Advanced Emission Reduction Technologies for Locomotives:

Fuels & Lubes

by

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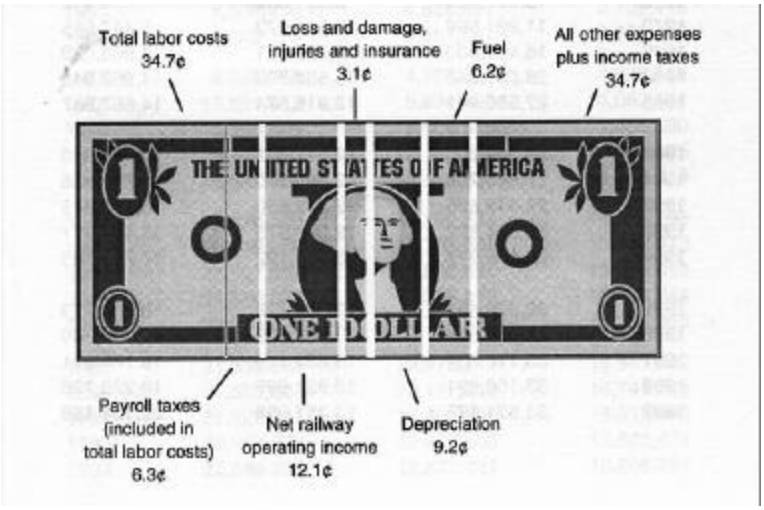
Railroad Energy Consumption

* 1999 Class I Railroads:
  - » 20,254 Locomotives
  - » 3.75 x10^9 Gallons Diesel Fuel Consumed
  - » = 185,120 gallons/year/locomotive
  - » Average Cost of $0.56 / gal

Source: AAR Railroad Facts 2000

RAILROAD REVENUE DOLLAR - 1999



Source: AAR Railroad Facts 2000

Fuels & Lubes Overview

* **Fuel-Saving Devices & Additives**
* Brief review of previous work
* Recent fuel-effect studies
* Lubricating Oil Issues
* Future research areas

Fuel Saving Devices & Additives

* AAR Recommended Practice RP-503 "Locomotive Diesel Fuel Additive Evaluation Procedure"
* Transport Canada & ESDC "Simplified Fuel Additive Test"
* Tampering Provisions in EPA Locomotive Rule
* EPA-Required Registration of Fuels and Fuel Additives (211b)

AAR Recommended Practice-503

* Voluntary Procedure
* Phase I: Analyze Fuel Properties
* Phase II: Single-Cylinder Cat 1G2
  - » A screening test to make sure the additive/device does not harm the engine - protects the more expensive locomotive test engines
* Phase III: EMD 2-567C Engine (fuel economy and exhaust emissions)
* Phase IV: EMD 12-645E3B or GE 127FDL fuel economy and exhaust emission tests
* RP-503 needs to be update to reflect EPA 40CFR92 locomotive exhaust emission procedures and requirements

* AAR RP-503 SwRI contact = John Hedrick (210) 522-2336
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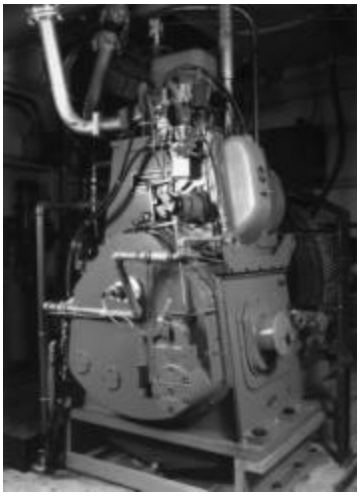
Simplified Fuel Additive Test

* SFAT - Simplified Fuel Additive Test
* Funded by the Transport Development Center of Transport Canada
* Work performed by Engine System Development Center (ESDC) in Montreal
* Based on Alco/Bombardier 1-251
* Goal is to develop a less-expensive alternative to the AAR RP-503



EPA 211(b)

