of whether the fuel is oxidizing.

You will find there is not a specific standard for thermal stability for B100, biodiesel or No. 1 or No. 2 diesel fuel in either ASTM D 6751 or ASTM D 975. ASTM D 975 does not suggest a thermal stability test procedure (ASTM D 6468) and limit (reflectance value 70% or more in a 90 minute test for a fuel in normal service and 80% or more in a 180-minute test for a fuel in severe service) that should provide satisfactory performance but does not go as far as to include it as part of the standard. Many railroads have adopted the ASTM D 6468 test method and suggested ASTM D 975 limits as part of their diesel fuel specification and most fuel suppliers routinely meet the specification.

ASTM D 6468 uses a reflectometer to measure the black residue formed as a fuel is subjected to very high heat. B100 forms very little black residue upon heating. It is yet to be determined whether ASTM D 6468 is an accurate means of predicting field performance problems such as fuel filter plugging, deposit formation, or injector failure with the use of biodiesel and biodiesel blends.

### **Microbial growth:**

Biodiesel contains approximately 11% oxygen by weight whereas con-

ventional No. 2 diesel fuel contains basically no oxygen. As a result of having a higher oxygen content and great unsaturation, biodiesel has more affinity for water. With the presence of water, microbial contamination of the fuel becomes a greater concern. Microbial contamination can contribute to fuel filter plugging as well as tank corrosion. Microbial contamination is a recognized concern with conventional diesel fuel and is normally controlled by either the routine draining of water from fuel storage tanks and/or the addition of biocides to the fuel. Routine removal of water that accumulates in the bottom of storage tanks is as important or more important with biodiesel as it is with conventional diesel fuel.

### **Cost**

At the time of the writing of this paper the biodiesel blends being offered to the railroads are in the order of 8 to 20 cents per gallon higher than conventional diesel fuel. Despite the higher cost, some states have passed legislation mandating the use of biodiesel blends. Understandably, the railroads have fought this legislation and are currently exempt. While the railroads would like to do their part in supporting our farm industry, reducing dependence on foreign oil and improving air quality, the cost differences between biodiesel blends and conventional diesel fuel are just too great. In particular, they are too great considering some of the potential negatives of biodiesel that may add further cost to their use. Until

biodiesel blends are, at a minimum, competitive with conventional diesel fuel, there is little incentive to their use.

### **Engine performance**

There have been no significant studies of short or long-term engine performance in medium-speed diesel engines. Most of the literature has centered on automobile, bus and truck fleets. These studies typically show that for engines designed or modified to run on biodiesel, engine performance is unaffected. The modifications typically replace components that degrade in the presence of biodiesel, (i.e. various "rubbers") with more resistive materials. However, there have also been some studies indicating potential problems associated with the use of biodiesel both neat and blended. Compared with No. 2 diesel fuel the biodiesel blends have higher viscosity, density, distillation range, lubricity, cetane number, and cloud and pour points. The blends have lower heating value, compressibility, and oxidation stability. These differences can have an effect on short and long-term engine performance and durability.

The increased viscosity and lower compressibility of biodiesel is expected to increase cylinder peak firing pressure and injector line pressure. Increased firing pressure will boost mechanical stresses that are imposed on engine components such as the fuel cams, high-pressure fuel equipment, power assemblies and bearings. Atomization of the injected fuel may be adversely affect-

ed, resulting in a reduction of the combustion and heat release rates, thereby lowering the engine fuel efficiency. The changes to the combustion rate due to energy content differences would result in late burning and an increase in pre-turbine temperatures. Increased lubricity properties of the blended fuel would result in lower wear rates of the fuel injection system components.

Based on some of the literature reviewed, biodiesel use can result in injector coking, increased intake valve deposits, increases in piston ring groove fill, ring sticking and reduced lube oil viscosity. The lower oxidation stability of the blends and differences of in-cylinder combustion may increase the oil change frequency. As the percentage of biodiesel in a blend decreases, the negative affects are lessened. The source material of the biodiesel may play a major role in any possible effects experienced. Other studies reviewed did not indicate any problems associated with biodiesel use other than solvency issues with seals.

The conflicting reports indicate additional work needs to be performed before there is a complete understanding of both the short and long-term affects. In addition and more relevant to the rail industry, is that the previous work has incorporated medium-speed diesel engines in only a limited number of the evaluations.

### **Regulatory issues:**

Recently, a few states have enacted legislation requiring use of

biodiesel or biodiesel blends for diesel equipment operating within their borders. So far the railroads have successfully avoided this requirement. However, the potential for these requirements does raise questions regarding potential regulatory conflicts. The lower energy content of biodiesel translates into reduced power output of the locomotive and any adjustment to the engine in service to compensate for such power loss may result in a violation of EPAs antitampering provision. In addition, use of biodiesel in a Tier locomotive will change the emissions characteristics, possibly putting the locomotive into a state of non-compliance due to increased NO<sub>x</sub> emissions associated with biodiesel.

Although the regulators are interested in expanding the use of alternative fuels, consideration must be given to the environmental impact and how their use complies with and affects current law.

### **EMA recommendations**

The Engine Manufacturers Association (EMA), which is an international membership organization representing the interests of manufacturers of internal combustion engines has published a "Technical Statement on the Use of Biodiesel Fuel in Compression Ignition Engines." February 2003. The following highlights some of the points of concern not previously mentioned:

- Diesel fuel injection equipment manufacturers ("FIE Manufacturers") issued a position statement

concluding that blends greater than B5 can cause reduced product service life and injection equipment failures.

- FIE Manufacturers disclaim responsibility for any failures attributed to operating their product with fuels for which the products were not designed.
- EMA members expect that blends up to a maximum of B5 should not cause engine system problems provided the biodiesel portion meets one of the current standards.

### Summary

Biodiesel appears to be on its way toward becoming a viable energy source and, at the minimum, a petrodiesel extender. Although current equipment and materials are not suitable for the use with B100, low level blends with petrodiesel (B1 to B20) do have potential, once the performance issues are fully understood and addressed. There are some noteworthy advantages to using biodiesel in reduced emissions, improved lubricity, reduced dependence on foreign oil, improving the balance of trade and stimulation of the agricultural economy. To gain acceptance with the railroads, biodiesel blends must first be cost competitive. Costs are currently 8 - 20 cents per gallon higher than conventional diesel and when coupled with the lower energy output, there is a substantial cost penalty associated with biodiesel use.

