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Transportation

**Federal Railroad
Administration**

Best Practices and Strategies for Improving Rail Energy Efficiency

Office of Research
and Development
Washington, DC 20590



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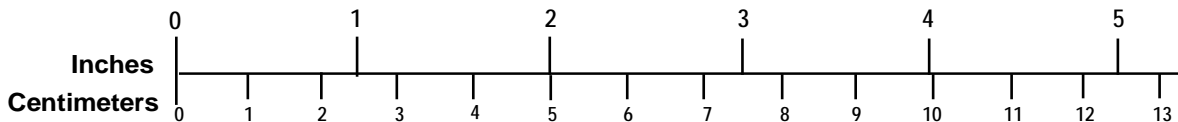
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1 mile (mi)	= 1.6 kilometers (km)
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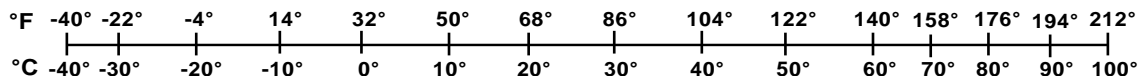
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Executive Summary

The DOT/RITA Volpe National Transportation Systems Center (Volpe Center) performed a review of contemporary international and domestic rail systems energy efficiency (E2) status and trends, in support of the Federal Railroad Administration (FRA), Office of Research and Development Energy, Environment, and Engine (E3) Research Program. The study identified rail industry and government Best Practices (BPs) and strategies for improving the E2 of freight and passenger railroads with technologically advanced equipment and infrastructure, and/or use of alternative fuels, operations optimization tools, and staff training. Specific E2 success stories across all rail industry segments illustrate the value and promise of energy consumption savings, economic and environmental benefits of advanced locomotive equipment, operations management software, and sustained implementation of multipronged sustainability initiatives.

Recommended strategies for improving rail E2 in the United States include:

- Fostering Public Private Partnerships (P3) involving Federal agencies (e.g., FRA, DOE, EPA), State and local transportation authorities, trade associations (AASHTO, AAR), and research bodies (e.g., TRB/NCRRP) in order to successfully develop, demonstrate, and deploy rail E2 and sustainability initiatives;
- Actively participate in international high speed rail (HSR) E3 initiatives, such as the annual UIC Sustainability Symposium and related R&D programs;
- Participate in multiyear joint research, development, test, and evaluation (RDT&E) initiatives and activities related to advanced locomotive traction and energy storage technologies, alternative fuels, and operations control optimization tools promising to reduce emissions while improving E2 performance;
- Join, implement, recognize, and reward rail industry energy efficiency, cross-enterprise sustainability commitments and initiatives, and related Climate Change¹ mitigation efforts;
- Join in rail industry sustainability initiatives led by industry and trade associations (e.g., the APTA Sustainability Commitment, the AAR Energy and Environment initiatives, and railroads' Best Practices (BPs) such as Amtrak's Climate Counts Scorecard.²)
- Join Standards Developing Organizations (SDOs) to help build industry consensus and facilitate the emergence of energy efficient rail technologies and fuels;
- Play an active role in rail industry partnerships co-funded with Federal, State, and regional agencies to improve air quality and reduce energy consumption.

The purpose of this study was to implement the E3 Action Plan recommendations and advance E3 Research Program objectives, which synergize with the Preliminary National Rail Plan (NRP)³ goals and the Obama Administration's Blueprint for a Secure Energy Future and Climate Change Action Plan.⁴ Study objectives were to develop guidance for rail transportation planners and operators, as well as to identify BPs and technology tools to improve the energy efficiency

¹ See DOT's Transportation and Climate Change Clearinghouse action plans at <http://climate.dot.gov/about/index.html>

² See <http://www.amtrak.com/ccurl/432/735/Amtrak-Recognized-Strong-Environmental-Program-ATK-12-135.pdf>

³ See NRP postings at <https://www.fra.dot.gov/Page/P0522>

⁴ See http://www.whitehouse.gov/sites/default/files/blueprint_secure_energy_future.pdf

of legacy rail systems and of planned high-speed passenger rail services. The technical approach was to conduct a comprehensive literature review on rail E2 and E3 technologies, successes, and trends, and then build upon those findings with input from rail sector subject matter experts (SMEs). These consultations permitted identification of success stories, strategies, and BPs that can serve as models for achieving freight and passenger railroads' E2 and E3 goals.