* Sections 211(b) and 211(e) of the Clean Air Act require registration of motor vehicle fuels and fuel additives with the EPA
* 40 CFR Part 79 -- Registration of Fuels and Fuel Additives
* Applies to On-Highway Motor Vehicles
* List of registered F/FA is available on EPA's web page: http://www.epa.gov.oms.regs/fuels/additives/web-dies.txt

EPA Locomotive Rule - Tampering

* Using a fuel additive or "fuel saving device" on a EPA-certified locomotive may constitute "tampering" under §92.1103
* If the additive or device contributes to the increase in emissions of a regulated pollutant, it is tampering…. "Subject to a civil penalty of not more than $25,000 for each violation"
* Make sure you have a "reasonable basis" to believe that you will not increase ANY of the regulated emissions before you use a product.

Questions: Fuel Saving Additives/Devices

* Is it registered with EPA under 211(b)?
  » Not a requirement, just a question.
* Has the product been evaluated using the AAR RP-503 procedure?
* Do you have a "reasonable basis" to believe that use of the additive or device will not constitute tampering under the EPA locomotive regulations?

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1972 - "Back to the Future"

* NOx reduction studies on EMD 2-567 for DOT & EPA (ASME 74-DPG-14)

* Retarded timing
* EGR (hot & cooled)
* Water Injection
* Boost air bleed

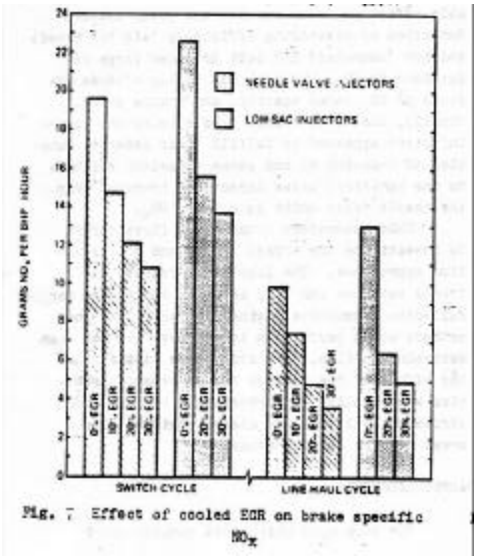
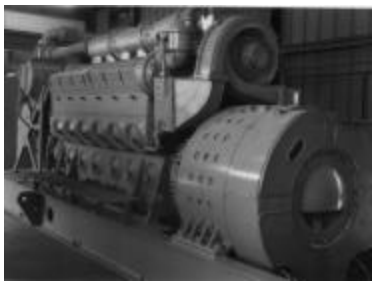


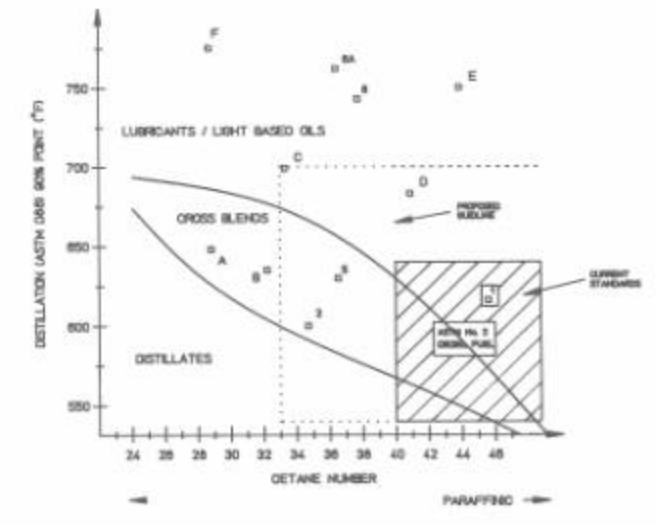
Fig. 7 Effect of cooled EGR on brake specific NO_x

Late 1970's Fuel Crunch!