There are significant differences between biodiesel and conventional No. 2 diesel. If these differences are

not addressed through blending and/or the addition of additives, performance could be inferior to No. 2 diesel in the following areas:

- Oxidation
- Increased microbial growth
- Reduced filter life due to increased solvency of biodiesel compared to No. 2 diesel (a short term issue)
- Reduced seal life due to increased solvency of biodiesel
- Increased fuel injector and pump costs due to higher firing pressure with biodiesel
- Poorer winter performance due to higher cloud point of biodiesel

There is very limited testing or experience with biodiesel blends in the North American railroad industry. There is much more experience in Europe but mainly with automobiles, trucks and bus fleets. However, it must be noted that the base feedstock for biodiesel in Europe (rape-seed oil) is different from that used in the United States (soybean oil) and therefore European experience may not be directly applicable.

While most B5 and some B20 biodiesel blends will meet the specifications for No. 2 diesel fuel, ATSM D 975, that does not mean the biodiesel blend is adequate for use. There are unique characteristics to the manufacture of biodiesel that require additional properties be specified in the standard. Completion of ASTM specifications for B5 and B20 fuels (the likely products to be introduced to the North American railroad Industry) that recognize the unique characteristics of

biodiesel, is an absolute minimum that must be accomplished for them to be considered for use by the railroad industry.

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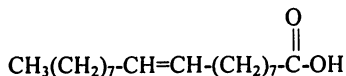
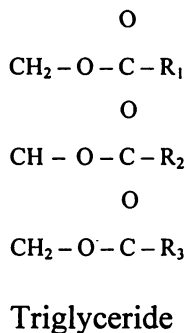
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Oleic acid - a fatty acid

Diagram 1

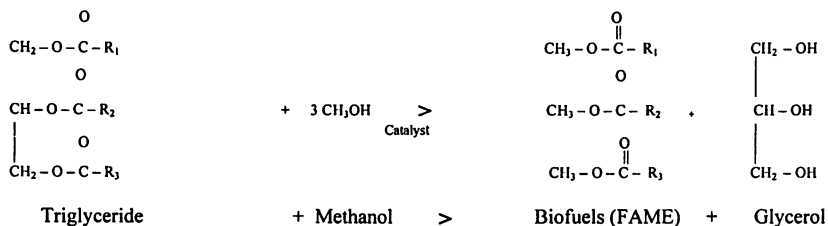


Diagram 2

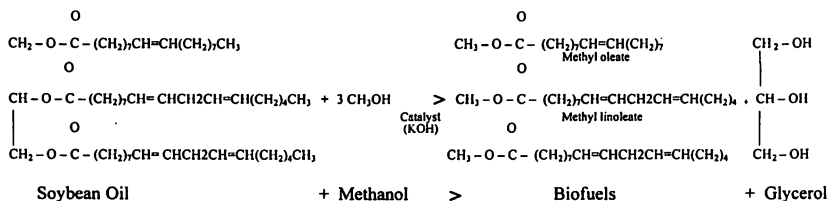


Diagram 3

Table 1

Fat or Oil	Fatty Acid Composition (Weight %)							
	Lauric acid	Myristic acid	Palmitic acid	Stearic acid	Oleic acid	Linoleic acid	Linolenic acid	Eruic acid
	0 double bond	0 double bond	0 double bond	0 double bond	1 double bond	2 double bonds	3 double bonds	1 double bond
Coconut	44 - 51	13 - 18.5	7.5 - 10.5	1 - 3	5 - 8.2	1 - 2.6		
Corn			7 - 13	2.5 - 3	30.5 - 43	39 - 52	1	
Linseed			6	3.2 - 4	13 - 37	5 - 23	26 - 60	
Olive		1.3	7 - 18.3	1.4 - 3.3	55.5 - 84.5	4 - 19		
Peanut		0.5	6 - 12.5	2.5 - 6	37 - 61	13 - 41		1
Rapeseed		1.5	1 - 4.7	1 - 3.5	13 - 38	9.5 - 22	1 - 10	40 - 64
Soybean			2.3 - 11	2.4 - 6	22 - 30.8	49 - 53	2 - 10.5	
Sunflower			3.5 - 6.5	1.3 - 5.6	14 - 43	44 - 68.7		
Tallow		3 - 6	25 - 37	14 - 29	26 - 50	1 - 2.5		

Table 2

Property	ASTM D 6751			Units	ASTM D 975	
	Test Method	Limits B100 Grade S15	Limits B100 Grade S500		Limits Grade 2-D	Test Method
Flash Point	D 93	<b>130 min</b>	<b>130 min</b>	°C	<b>52 min</b>	D 93
Water & Sediment	D 2709	0.05 max	0.05 max	% volume	0.05 max	D 2709
Kinematic Viscosity @ 40°C	D 445	<b>1.9 – 6.0</b>	<b>1.9 – 6.0</b>	mm <sup>2</sup> /s	<b>1.9 – 4.1</b>	D 445
Sulfated Ash	D 874	0.02 max	0.02 max	% mass		
Sulfur	D 5453	0.0015 max	0.05 max	% mass	0.50 max *	D 2622
Copper Strip Corrosion	D 130	No. 3 max	No. 3 max		No. 3 max	D 130
Cetane Number	D 613	<b>47 min</b>	<b>47 min</b>		<b>40 min</b>	D 613
Cloud Point	D 2500			°C		
Carbon Residue	D 4530	<b>0.05 max</b>	<b>0.05 max</b>	% mass	<b>0.35 max</b>	D 524
Acid Number	D 664	<b>0.80 max</b>	<b>0.80 max</b>	mg KOH/g		
Free Glycerin	D 6584	<b>0.20</b>	<b>0.20</b>	% mass		
Total Glycerin	D 6584	<b>0.240</b>	<b>0.240</b>	% mass		
Phosphorous Content	D 4951	<b>0.001 max</b>	<b>0.001 max</b>	% mass		
Distillation – 90% Recovered	D 1160	<b>360 max</b>	<b>360 max</b>	°C	<b>282 - 338</b>	D 86

**Table 3**

<b>Comparison of Yearly Consumption and Costs</b>				
<b>Number of Locomotives</b>	<b>Typical Consumption Using No. 2 Diesel</b>	<b>Estimated Consumption Using B20</b>	<b>Increase (2%) in Gallons of Fuel Consumed</b>	<b>Annual Cost Increase (assuming \$0.14 differential)</b>
1	300,000 to 400,000	306,000 to 408,000	6,000 to 8,000	\$840 to \$1120
100	30,000,000 to 40,000,000	30,600,000 to 40,800,000	600,000 to 800,000	\$84,000 to \$112,000
3000	900,000,000 to 1,200,000,000	918,000,000 to 1,224,000,000	18,000,000 to 24,000,000	\$2,520,000 to \$3,360,000