Rail transportation is currently one of the most energy efficient (per passenger-mile, or ton-mile) and environmentally compatible transportation mode. The fuel efficiency of Class I freight rail is 2 to 5.5 times better than that of trucks, having doubled over the past 30 years (1980–2011) to 480 ton-miles/gallon (183,345 kg-km/l fuel)⁵. Fuel efficiency has improved by 1 percent per year over the last decade (2000–2010) through upgrades in equipment (e.g., locomotives, freight cars, track structures, signal and control systems) and enhanced operating practices for asset and dispatch management. The energy intensity of U.S. intercity passenger rail (in Btu per passenger-mile) has also decreased by 1.9 percent annually over the past decade. Operational HSR systems worldwide have proven to be up to eight times more energy efficient than commercial aircraft and four times more efficient than car travel over the same geography and distances. In Europe, HSR uses one-third of the energy used by automotive travel, and in Japan, it is one-sixth due to technological advances.

The E2 metric for freight rail (Btu per ton-mi/gal) does not allow easy comparison with passenger rail (Btu per passenger-mi, or per seat-mile). The range of E2 for U.S. freight and passenger rail is very broad, reflecting many factors and variables including: aerodynamic losses, the weight and length of consists, number, age and technological vintage of locomotives, the railcar loading ratio, and idling due to network congestion. Stricter Tiers 3 and 4 EPA requirements for locomotives demand extra emissions abatement equipment that adds weight and cuts fuel efficiency. Also, mounting fuel costs have driven railroads to implement a broad range of new technologies and strategies to reduce both consumption and emissions, at lower operating cost. Projected passenger rail demand growth could counteract energy efficiency improvements and associated emissions reductions. It is also desirable to prevent and mitigate the increased energy consumption for emerging HSR projects per passenger-mile, the so-called “cost of speed.”

International rail E2 BPs applicable to the United States include: a UIC Railenergy online calculator and its database of 95 technology options, ranked by potential to improve E2 of passenger and freight rail. A Swedish study of HSR E2 (per seat-km) versus speed, found a negative “cost of speed” by 25–45 percent. In Japan, rail electrification, use of Electric Multiple Units (EMUs) with AC traction power and regenerative braking, and hybrid electric locomotives with onboard energy storage have improved E2 by 20–30 percent. For commuter rail with frequent stops, regenerative braking is an attractive E2 option. Since few U.S. intercity or commuter rail systems are electrified, they do not yet capture and reuse braking energy. Newer electric rail systems with regenerative braking capability (Amtrak *Acela* and some commuter rail) were able to save and reuse 10 to 20 percent of energy consumption. E2 equipment discussed include: Gensets increasingly deployed in rail yards to comply with Tier 3 EPA emission standards; fuel efficient switcher locomotives with 2 to 4 off-road diesel engines that

⁵ See AAR white papers posted at AAR Energy and Environment site:
https://www.aar.org/keyissues/Pages/Energy-And-Environment.aspx#.Us6hk_RDtLA

can be turned on if needed. Ultra-clean diesel electric locomotives and repower kits are available for upgrades.

Diesel Multiple Units (DMUs) in distributed power configurations combined with idle reduction devices and energy use monitoring capabilities reduce fuel consumption. EMUs on electrified track and hybrid electric and dual power locomotives offer E2 advantages in mixed-use territory, while a short-haul battery electric locomotive was tested and is being improved for long haul. Software tools for streamlined operations also improve asset management, logistics, and E2. Rail operations on shared track using GPS and Positive Train Control (PTC) for safety and asset management also improve E2. Alternative fuels being explored for environmental sustainability (biodiesel, hydrogen fuel cells, CNG, and LNG) promise equal or better E2. E2 success stories for industry leaders are illustrated to offer proven BPs as a model.

1. Background and Need to Improve Rail Energy Efficiency (E2)

1.1 Study Background, Objectives, and Approach

The Federal Railroad Administration (FRA) Energy, Environment, and Engine (E3) research program supports the development and demonstration of technologies to advance and enhance the energy efficiency and environmental sustainability of the national rail system. The FRA E3 program was motivated by the U.S. Department of Transportation's (DOT) strategic goal of environmental sustainability, the 2007 Energy Independence and Security Act (EISA), and phase-in of the Environmental Protection Agency (EPA) Tiers 3 and 4 locomotive exhaust emission regulations, reflecting rail community needs. The E3 program supports the development and demonstration of technologies which advance and enhance the energy efficiency and environmental sustainability of the national rail system. The primary goal of these efforts is to help ensure the safety of such new technology.