* 1978 - Started "Alternative Fuels for Medium-Speed Diesel Engines" - DOE-FRA funding; AAR program planning
* 1980 - AAR member roads provide two test engines
  - » EMD 12-645E3 - 2,500 hp
  - » GE 7FDL12 - 2,500 hp
* 1981 - DOE & FRA funding ends - AAR assumed sole sponsorship



AAR Fuels Program

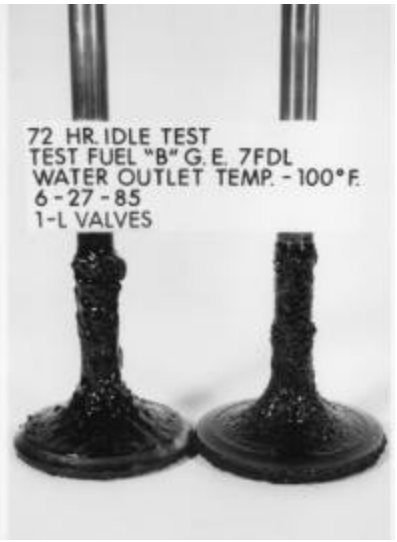


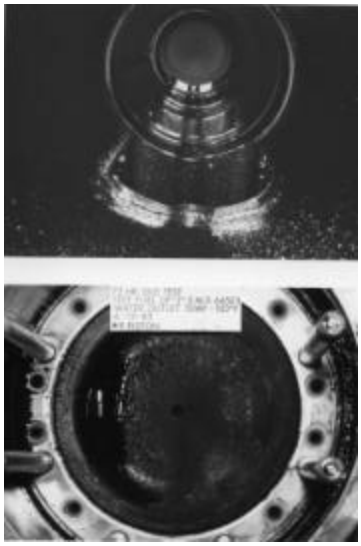
1978-1987
AAR Fuels Research at SwRI

* Broadened specification diesel fuels
  - » Fuel characterization
  - » 72-hour idle tests
  - » 500-hour screening tests
  - » Field tests
  - » Very limited exhaust emissions testing

RESULT = AAR FUELS MANUAL

Broadened-Specification Diesel Fuels





1986 Dual-Fuel EMD

* DOE-funded project
* EMD 2-567C engine
* High-Pressure, Dual-Fuel (diesel & LNG) injector developed
* Achieved full power with 99% gas substitution w/o reducing CR
* SAE 872041

BN DUAL-FUEL LOCOMOTIVE

* ECI Conversion
* 2,250 kW
* Dual-Fuel
* Revenue Coal Service 1992-95

EMD DUAL-FUEL LOCOMOTIVE

MK Rail 1200G LNG Switcher

* CAT 3516G
* 1,000 kW
* Spark Ignited
* 2.7 g/kW-hr NOx
* Operating in LA
* UP & BNSF

GAS RAIL USA

- Cooperative Industry Research Project
- Coordinated by SwRI
- Initiated in 1993
- Objective:
  - » Develop Gas Engine Technology for a Low NO_x Passenger Locomotive
  - » Apply Technology to Revenue Service Demonstration in Los Angeles, California

GAS RAIL USA Participants

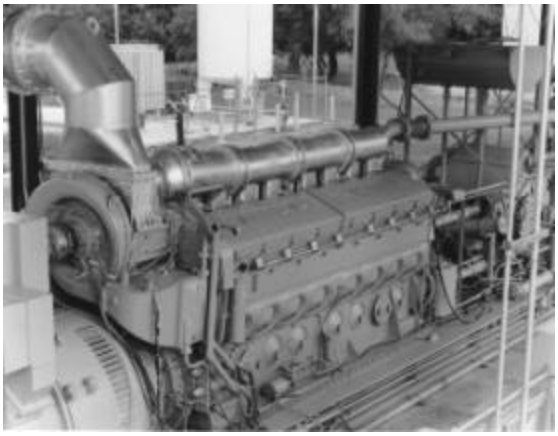
- Southwest Research Institute
- U.S. Department of Energy
- South Coast Air Quality Management District
- Southern California Regional Rail Authority
- California Air Resources Board
- Union Pacific Railroad
- Electro-Motive Division of General Motors
- Southern California Gas
- Gas Research Institute
- Amoco Petroleum Products