Table 4

		Calculated	Calculated				
LHV BTU/Lb	LHV BTU/Gal	HHV BTU/Lb	HHV BTU/Gal	% BioFuel	%Deisel	Density	Lb/Gal
15979	117093	17128	125517	100	0	0.88	7.328
16236	118513	17385	126966	90	10		7.303
16493	119933	17642	128402	80	20		7.278
16749	121354	17899	129826	70	30		7.253
17006	122774	18156	131236	60	40		7.228
17263	124194	18412	132634	50	50		7.204
17520	125614	18669	134019	40	60		7.179
17777	127034	18926	135392	30	70		7.154
18033	128455	19183	136751	20	80		7.129
18290	129875	19440	138098	10	90		7.104
18547	131295	19697	139432	0	100	0.85	7.079
		115%	111%				
		15%	11%	<-- (Diesel/B100)*100			
		3%	2%	<-- (Diesel/B20)*100			

## Appendix A

**Flash Point:** The flash point of properly prepared B100 is typically much higher than No. 2 diesel fuel. A minimum flash point of 130°C (266°F) was set to ensure excess alcohol (methanol or ethanol) from the manufacturing process is removed properly.

**Water and sediment:** Water and sediment refers to the presence of free water droplets and sediment particles. Poor drying techniques in manufacturing or contact with excessive water in transfer or storage of the biodiesel can cause the B100 to be out of specification for water content. Excess water can lead to corrosion and provides an environment for microorganisms. Excess sediment in a fuel can cause premature filter plugging as well as injector problems. Although the water and sediment standard (0.05%) for B100 is the same as that for No.2 diesel fuel, most railroads desiring long filter life have much tighter fuel specifications for water and sediment. A water content of 0.03% and particulate content of 7.00 mg/L is the current No. 2 diesel specification for one large western railroad.

**Viscosity:** Biodiesels typically have a higher viscosity than No. 2 diesel fuel. The maximum usable viscosity for an application is limited by the design of the injection system. Higher viscosity fuels can cause poor fuel combustion that leads to deposit formation as well as higher in-cylinder penetration with resultant elevated fuel dilution of the oil.

Higher viscosity fuels can also reduce the amount of injector barrel/plunger leakage which results in a slight increase in injector efficiency.

**Sulfated ash:** Ash forming material may be present in biodiesel in 3 forms; (1) abrasive solids, (2) soluble metallic soaps and (3) unremoved catalyst. The sulfated ash test measures all of these ash-forming materials. Ash-forming material can contribute to injector, fuel pump, piston and ring wear, engine deposits and filter plugging.

**Sulfur:** Sulfur is limited to reduce sulfate and sulfuric acid pollutant emissions and to protect exhaust catalytic systems when they are deployed on diesel engines in the future. Biodiesel generally contains less than 15 ppm sulfur. The ASTM test for sulfur in a biodiesel is ASTM D 5453. The ASTM D 2622 procedure used for No. 2 diesel is not suitable as the oxygen in the biodiesel interferes with the analysis and is incorrectly counted as sulfur.

**Copper strip corrosion:** This test is used to indicate the potential difficulties with copper and bronze fuel system components.

**Cetane number:** Conventional diesel in the United States has a cetane number in the range of 42-44. Higher cetane numbers ensure good cold starting properties and minimize the formation of white smoke. Highly saturated B100 such as that made from animal fats or

cooking oils can have a cetane number of 70 or higher. Common polyunsaturated fuels such as those made from soy, sunflower, corn and canola (rapeseed) oils have a cetane number around 47 or slightly higher.

Cetane number is a value determined through engine test. Cetane index, a value based on the specific gravity and distillation curve of a diesel fuel, is often used as a predictor of the the cetane number for No. 2 diesel fuel. Cetane index is not an accurate predictor for biofuels as the specific gravity and distillation curves of No. 2 diesel and biofuel are quite different.

**Cloud point:** The cloud point of biodiesel is quite high compared to conventional No. 2 diesel. The cloud point is the reason why most users of biodiesel use biodiesel blends rather than B100 biodiesel. It should be noted that D 975 does not provide a maximum specification for the cloud point but most pipeline specifications do have a maximum winter cloud point specification of  $-9^{\circ}\text{C}$  ( $+15^{\circ}\text{F}$ ).

**Carbon residue:** The carbon residue gives a measure of the carbon-depositing tendency of a fuel. With conventional fuel, the carbon residue is measured on the 10% distillation residue. Because B100 boils entirely at the high end of the diesel fuel range and at near the same temperature, it is difficult to leave only a 10% residual when distilling biodiesel. For that reason the biodiesel standard specifies the entire biodiesel sample be used

rather than 10% residual with conventional diesel fuel.

**Acid number:** For biodiesel, the acid number is primarily an indicator of free fatty acids (natural degradation products of fats and oils) and can be elevated if fuel is not properly manufactured or has undergone oxidative degradation. Acid numbers higher than 0.80 have been associated with fuel system deposits and reduced life of fuel pumps and filters.

**Total and free glycerin:** Incomplete conversion of the fats and oils into biodiesel can lead to high total glycerin. Incomplete removal of glycerin can lead to high free glycerin and total glycerin. If these numbers are too high, storage tank, fuel system and engine fouling can occur.

**Phosphorous:** Phosphorous content is limited to 10 ppm maximum in biodiesel because higher levels can cause damage to catalytic converters. Phosphorous content above 10 ppm can be present in some sources of biodiesel such as vegetable oils.

**T90 distillation specifications:** The fatty acids from which biodiesels are derived are mainly straight chain hydrocarbons with 16 to 18 carbon atoms that have close boiling temperatures. For that reason the biodiesels generally have a tight range from  $330^{\circ}\text{C}$  to  $357^{\circ}\text{C}$  ( $626^{\circ}\text{F}$  to  $675^{\circ}\text{F}$ ). An upper limit of  $360^{\circ}\text{C}$  ( $680^{\circ}\text{F}$ ) was placed in the

biodiesel specification to ensure the fuels are not contaminated with high boiling materials such as used motor oil.

## CONSTITUTION AND BY-LAWS LOCOMOTIVE MAINTENANCE OFFICERS ASSOCIATION

*Revised September 22, 2003*

### **Article I - Title:**

The name of this Association shall be the Locomotive Maintenance Officers Association (LMOA).

### **Article II - Purpose of the Association**

The purpose of the Association, a non-profit organization, shall be to improve the interests of its members through education, to supply locomotive maintenance information to their employers, to exchange knowledge and information with members of the Association, to make constructive recommendations on locomotive maintenance procedures through the technical committee reports for the benefit of the railroad industry.