The FRA E3 program goals are achieved through collaborative research, demonstration, and testing efforts. FRA partners with stakeholders to disseminate findings, and to transfer to users technologies advancing rail energy efficiency (E2), emissions reduction, and engine upgrades.

This research effort builds on the 2010 Volpe Center E3 Action Plan for FRA,⁶ which identified technology options, strategies, and lessons learned from international rail experience, as well as opportunities to enhance E3 for U.S. railroads and to leverage investments in high-speed rail (HSR). The Action Plan's most promising E2 strategies and technology options included:

- Modernizing power and propulsion equipment and infrastructure (e.g., track electrification and modernization of traction power substations) and use of wayside energy storage at or near substations;
- Modernization or fleet replacement for locomotives and railcars (e.g., through light-weighting or mass reduction, aerodynamic shaping, fuel-efficient diesel electric), or use of electric multiple units (EMUs) in electrified territory, using dual hybrid locomotives;
- Fleet renewal and equipment upgrades (e.g., automated start-stop to limit idling, speed limiters, shore-power for warm-up, electronic speed control, and global positioning system (GPS), that reduce fuel consumption, or radio communications for automated signal and control for positive train control (PTC) interoperability;
- Adoption of proven operational Best Practices (BPs) (e.g., the use of GPS for tracking and asset management, and of logistics optimization tools for efficient dispatch and routing, fuel burn monitoring, improved maintenance (lubrication), and engineer training and performance incentives for fuel conservation.

To implement the E3 Action Plan recommendations and advance FRA's E3 Research Program objectives, this study aims to develop guidance for rail planners and operators. The goal is to provide them with BPs and tools enabling improvements of legacy rail systems energy efficiency, environmental sustainability, and the development of more efficient commuter rail systems and HSR. The study approach was to combine and analyze literature review and technology scan findings, with selected inputs and success stories from experts on recent and

⁶ "FRA Energy, Environment and Engine Technology (E3) Action Plan," August 2010. Internal FRA report.

planned rail industry upgrades in technology and operational BPs proven effective in improving E3 freight and passenger rail system performance.

The goals of this study were to:

- Review initiatives on “greener” passenger rail transportation options applicable to the U.S. environment for power and propulsion of vehicle equipment and infrastructure (both new and retrofits), using transferable international lessons learned from deployment and operation of HSR systems and electrification (UIC/EU, Japan, Korea, and China);
- Identify appropriate rail industry metrics for energy efficiency and environmental performance;
- If data permit, and using consistent metrics, compare U.S. passenger and freight rail energy efficiency and environmental footprint with modern systems (Europe, Japan, China);
- Identify international and U.S. standards and guidelines relevant to rail electrification infrastructure and vehicles’ energy efficiency, developed by Standards Developing Organizations (SDOs), such as: the Institute of Electrical and Electronics Engineers (IEEE), American Railway Engineering and Maintenance-of-Way Association (AREMA), the Association of American Railroads (AAR), International Engineering Consortium (IEC), and the European Committee for Electrotechnical Standardization (CENELEC);
- Identify the international BPs applicable and transferable to the U.S. rail operating and financial environment to improve energy efficiency of passenger and freight rail;
- Define E2 strategies that adapt and adopt available technologies to limit increased energy consumption with speed;
- Identify cost-benefit tradeoffs (e.g., retrofit versus fleet renewal) of introducing new technologies for energy recovery, storage, and management;
- Develop practical E2 Guidance for HSR, passenger rail, and freight rail planners and operators.

The specific study objectives addressed in this report include:

- Improved understanding of energy efficiency metrics and tradeoffs against environmental emissions, as well as the effects of increasing speed on cost and E2;
- Identification of near-term options for reducing rail fuel consumption, while simultaneously achieving environmental compliance with EPA emissions requirements;
- Documentation of rail industry BPs and of “least-cost, no-cost” strategies that produced energy efficiency gains for passenger and freight rail projects;
- Development of a useful E2 resource with guidance for rail systems and operators, customized to the extent possible to high-speed and commuter passenger rail, and freight rail by Class I-III. The E2 Guidance should assist railroads in adopting BPs in planning,

design, implementation, and deployment of new technologies and fuels, as well as help streamline operations.