GAS RAIL ENGINE DEVELOPMENT

* 49.2 m^3 (13,000 gal) LNG Storage Tank
* Cryogenic Pumps to 41.4 MPa (6,000 psi)
* Vaporizers
* 725 kg/hr Methane

1992 - EMD 710 Engines Installed to Support Gas Rail USA

EMD 1-710 single-cylinder test engine



EMD 16-710G3 test engine

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CARB Fuel Effects Study

* Began August 1998
* Test 4 fuels in a total of 6 locomotives
  - » CARB diesel vs. on-hwy Federal diesel vs. two nonroad diesels
  - » GE C44-9 (UP)
  - » EMD SD70MAC (BNSF)
* Participant List:
  - » CARB
  - » UP
  - » BNSF
  - » AAR
  - » EMD & GE locomotive support

CARB - Unregulated Emissions

* Selected unregulated emissions were also measured
  - » Volatile Organic Fraction (VOF) of total particulate
  - » Sulfates
  - » Benzene
  - » 1,3-Butadiene
  - » Formaldehyde
  - » Acetaldehyde
  - » PAH (both gas phase and PM phase)
  - » Metal Particulate
  - » Soluble Organic Fraction (SOF)

SwRI Locomotive Emissions Test Center

* Established in 1992 for the AAR
* To date, over 50 locomotives tested
* Projects for EPA, CARB, CaDOT, DOE, AAR, RR's, and OEM's
  - » Most of this data is in the public domain

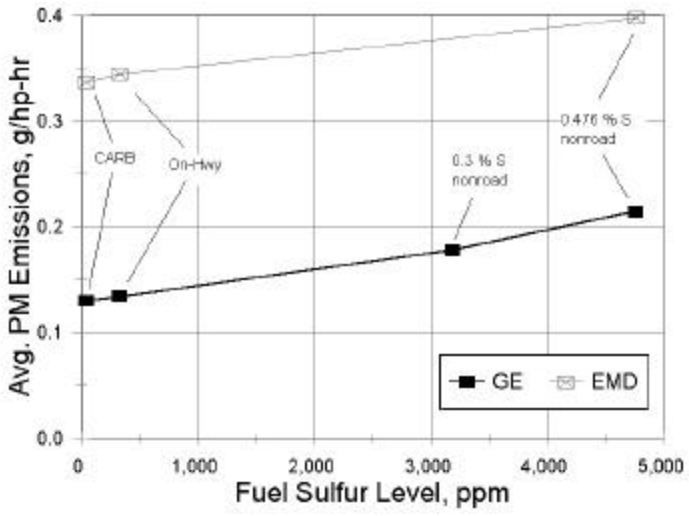
CARB Fuel-Effects Study

TABLE 1. AVERAGE CHANGE IN REGULATED LOCOMOTIVE EXHAUST EMISSIONS BETWEEN TEST FUELS

FUEL CHANGE	Percent change in Average Line-Haul Composite Emissions[a]			
	HC	CO	NOx	PM
EMD SD70MAC				
CARB vs. On-Hwy	+ 1 %	+ 7 %	- 4 %	- 3 %
CARB vs High Sulfur [b]	+ 3 %	+ 8 %	- 6 %	- 16 %
On-Hwy vs High Sulfur [b]	+ 1 %	+ 1 %	- 3 %	- 13 %
GE DASH9-44CW				
CARB vs On-Hwy	- 4 %	- 1 %	- 3 %	- 3 %
CARB vs High Sulfur [b]	+ 2 %	- 2 %	- 7 %	- 39 %
On-Hwy vs High Sulfur [b]	+ 6 %	- 2 %	- 4 %	- 38 %
CARB vs 0.3% Sulfur [c]	+ 1 %	- 3 %	- 5 %	- 27 %
On-Hwy vs 0.3% Sulfur [c]	+ 4 %	- 2 %	- 2 %	- 25 %
0.3% Sulfur [c] vs High Sulfur [b]	+ 2 %	0 %	- 2 %	- 17 %