### **Article III - Membership**

**Section 1** - Railroad Membership shall be composed of persons currently or formerly employed by a railroad company and interested in locomotive maintenance. Membership is subject to approval by the General Executive Committee.

**Section 2** - Associate Membership shall be composed of persons currently or formerly employed by a manufacturer of equipment or devices used in con-

nection with the maintenance and repair of motive power, subject to approval of the General Executive Committee.

Associate members shall have equal rights with railroad members in discussing all questions properly brought before the association at the Annual Meeting, and shall have the privilege of voting or holding elective office.

**Section 3** - Life membership shall be conferred on all Past Presidents. Life membership may also be conferred on others for meritorious service to the Association, subject to approval by the General Executive Committee.

**Section 4** - Membership dues for individual railroad and associate membership shall be set by the General Executive Committee and shall be payable on or before September 30th of each year. The membership year will begin on October 1 and end September 30. Members whose dues are not paid on or before the opening date of the annual convention shall not be permitted to attend the annual meeting, shall not be eligible to vote and/or shall not be entitled to receive a copy of the published Pre-Convention Report or the Annual Proceedings of the annual meeting. Failure to comply will result in loss of membership at the end of the current year. Life members will not be required to pay dues, but will be entitled to receive a copy of the Pre-Convention Report and Annual Proceedings.

## **Article IV - Officers**

**Section 1** - Elective Officers of the Association shall be President, First Vice President, Second Vice President and Third Vice President. Each officer will hold office for one year or until successors are elected. In the event an officer leaves active service, he may continue to serve until the end of his term, and, if he chooses, continue to serve as an executive officer and be allowed to elevate through the ranks as naturally occurs, to include the office of President.

**Section 2** - There shall be one Regional Executive officer assigned to oversee each technical committee. Regional Executives shall be appointed from the membership by the General Executive Committee for an indefinite term, with preference given to those having served as a Technical Committee Chairperson. A Regional Executive who leaves active service may continue to serve as such, and shall be eligible for nomination and election to higher office.

**Section 3** - There shall be a General Executive Committee, composed of the President, Vice Presidents, Regional Executives, Technical Committee Chairpersons, and all Past Presidents remaining active in the Association.

**Section 4** - There shall be a Secretary-Treasurer, appointed by, and holding office at the pleasure of the General Executive Committee, who will contract for

his or her services with appropriate compensation.

**Section 5** - All elective officers and Regional Executives must be LMOA members in good standing. (See Article III, Section 4.)

## **Article V - Officer, Nomination and Election of**

**Section 1** - Elective officers shall be chosen from the active membership. A Nominating Committee, composed of current elective officers and the active Past Presidents, shall submit the slate of candidates for each elective office at the annual convention.

**Section 2** - Election of officers shall be determined by a voice vote, or if challenged, it shall require show of hands.

**Section 3** - Vacancies in any elective office may be filled by presidential appointment, subject to approval of the General Executive Committee.

**Section 4** - The immediate Past President shall serve as Chairman of the Nominating Committee. In his absence, this duty shall fall to the current President.

## **Article VI - Officers - Duties of**

**Section 1** - The President shall exercise general direction and approve expenditures of all affairs of the Association.

**Section 2** - The First Vice President, shall in the absence of the President, assume the duties of the President. He shall additionally be responsible for preparing and submitting the program for the

Annual Meeting.

The Second Vice President shall be responsible for selecting advertising. He will coordinate with the Secretary-Treasurer and contact advertisers required to underwrite the cost of the **Annual Proceedings**.

The Third Vice President will be responsible for maintaining a strong membership in the Association. He will ensure that membership applications are properly prepared and distributed, monitoring membership levels and reporting same at appropriate time to the General Executive Committee.

The Vice Presidents shall perform such other duties as are assigned them by the President.

**Section 3** - The Secretary-Treasurer shall:

A. Keep all the records of the Association.

B. Be responsible for the finances and accounting thereof under the direction of the General Executive Committee.

C. Perform the duties of the Secretary of the Nominating Committee, and General Executive Committee, without vote.

D. Furnish surety bond in amount of \$5000 on behalf of his/her assistants directly handling Association funds. Association will bear the expense of such bond.

**Section 4** - The Regional Executive officers shall:

A. Participate in the General Executive Committee meetings.

B. Monitor material to be pre-

sented by the technical committees to ensure reports are accurate and pertinent to the goals of the Association.

C. Attend and represent LMOA at meetings of their assigned technical committees.

D. Promote Association activities and monitor membership levels within their assigned areas of responsibility.

E. Promote and solicit support for LMOA by helping to obtain advertisers.

**Section 5** - Duties of General Executive Committee:

A. Assist and advise the President in long-range Association planning.

B. Contract for the services and compensation of a Secretary-Treasurer.

C. Serve as the Auditing and Finance Committee.

D. Determine the number and name of the Technical Committees.

E. Exercise general supervision over all Association activities.

F. Monitor technical papers for material considered unworthy or inaccurate for publication.

G. Approve topics for the Annual Proceedings and Annual Meeting program.

H. Approve the schedule for the Annual program.

I. Handle all matters of Association business not specifically herein assigned.

**Section 6** - The General Executive Committee is entrusted to handle all public relations deci-

sions within LMOA and coordinated associations with confidentiality.

## **Article VII - Technical Committees**

The technical committees will consist of:

**Section 1** - A chairperson, appointed by the President and approved by the General Executive Committee.

**Section 2** - A vice chairperson, selected by the chairperson and approved by the President.

**Section 3** - Committee members, selected as follows:

A. Representatives of operating railroads and regional transit authorities submitted by their Senior Mechanical and Materials Officers and approved by the President of LMOA.

B. Representatives of locomotive builders designing and manufacturing locomotives in North America.

C. The Fuel and Lube Committee will include members from major oil companies or their subsidiaries as approved by the General Executive Committee.

D. At the direction of the General Executive Committee, non-railroad personnel may be allowed to participate in committee activities.

**Section 4** - All individuals who are on technical committees must be LMOA members in good standing. (See Article III, Section 4).

**Section 5** - Subjects for technical

papers will be selected and approved by the General Executive Committee.

## **Article VIII - Proceedings**

**Section 1** - The Locomotive Maintenance Officers Association encourages the free interchange of ideas and discussion by all attendees for mutual benefits to the railroad industry. It is understood that the expression of opinion, or statements by attendees in the meeting, and the recording of papers containing the same, shall not be construed as representations or statements ratified by the Association.