Therefore, the technical approach for this study was to:

- Conduct first a comprehensive literature review on rail E2 and E3 technologies, successes, and trends;
- Complement the literature findings with inputs on rail E2 and E3 plans, programs, and BPs from representative rail industry subject matter experts (SMEs);
- Identify passenger and freight rail, as well as supplier industry strategies, BPs, and success stories that can serve as models for achieving E2 and E3 goals; and finally
- Disseminate the findings and recommendations to assist freight and passenger railroads.

1.2 Synergy of the National Rail Plan with the National Energy Policy

The 2011 U.S. Department of Energy (DOE) analysis⁷ of transportation energy consumption total and modal shares indicates that rail consumes only 2 percent of total transportation energy use compared with 21 percent consumed by highway mode, 7 percent by air, and 4 percent by marine, as shown in Figure 1.

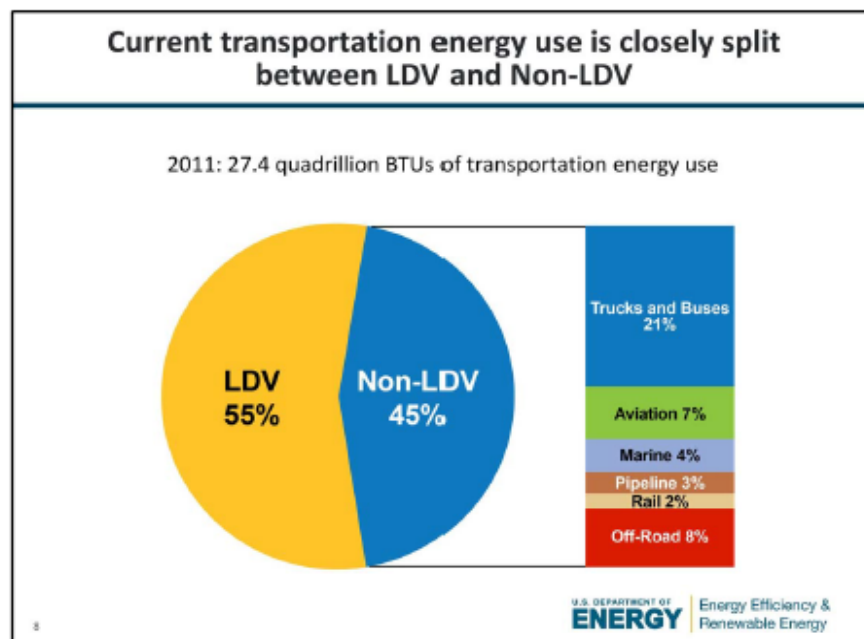


Figure 1. Total Energy Consumption and Modal Shares in 2011⁸

⁷ See Transportation Energy Futures overview posted at <http://www1.eere.energy.gov/analysis/transportationenergyfutures/index.html>

⁸ Source: DOE Transportation Energy Futures overview

Rail transportation has been recognized as the most energy efficient and environmentally compatible (per passenger-mile, or ton-mile) transportation mode, as shown by the U.S. and international data in Figure 2 and Figure 3. In particular, HSR systems have proven to be up to 8 times more efficient than aircraft and 4 times more efficient than car travel.