Notes: a - EPA Line-Haul duty cycle weighted emissions.
b - 4,670 ppm sulfur nonroad fuel, EM-2664-F
c - 0.3% Sulfur fuel = 3,190 ppm sulfur, EM-2708-F

CARB Fuel-Effects Study



DOE-NREL Biodiesel Study

* U.S. DOE (National Renewable Energy Lab) Project at SwRI to test Biodiesel fuel in a locomotive
  - » Diesel baseline, CARB diesel baseline, B20, C20
  - » Triplicate EPA tests on each fuel
  - » NREL Contact is Dr. Shaine Tyson 303-275-4616
* Current Status - Recently completed testing
  - » CSXT No. 2629
  - » EMD GP38-2
  - » EMD 16-645-E (roots-blown)
* Final report soon

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Lubricating Oil Issues

* Retarded fuel injection timing will lead to increased soot loading, and higher viscosity
* New oil formulations likely to be necessary
* Lube suppliers working to address engine oil needs for Tier 0, 1, and 2 locomotives
* Lessons learned from truck engine experiences
* Need access to Tier 2 engines NOW to be assess issues

Lube Oil Contribution to PM

* At 50 ppm fuel sulfur, the lubricating oil contribution to PM sulfate is about the same as that from fuel
* Low oil consumption cylinder kits
* Lower sulfur lubricating oil base stocks
* Metal additive effects on PM size and number

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Diesel Technology Options

F.I. SYSTEM	COMBUST[ON	[NDUCT[ON	FUEL	AFTERTREATMENT
H[GH N.. PRESS.	REENTRANT BOWLS	COLD CHARGE A[R	LOW SULFUR	OX[DAT[ON CATALYSTS
SMALL HOLE NOZ.	H[GHER TOP R[NG	BETTER TURBO MATCH	SULFUR-FREE, ARO$_s$-FREE	LEAN NOx CATALYSTS
LOW SAC VOLUME	CONCENTR[C BOWLS	NEW [NT. MAN[FOLDS	DME	LEAN NOx CAT. w/REDUCTANT
[N.. RATE SHAPE	BETTER A[R UT[L[ZAT. *CENTRAL INJECTOR FOUR VALVES*	SW[RL RAT[O MATCH W. F[E CHARACT.	NG	PLASMA - ASS[STED LEAN NOx CATALYSTS
T[M[NG RETARD		EXH. GAS REC[RC.	LPG	SELECT[VE CATALYT[C REDUCT[ON (NH_3, UREA)
ELECTRON[C CONT. *FLEX. GOVERNING FLEXIBLE TIMING*	COMPL[ANT R[NGS	COOLED EGR	EMULS[ON	THERMALLY - REGEN. TRAP
	H[GHER COMP. RAT[O	COOLED/F[LTERED EGR	B[OD[ESEL	CATALYST - ASS[STED TRAP
	HOMOGENEOUS CHARGE COMP. [GN[T[ON (HCCI)	T[MED PORT EGR		ADD[T[VE - ASS[STED TRAP
		FAST A[R BOOST		OFF-L[NE REGENERATED TRAP

Technology Options

- Water emulsions
  - » PuriNOx
  - » A-55
  - » Auqazole
  - » others?
- Idle shutdown systems
  - » Automatic shutdown & restart
  - » Kim Hotstart APU
  - » Others
- Lubricant issues
- Fuel Cells
- DB Energy recovery systems

Diesel Fuel Summary

- Daily use fuel not regulated by EPA (…yet)
- Emissions test fuel is specified by EPA, with a sulfur content of 2,000 to 4,000 ppm
- Expect future emphasis on reducing fuel sulfur level to follow on-highway regulations
- Current US on-highway fuel sulfur 500 ppm max.
- 2007 = 15 ppm max for on-highway