**Section 2** - Those present at any meeting called on not less than thirty days advance written notice shall constitute a quorum.

## **Article IX - Rules of Order**

The proceedings and business transactions of this Association shall be governed by Roberts Rules of Order, except as otherwise herein provided.

## **Article X - Amendments**

The Constitution and By-Laws may be amended by a two-thirds vote of the active members present at the Annual Meeting.

**DIESEL MECHANICAL MAINTENANCE COMMITTEE  
TWENTY-FOUR YEAR INDEX**

**2004**

1. GE Evolution Series-Maintenance and Reliability
2. EMD 70ACe and SD70DC-Tier 2 Locomotive Models-Mechanical Maintenance Enhancements
3. Best Practices Series-For Regional and Shortline Railroads-Managing Locomotive Wheel Wear
4. Maintenance Savings - Mother/Daughter Units

**2003**

1. Training 60/30 Impact Now & Beyond
2. Condition Based Maintenance, Practical Approaches and Techniques

**2002**

1. Detrimental Effects of Locomotive Engine Idling
2. Emissions Standard Compliance for the GE Dash 8 Locomotives
3. Tier 0 Emissions Compliance for the GE Dash 8 Locomotive
4. Locomotive Inspection Training - A Preview of CFR 229/238
5. Computerized Record Keeping to Improve Performance and Reduce Maintenance Expense for Shortline and Regional Railroads

**2001**

1. Troubleshooting Electronic Fuel Injection on GE Locomotives
2. Troubleshooting Electronic Fuel Injection-EMDEC Electro Motive Division Two-Stroke Engine
3. How to Maintain ALCO Locomotives in the 21st Century
4. Catastrophic Engine Failures: Shortlines & Regionals (Best Practices)
5. Are We Ready for Reliability-Centered Maintenance?

**2000**

1. 2000 Emissions Review - GE Perspective
2. 2000 Emissions Review - EMD Perspective
3. EMD Diesel Engine Crankshaft Main Bearings Edge-Load Condition (Description, Detection and Resolution)
4. 2000 - LMOA Best Practice Series: Locomotive Truck Overhaul Procedures

**1999**

1. Vibration Analysis
2. EMD Power Assemblies Change Out Practices for Regional and Shortline Railroads
3. Improved Access to GE7FDL Engine Intake Manifold for Cylinder Inlet Port Cleaning
4. What's Ahead in Plastics for Locomotive Applications
5. Cast Iron, Composition Brake Shoe Arrangements vs. Type-J Relay

**1998**

1. LMOA Best Practices Series: GM Engine Crankcase Pressure Troubleshooting
2. Union Pacific's New EMD Diesel Engine Rebuild Line At Downing B. Jenks Locomotive Facility-No. Little Rock, Arkansas
3. GE Turbo Rebuild Procedures
4. Mechanical Impact of Locomotive Emissions Regulations
5. Locomotive Engine Bearing Developments

**1997**

1. LMOA Best Practices - GE Water Leaks
2. Locomotive Update - MK 1200G LNG Powered Switcher
3. Proper Use of Gaskets and Seals

**1996**

1. Air Brake Trouble Shooting-Where We Are Now

- 2. Best Practices - Internal Water Leaks on EMD Locomotives
- 3. Best Practices - Oil Out Stack

**1995**

- 1. General Electric New 7HDL 6000 HP Diesel Engine
- 2. LMOA Best Practices Series - Low Oil Pressure Trouble-shooting Procedures for EMD Turbocharged Locomotives
- 3. How Can a Regional or Shortline Justify a Wheel Truing Machine?
- 4. EMD SD60M Natural Gas Locomotive Development

**1994**

- 1. Electronic Fuel Injection.
- 2. ICAV - The Physical Affects on Instantaneous Crank Shaft Angular Velocity Technology
- 3. Maintenance Practices Comparison Between Regionals and Class I Railroads
- 4. Amtrak Document Management.

**1993**

- 1. EMD's Three-Axle Radial Steering Truck
- 2. The Natural Gas Locomotive at BN RR
- 3. Locomotive Waste Oil Retention
- 4. Fragmented Maintenance

**1992**

- 1. Mechanical Quality Progress Developing on Major Railroads.
- 2. Coal Fuelled Diesel Locomotive Development.
- 3. 18:1 Upgrade for the 645E Engine
- 4. Automatic Stop and Start Control System
- 5. Acquiring Locomotives for Regionals and Shortlines

**1991**

- 1. Recommended Practices for upgrading 567 to 645 Design.
- 2. Conversion of SD40 Locomotives to SD 40-2 on CSX
- 3. Update: Diesel Engine Emission Controls
- 4. Stationary and Dynamic Test Procedure for Locomotive Fuel Efficiency Measurement

- 5. Personnel training on New Technology.

**1990**

- 1. Caterpillar Power in Remanufactured Locomotives.
- 2. The EMD 710G3A Engine
- 3. Improving Performance of Traction Motor Friction Suspension Bearings.
- 4. Fluid Leaks on GE 7FDL Engine.
- 5. Rebuild of the EMD F3B Fuel Injector.

**1989**

- 1. Wheel Axle Gear Wear/Impact on Traction Motor Life
- 2. 710 Engine - Operational and Overhaul Update
- 3. GE Power Assembly Improvements on Welded Head-to-Liner
- 4. Assembly Rework Procedures.
- 5. EMD Engine Oil Leaks. Secondary Air Filtration - Barrier vs. Impingement

**1988**

- 1. Low-idle Operating Costs vs. Fuel Savings.
- 2. Rebuilding GE's EB Liner
- 3. The Extended Maintenance Truck
- 4. Flange Lubricator Update
- 5. Permaspray II - Cylinder Liner

**1987**

- 1. EMD Water Pump Rebuilding
- 2. On Board Flange Lubricator
- 3. Gear Case, Bull Gear and Pinion Gear Longevity in the 1980's - Gear Cases - Canadian National Experience.
- 4. Maintenance of Locomotive Fueling Systems for a Spill Free Operation

**1986**

- 1. Rebuild of Valve Bridge Assemblies
- 2. Update of New Locomotive Service Problems, EMD and GE Effecting Quality Performance
- 3. Chromium Plating and Its Uses
- 4. Development of a New Diesel Engine for Heavy-Duty Locomotive Service

**1985**

1. Procedures for Storing Serviceable Locomotives for Quality Performance
2. New Locomotive Service Problems, EMD and GE
3. 92 Day Service Requirements: EMD, GE and Bombardier