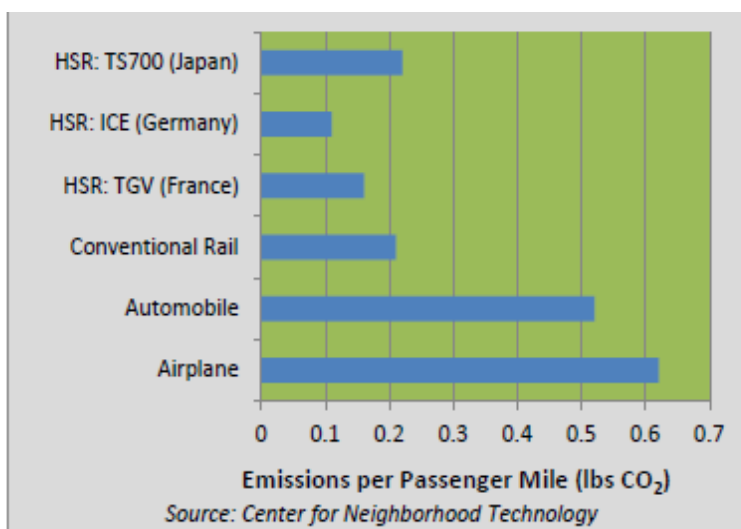


Figure 2. Comparative Rail vs. Other Modal CO₂ Emissions per Passenger-Mile⁹

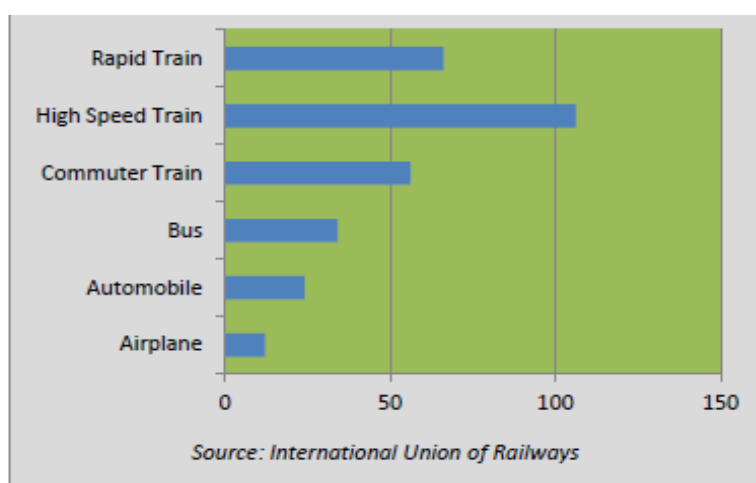


Figure 3. Comparative Energy Efficiency for Rail vs. Other Modes Based on UIC Data

An FRA report comparing highway and rail energy efficiency and environmental footprint¹⁰ showed that the fuel efficiency in ton-miles per gallon of Class I freight rail is 2 to 5½ times better than that of trucks. The fuel efficiency of freight railroads has doubled over the past 30 years and improved in the last decade by 1 percent per year through upgrades in equipment

⁹ Source: JRC2012-74130, P.A. Alexander, "Rail Transportation Energy Efficiency-Oriented Technologies." Figures 2 and 3 courtesy of American Society of Mechanical Engineers

¹⁰ "Comparative Evaluation of Rail and Truck Fuel Efficiency on Competitive Corridors" by ICF, 2009 at <http://www.fra.dot.gov/eLib/details/L04317>

(locomotives, freight cars, signal, and control), track systems, and operating practices including asset and dispatch management. The AAR 2011 Railroad Facts¹¹ indicate that there are 7 Class I long-haul major freight railroads operating in the United States, about 33 Regional (Class II), and approximately 540 short-line (Class III) railroads.

“With its comparative energy advantage, rail serves a vital role in helping to reduce the need for foreign oil and to increase environmental sustainability. High-performance freight rail is more fuel efficient than trucks, and state-of-the-art, high-speed passenger rail can provide an environmentally friendly alternative to air travel. Rail can thus contribute to DOT’s goal of reducing emissions from freight transportation by improving the fuel efficiency of freight vehicles, as well as by reducing transportation’s petroleum consumption. (“National Rail Plan-Moving Forward, A Progress Report,” September 2010)

In order to successfully implement FRA’s National Rail Plan¹² and related High-Speed Intercity Passenger Rail (HSIPR) initiatives, better E2 and E3 information using standardized metrics are needed (as discussed in Section 2.2), as well as a broad range of tools and strategies for railroad planners, owners, and operators.

In 2011, the White House issued a comprehensive National Energy Policy,¹³ which called for reducing the fuel consumption of the national transportation system and expanding the use of renewable energy and fuels, as well as for rapid electrification or hybridization of power and propulsion in renewing the vehicle fleet. The March 2012 1-year progress report cited the HSR and greening of Amtrak initiatives as promising strategies to improve the rail E2 performance.¹⁴

Expanding the U.S. High-Speed Rail network:

President Obama has established a goal to give 80 percent of Americans access to high-speed rail within 25 years. Over the past 3 years, the Administration has continued to develop and expand America’s high-speed and intercity passenger rail system. In May 2011, DOT announced \$2 billion in high-speed rail, bringing our unprecedented investment to \$10.1 billion to date. In FY 2011, intercity rail ridership surpassed 30 million trips, marking a new record in Amtrak’s history. (“The Blueprint for a Secure Energy Future: 1 Year Progress Report,” March 2012)