**1984**

1. Mechanical Aspects of New Locomotive Designs
2. Maintenance of Locomotive Components

**1983**

1. Leaks: Cooling Water, Lube Oil, Fuel Oil and Air
2. Torquing Recommendations.
3. Update on Fuel Efficient Locomotives
4. Radiator Screens
5. Alternate Starter Systems

**1982**

1. Fuel Conservation - Effects on Maintenance
2. Fuel Conservation - What It Costs.
3. Diesel Fuel Receipt and Disbursement
4. Turbochargers

**1981**

1. Running Gear
2. Filtration
3. FRA Rules
4. Follow-up on Previous Topics

**DIESEL MATERIAL CONTROL COMMITTEE  
 TWENTY-FOUR YEAR INDEX**

**2004**

1. Milk Run: Norfolk Southern's Dedicated Locomotive Parts Shipping System

**2003**

1. Just in Time Delivery - The Juniata - Shop Material Control Program
2. The Continuous Improvement Approach

**2002**

1. "Mentored Champion Process" - CSX Supply and Service Management

**2001**

1. RAILMARKETPLACE.COM - The Industry's Market Exchange

**2000**

1. GE Global eXchange Services
2. My.SAP.Com

**1999**

1. Composite Floors and Doors for Locomotives
2. Packaging Standards

**1998**

1. Tighter is Not Better
2. Are Vending Machines the New Wave for Safety Items?

**1997**

1. Raising Our Standards for Safety
2. The Rail Industry's Electronic Parts Catalog Exchange Standard (EPCES) - A Better Way

**1996**

1. Technology Transfer-The Hot Process of the 90's-Condition Based Maintenance
2. Warehouse Automation

**1995**

1. Warranty and Reliability Management
2. Railroad Industry Group (RIG)

Exchange Standard for Parts Catalog Information

**1994**

1. Material Consignment
2. The Next Step in Electronic Information Management - Interactive Technical Manuals.
3. Electronic Catalog Alternatives.

**1993**

1. Technology Transfer
2. Electronic Cataloging from a Material Perspective
3. Computerized Reordering from the Mechanical Employee's Point of View

4. Electronic Catalogues: OEM /Supplier Point of View

**1992**

1. Warranty Overview and Issues
2. Recycling - 1992
3. Bar Coding

4. Material Packaging

**1991**

1. The World of Recycling
2. Problems with Solution
3. Problems with Opportunities

**1990**

1. Waste Minimization.
2. Hazardous Materials End Cost
3. The Role of the Suppliers

**1989**

1. Packaging and Containerization for Today's Railroad.
2. Innovations in Material Distribution Resulting from Shop Consolidations.
3. Outsourcing! Does Anyone Really Understand the Difference Between UTEX and Repair and Return and the Affect on the Budget?
4. "Stuff" Happens! - A Skit About the Necessity of Feedback from Suppliers - Suppliers to the end

User

**1988**

1. Communication - The Vital Link in Materials Acquisition
2. Quality Assurance Through Communications and Feed-back
3. Paperless Requisitions
4. A Practical Application of Bar Coding in the Railroad Industry

**1987**

1. Suppliers Selection for Component Failure Analysis
2. Vendor Performance or Service Level
3. Bar Codes
4. Bar Coding - Railroads
5. Material Handling Innovations by the Airline Industry

**1986**

1. The In-House Electronic Requisition System
2. Electronic Data Interchange.
3. RAILING and Electronic Purchasing
4. Quality Evaluation of Material Sourcing Decisions

**1985**

1. Evaluating Locomotive Maintenance Projects
2. Reconditioning Material: In-House vs. Vendo
3. Identification and Disposition of Surplus Material
4. Cost of Carrying Surplus
5. Evolution and Future Directions of Material Handling Equipment in Railroad Use

**1984**

1. Bar Coding of Material
2. Forecasting Material Requirements
3. a. Fuel Security - Are You Getting What You Pay For?

b. Fuel Oil Is Expensive

4. Pros and Cons of Material Purchasing Contracts (Single Source - Just In Time Inventory)

**1983**

1. Improved Locomotive Productivity Through Computerized Data
2. Inbound Material Inspection
3. Minimize Maintenance Cost Through Material Management Systems
4. New Ideas In Material Storage Containers

**1982**

1. Use of kits in locomotive maintenance
2. Cost effective methods of shipping material from vendors.
3. Union Pacific's Component Inventory Maintenance System (CIMS).
4. Advantages of using shipping containers

**1981**

1. Disposal of Unserviceable Component Parts: What is the Most Profitable Method?
2. Innovations in Stores Material Handling, Via Computer Technology
3. Locomotive Held for Material: an Update for the 80's
4. The Best Approach to Procuring Material; New, UTEX, Repair and Return or Shop Repair

## SHOP EQUIPMENT AND PROCESSES COMMITTEE TWENTY-FOUR YEAR INDEX

### 2004

1. Under the Hook Lifting Devices
2. Sanding in the Railroad Industry- Part III - A Gentle Answer for an Abrasive Situation

### 2003

1. Locomotive Shop Support Systems and Equipment
2. Hand Tools - An Ergonomic Update
3. Locomotive Lifting Systems

### 2002

1. NOTE: PAPER ON LIFTING SYSTEMS WAS PRESENTED BY RON BEGIER OF PORTEC AT THE 2002 CONVENTION; HOWEVER IT DID NOT APPEAR IN PUBLICATION - WILL APPEAR IN THE 2003 PROCEEDINGS PUBLICATION

### 2001

1. Standing in Railroad Industries - Part II - How to Specify Reliable and Safe Sanding Systems

### 2000

1. The Tandem Wheel Truing Machine at Amtrak's Ivy Shop
2. Shop Talk 2000: Fall Protection Technology
3. Sanding in the Railroad Industry

### 1999

1. Increasing Diesel Shop Capacity
2. Conrail-Cold Asphalt Processing of Environmental Waste Sand and Sludge
3. Dry Ice Cleaning of GE Intake Ports
4. AAR-LFIS No Spill Fueling System

### 1998

1. Smoke Opacity Testing-Emission Detection Equipment and its Use
2. Hydraulic Tensioning Tools and its Use
3. High Speed Portable Align Boring Series
4. Locomotive Mobile Servicing

### 1997

1. Wheel Truing as Preventive Maintenance
2. Conrail-Selkirk Diesel Terminal Wastewater Treatment Facility Recent Environmental Improvements

### 1996

1. Locomotive Painting
2. Drop Table Tooling for New EMD and GE Locomotives

### 1995

1. Pre-Maintenance Inspection
2. Railroad Turntable Modification
3. Mobile Locomotive Service Vehicle

### 1994

1. Electronic Fuel/Unit Injection Tooling.
2. Locomotive Roller Support Bearing Tooling.
3. Fall Protection and Man Lifts.
4. Locomotive Washing Systems.

### 1993

1. Dynamic Balancing for GE Dash 8 Model Locomotives
2. Air Compressor Automated Station
3. Ergonomics in the Work Place
4. Hydraulic Traction Motor Shimming Table

### 1992

1. Automated Test and Production Equipment
2. Safety Corrective Action Team
3. Automated Locomotive Wheel Shop
4. Cleaning and Surface Pre-paration with Sodium Bicarbonate Based Abrasive Blasting
5. Trainline Continuity Tester
6. BN - Railroad Power Assembly Shop of the 1990's

### 1991

1. Economic Separation of Emulsified Oil from Waste Water Using Ultra Filtration Membranes

2. EMD Cylinder Head Valve Seat Machining
3. Automated Barring Over Machine for EMD Diesel Engines
4. New Equipment for Testing EMD Engine Protectors
5. Compressed Air for Railroad Facilities Issues and Solutions to Achieve Clean, Dry, Oil Free Air

**1990**

1. EMD Valve Bridge Machine
2. GE Traction Motor Roller Suspension Bearing Replacement Equipment and Procedure.
3. Locomotive Component Replacement Forklift Attachment.
4. Locomotive Sanding, Fueling and Drop Tables.
5. Hazardous Waste Disposal

**1989**

1. Automated Locomotive Wheel Shop
2. Laser Guided Material Handling Vehicles
3. Bulk Rail Lubrication Storage & Fill Systems
4. Pilot Plate Straightening Equipment

**1988**

1. Fuel Management Control Systems
2. Locomotive Mounted Rail Lubrication Fill Systems.
3. Comparison of Shop Air Compressors
4. Locomotive Toilet Servicing Equipment
5. Innovations in Blue Flag and Derail Protection

**1987**

1. Modern Servicing Facility for Improved Reliability and Availability
2. New Developments in GE Tools.
3. Implementation of a Quality Process
4. A Quality Traction Motor Shop.
5. Wheel Truing Machine Technology

**1986**

1. Robotics Update 1986 - Now What?
2. CNC Machine Tools
3. A New GE Power Assembly Area
4. Locomotive Wash System - 1986

**1985**

1. Computer-Assisted Preventative Maintenance
2. New Tools for Material Handling and Overview of Balancing Technology
3. Effect of Governmental Regulations on Locomotive Finishing

**1984**

1. Shop Tools.
  - A. New Tools
  - B. Shop-Made Tools
2. Traction Motor Shop Equipment Up-Date
3. Hazardous Waste Handling and Disposal

**1983**

1. Locomotive Maintenance Using a Production Line Process
2. Shop Tools to Increase Productivity and Improve Quality.
3. Dynamic On-Line Performance of Locomotives Without On-Board Tele-Metering
4. Management in Action
5. New GE Training Center
6. Welding Qualifications

**1982**

1. Tools
2. Rebuild line for EMD turbochargers
3. Air brake equipment line
4. Industrial robots
5. Automated machines
6. Safety related items and equipment

**1981**

1. Training Aids.
2. Testing Devices Inspired by New FRA Laws
3. Tools and Training for Productivity
4. Changes to Shop Facilities Required by Newly Adopted EPA

& OSHA Regulations

5. Tour through Conrail Altoona Shop
6. Supply/Service Facilities
7. GE Assembly Shop

## DIESEL ELECTRICAL MAINTENANCE COMMITTEE TWENTY-FOUR YEAR INDEX

### 2004

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

### 2003

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

### 2002

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

### 2001

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

### 2000

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

### 6. An Alternate Adhesion System

### 1999

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

### 1998

1. Locomotive Troubleshooting Assistant
2. Locomotive Electronic Brake Maintenance
3. SD70MAC Capacitor Discharge Procedure
4. Power Savings for Electrical Locomotives
5. Auto Stop/Start and Layover Systems

### 1997

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

### 1996

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

### 1995

1. Canadian National Battery Water Usage
2. Remote Diagnostics-Radio Download
3. Programmed Preventive Maintenance
4. Commutation Monitoring in

- Locomotive DC Traction Motors
5. The EMD Diesel Engine Control (EMDEC) System

**1994**

1. Safety First - Video on Electrical Safety
2. Locomotive Health Monitoring Systems
3. Event Recorder Update
4. SD60 Dynamic Brake Improvements

**1993**

1. Automatic Engine Shutdown and Restart System
2. Layover Systems/Standby Power Systems
3. CN North America - Electronic Temperature Control
4. Speed Sensing Devices
5. Adhesion Alternative
6. Modern Tooling Update

**1992**

1. Nickel-Cadmium Batteries as an Alternative
2. Overview of Locomotive Microprocessor Based Controls
3. Locomotive Air Conditioning
4. Testing Traction Alternator Fields on EMD Locomotives
5. Flange Lubricators

**1991**

1. Locomotive Rebuilding - Something Old - Something New. Standardization of Electrical Equipment
2. Locomotive Batteries
  - a. Storage Handling Procedures
  - b. Recommended Maintenance Procedures
  - c. Recommended Repair Procedures
3. Amtrak's AC Traction Locomotives
4. Modern Tooling for Electricians Recorders
3. Why Can't We Have One Central Computer?
4. EPA and Regulation Driven Cleaning

**1990**

1. Modern Tooling of Electrical

## Troubleshooting

2. Maintaining Solid State Event Recorders
3. Why Can't We Have One Central Computer?
4. EPA and Regulation Driven Cleaning

**1989**

1. Modern Tooling for the Troubleshooting Electrician: a) test meters available (single function); b) test meters available (multiple functional); c) analysis and diagnostic tools
2. Sound Electrical Repairs and Practices for: a) traction motors; b) grids and fans; c) wire and cable solderless termination
3. Guidelines for Preparing Electricians for the 1990s

**1988**

1. Utilizing Magnetic Tape Event Recorders for Locomotive Maintenance
2. Solid State Locomotive Data Recorder
3. Improved Utilization of GE DASH 8 Data Recording Systems
4. Locomotive Health Data and Its Uses To The Railroad
5. Improved Data Acquisition From EMD's 60 Series Display Computer

**1987**

1. Proper Maintenance of Electrical Fuel Savings Options
2. Preliminary Report on AAR Traction Motor Study

**1986**

1. Cleaning, Handling & Storage of Electrical Equipment
  - A. Solid State Components
  - B. Rotating Equipment
2. Qualification of Locomotive Power plants through self load