U.S. freight railroads have been steadily improving their fuel efficiency: E2 gains for U.S. Class I railroads were announced on Earth Day 2010 by the AAR.¹⁵ E2 more than doubled over the

¹¹ https://www.aar.org/newsandevents/Press-Releases/Pages/AAR-Issues-2012-Edition-Of-Railroad-Facts.aspx#.UN3zfG_XYwM

¹² Oct 2009 “Preliminary NRP” at <http://www.fra.dot.gov/Page/P0522> and the 2010 progress report at <http://www.fra.dot.gov/eLib/details/L02696>

¹³ “Blueprint for a Secure Energy Future” at http://www.whitehouse.gov/sites/default/files/blueprint_secure_energy_future.pdf

¹⁴ “The Blueprint for a Secure Energy Future: 1 Year Progress Report” at http://www.whitehouse.gov/sites/default/files/email-files/the_blueprint_for_a_secure_energy_future_oneyear_progress_report.pdf

¹⁵ “The Nation’s Freight Railroads Now Average 480 Ton-miles-per-gallon” at <https://www.aar.org/newsandevents/Press-Releases/Pages/2010-04-21-EarthDay.aspx>

past 30 years to 480 ton-miles/gallon (183,345 kg-km/l) fuel, thus making freight rail greater than four times more fuel efficient than trucks. The seven largest Class I freight railroads operate a fleet of more than 43,000 locomotives, and efficiently move across the Nation 43 percent of all goods transported annually, with better efficiency than trucks by factors of 2–5. However, stricter Tiers 3 and 4 EPA requirements for extra emissions abatement equipment that adds weight and cuts fuel efficiency and mounting fuel costs require that railroads implement a broad range of technologies and strategies to reduce their fuel consumption and emissions at lower operating cost.

The range of energy efficiency for freight trains, measured in ton-miles per gallon of fuel, is very broad (see Figure 4), reflecting to a large extent the aerodynamic losses due to the shape of rail cars, the length of the consist, number of locomotives, railcar loading ratio, and the network congestion that leads to idling.

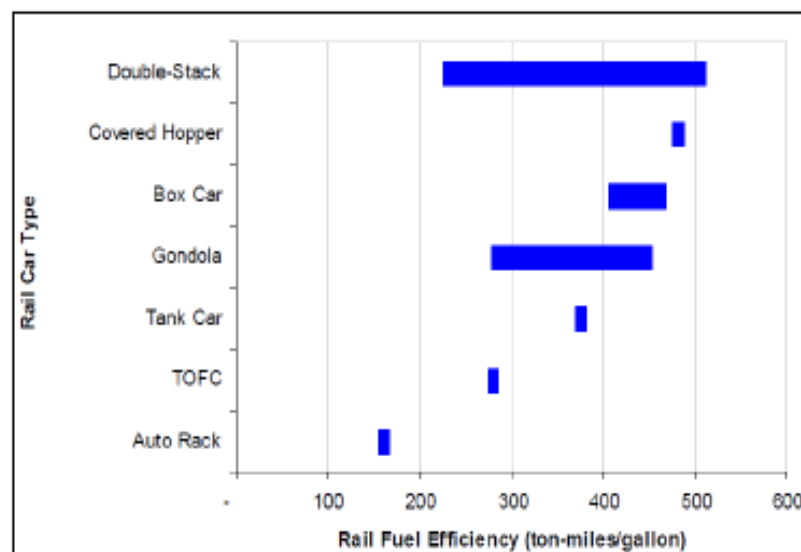


Figure 4. Ranges of Fuel Efficiency of Freight Trains by Type of Rail Car and Application, Based on the ICF 2009 Analysis¹⁶

The energy intensity of intercity passenger rail (in Btu per passenger-mile) has also decreased over the past decade by 1.9 percent annually, as shown by time series trend and comparative data in the recent *Transportation Energy Data Book*.¹⁷ Projected passenger rail demand growth could counteract energy efficiency improvements and associated emissions reductions. It is also desirable to prevent and mitigate the increased energy consumption for emerging HSR projects per passenger-mile, the so-called “cost of speed,” as shown in Figure 5.

¹⁶ See ICF International. *Comparative Evaluation of Rail and Truck Fuel Efficiency on Competitive Corridors*. Tech. Fairfax, VA: ICF International, 2009 at http://ntl.bts.gov/lib/31000/31800/31897/Comparative_Evaluation_Rail_Truck_Fuel_Efficiency.pdf

¹⁷ *Transportation Energy Data Book 2012* at http://cta.ornl.gov/data/tedb30/Edition30_Full_Doc.pdf [WEBPAGE CANNOT BE FOUND.]

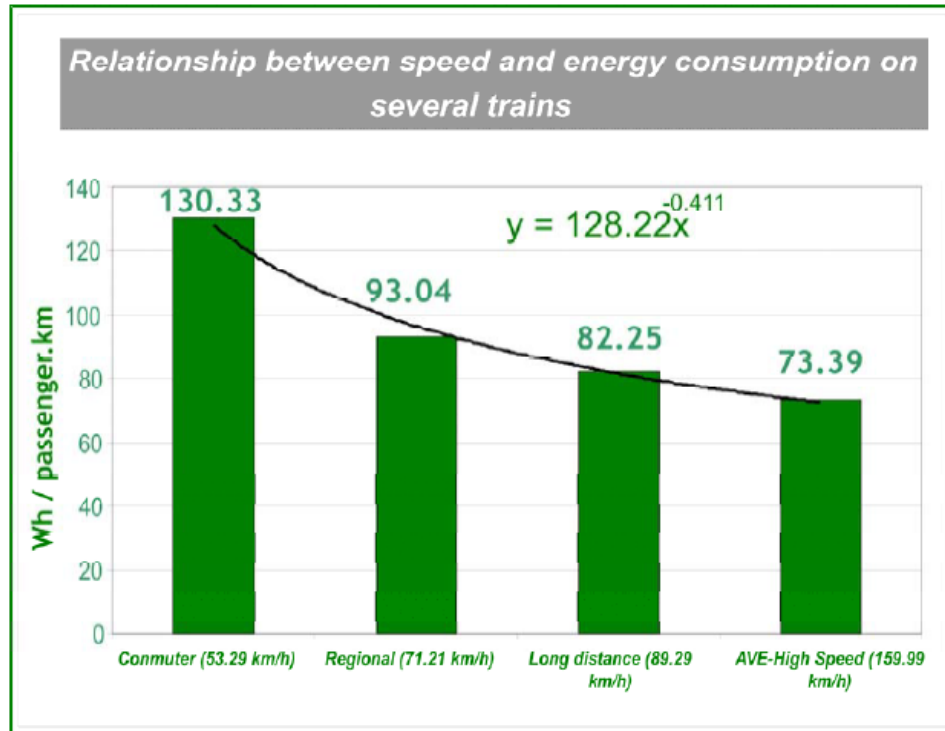


Figure 5. UIC Data on Relative E2 among Commuter, Regional, and Long Distance Conventional and High-Speed Rail¹⁸

Since passenger and freight rail frequently share track right-of-way (ROW) in the United States, improving infrastructure and equipment, including signal, control, and communications (e.g., upgrading fleet tracking with NDGPS and PTC, and streamlining operations), could improve energy efficiency, as well as operations safety and on-time performance on shared tracks.

Existing and emerging technologies for upgrading equipment, infrastructure, and operations, and the industry BPs cited below, promise relatively low-cost options and opportunities for further advances in both energy efficiency and environmental performance.¹⁹

1.3 Current High-Speed Rail (HSR) Initiative

1.3.1 Cost of Inaction of HSIPR Development

Today train travel is 17 percent more fuel efficient than airline travel on a per passenger-mile basis. According to the American Public Transportation Association (APTA), “with a 70 percent load factor, energy consumption per seat kilometer for aircraft is 2.57 megajoules (MJ) per p/km [1.14 kWh per p/mile], compared with 0.5 MJ per p/km [0.22 kWh per p/mile] for conventional trains and 0.76 MJ per p/km [0.34 kWh per p/mile] for high-speed trains.”²⁰ According to the International Transport Forum, the HSIPR advantage over air travel is that “...trains running at speeds up to 150 km/h [95 mph] emit 9.5 grams of carbon dioxides (CO₂) per seat km [0.539 oz