**1985**

1. Locomotive Microprocessor Technology in Retrospect
2. Dynamic Brake Protective devices and Troubleshooting EMD-2 and GE-7 Locomotives
3. Indicators and Recorders for Locomotive Retrofit Application -

Fuel, Speed, Power and Selected  
Events

**1984**

1. On-Board Diagnostics
2. GE's **CATS** (Computer Aided Troubleshooting System)
3. Fuel Conservation Through
4. Electrical Modifications
5. Performance of Locomotives After Storage

**1983**

1. Ground Relay Trouble Shooting
2. Specification for remanufactured D87 Traction Motor Frames (Using D-77 Armature Coils)
3. Locomotive Storage (Electrical)
4. Water Cooling and Refrigerating Methods for Locomotive Cab Application

**1982**

1. Tests on Traction Motors
2. Transition Trouble-Shooting
3. Onboard Diagnostic Systems
4. Starting Systems

**1981**

1. Evaluation of Improved Test Methods
2. Teflon Bands
3. New Generation Locomotives
4. Electrical Troubleshooting
5. Batteries and Charging Systems
6. Troubleshooting EMD AC Auxiliary Generator System
7. Selection of Locomotives for Major Locomotive Overhauls

## NEW TECHNOLOGIES COMMITTEE TWENTY TWO-YEAR INDEX

### 2004

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

### 2003

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

### 2002

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

### 2001

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

### 2000

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

### 1999

1. Locomotive Filtration-Where are

We Going?

2. EMD Markets a New Line of Switchers

### 1998

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

### 1997

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

### 1996

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

### 1995

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

### 1994

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

### 1993

1. New Technology to Solve Old Problems

2. Developments in Off-Shore Technology
  3. Updates on AC Traction Developments
- 1992**
1. Talking to the "Smart" Locomotive
  2. Cab Noise Abatement
  3. Electronic Management of Locomotive Drawings
  4. Update on High Productivity Integral trains
  5. AC Traction - A New Development
- 1991**
1. Locomotive Cab Integration and Accessory Management
  2. Improvements in Locomotive Adhesion Performance
  3. The Role of Duty cycles in Locomotive Fuel Consumption.
  4. What's New in Gadgets and Black Boxes: What do our Locomotives Really Need?
  5. Failure Analysis
- 1990**
1. Motor Driven Air Compressors for Diesel-Electric Locomotives
  2. Locomotive Cab (HVAC) Heating, Ventilation and Air Conditioning Systems
  3. Effect of Technology on Standardization of Cab Control Equipment
  4. Locomotive Durability, Reliability and Availability - Understanding Your Abilities
- 1989**
1. A Rational Approach to Testing Locomotive Components
  2. New Developments in Locomotive Cab Design
- 1988**
1. Amtrak F69 PH AC Passenger Locomotives
2. New Component Developments Retrofittable to Older Model Locomotives
  3. Locomotive Applications of Caterpillar Engines
  4. Wheelslip Control for Individual Axles
- 1987**
1. Electronic Fuel Injection Systems
  2. Update on Electronic Governors
  3. Recent Advances in Steerable Locomotive Trucks - the E.M.D. 4 Axle, 4 Motor HT-BB Articulated Truck
  4. Converting an F40 Locomotive to A.C. Traction
- 1986**
1. Future Train Control Systems
  2. Bringing Future Train Control Systems Back to Earth
  3. Low Maintenance Locomotive Batteries
  4. Electronic Engine Control Systems
- 1985**
1. The Sprague Clutch for E.M.D. Turbocharged Engines
  2. A.C. Traction Locomotives Update
  3. Natural Gas Locomotive Update
  4. Ceramic Coated Engine Components
  4. Locomotive Cab Developments
- 1984**
1. G.E. Dash 8 Locomotives
  2. E.M.D. 50A Series Locomotives
  3. Natural Gas Locomotives
  4. Appraisal of the A.C. Traction Locomotive
- 1983**
1. Microprocessors for Locomotive Control and Self Diagnosis.

2. Locomotive Fuel Tank Gauges
3. Locomotive Aerodynamics
4. Bombardier HR 616 Locomotive
5. Missouri Pacific - Phase III  
Locomotive Heavy Repair Facility,  
N. Little Rock, Arkansas

## FUEL, LUBRICANTS AND ENVIRONMENTAL COMMITTEE TWENTY-FOUR YEAR INDEX

### 2004

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

### 2003

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

### 2002

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

### 2001

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

### 2000

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

### 1999

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

### 1998

1. Safety and Chemical Cleaners

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

### 1997

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

### 1996

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

### 1995

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

### 1994

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

### 1993

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

## 3. Bioremediation

**1992**

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

**1991**

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

**1990**

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

**1989**

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

**1988**

1. Used Oil Analysis and Condemning Limits
2. Review of A.A.R. Procedure RP - 503, "Locomotive Diesel Fuel Additive Evaluation Procedure"
3. Update on Improved Oils - Multigrade
4. Wheel Flange Lubrication Update - Lubricants Being Used
5. Survey of Disposable Practices or

Locomotive Engine Lube Oil and Lube Oil Filters

6. Speaker on Overview of Environmental Requirements for The Use of Petroleum Products in The Railroad Industry - Peter Conlon - AAR

**1987**

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

**1986**

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

**1985**

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

**1984**

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

**1983**

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

**1982**

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

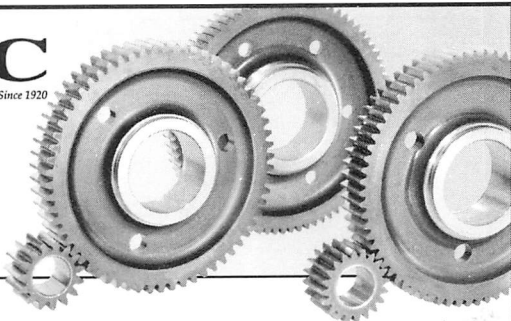
**6. Traction Motor Gear Case Seals****1981**

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

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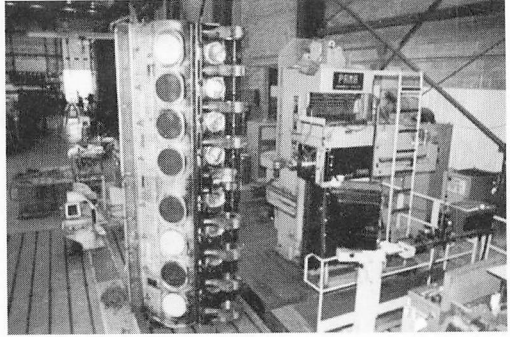
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