¹⁸ A.A. Garcia, “High Speed, Energy Consumption and Emissions, December 21, 2010, p. 17

¹⁹ JRC2012-74130, P.A. Alexander, “Rail Transportation Energy Efficiency-Oriented Technologies”

²⁰ <http://www.apta.com/resources/reportsandpublications/Documents/HPPR-Cost-of-Inaction.pdf>

per seat mile]; and trains running at speeds up to 280 km/h [174 mph] emit 15.4 grams of CO₂ per seat km [0.874 oz per seat mile], compared with aircraft emitting 93.8 grams of CO₂ per seat km [5.325 oz per seat mile].”²¹

The energy cost saving in the Northeast Corridor alone could be more than \$404 million a year. HSR could produce as much as 6.5 times less particulate matter (PM) per passenger and 31.9 times less nitrogen oxides per passenger than aircraft over the same distance. Between 100 and 500 miles (161 km and 805 km), HSR can overcome air travel’s speed advantage because of reductions in access and waiting times—HSR will take you from city center to city center.

In Europe, HSR uses one-third the energy used by automotive travel, and in Japan, it is one-sixth due to technological advances. In the United States, car and light truck transportation currently consume approximately 60 percent of the Nation’s energy demand. Train travel (including intercity and commuter passenger rail travel) is 21 percent more fuel efficient than auto travel. The APTA report cited sizeable expected socioeconomic gains, in addition to the energy and environmental benefits from investing in HSIPR infrastructure and equipment: over a 40-year period, an improved rail network could generate a net benefit of \$660 million annually, or \$26.4 billion total. The cost of building and/or improving rail lines is also estimated to be significantly less than the cost per mile of alternative air and highway infrastructure. In many corridors, passenger rail is the only feasible option for adding capacity, given the congestion and land acquisition constraints on air and highway expansion.

²¹ <http://www.internationaltransportforum.org/jtrc/DiscussionPapers/DP200928.pdf>

2. International and U.S. Rail Energy Efficiency Models and Best Practices

2.1 The UIC Railenergy Program and Products

The UIC has formulated a sustainability strategic plan and action plans for its implementation. Progress is monitored and reported every 2 years at the UIC Rail Sustainability conferences. The emphasis is on rail improvement of GHG/environmental performance and energy efficiency based on the comparative intermodal analysis illustrated in Figure 2 and Figure 3.

The European Commission (EC) 6th Programme has co-funded, with the European Rail Industry UNIFE multiple partners, and with UIC, a 4-year (2006–2010) comprehensive Railenergy R&D project, or NRG.²² The NRG project structure designed to develop a Railenergy global model is shown in Figure 6. The NRG data flow diagram displays steps to assess and optimize rail system E2 at both technical and operational levels.

Seven Railenergy workshops were held between 2006 and 2010²³ to monitor progress, develop E2 data and performance indicators or metrics for railroad vehicles and operations, as well as develop a consistent assessment approach to energy consumption. A *Railenergy Online Calculator*²⁴ with nine steps was developed and applied, which includes both technology and operational E2 measures, and may also be usable by U.S. railroads. Several useful reviews of rail market segments, infrastructure, equipment, operations management practices, decision support tools, and innovative technologies (e.g., electric traction, transformers, regenerative braking, trackside and on-board energy storage), as well as informative presentations on HSR efficiency with energy consumption facts and figures, were posted. The final UIC/UNIFE technical recommendations and voluntary standards are posted on a TecRec Web site.²⁵ In addition, the ECORails Guidelines issued in 2011 provide energy efficiency principles and practices in procurement of regional rail systems, and promise a 5 percent short-term energy gain and 15 percent by 2020.²⁶

²² See Railenergy and “Innovative Integrated Energy Efficiency Solutions for Railway Rolling Stock, Rail Infrastructure and Train Operation” postings at www.railenergy.org

²³ See Railenergy news and project outputs posted at www.railenergy.org/news.php#item1222

²⁴ See 2010 final conference and calculator at www.railenergy.eu

²⁵ See postings at www.tecrec-rail.org

²⁶ “Energy Efficiency and Environmental Criteria in the Awarding of Regional Rail Transport Vehicles and Services; Guidelines for Public Transport Administrations in Europe,” 2011 at http://www.ecorails.eu/media/de/ecorails_guide_english_freigabe_final.pdf

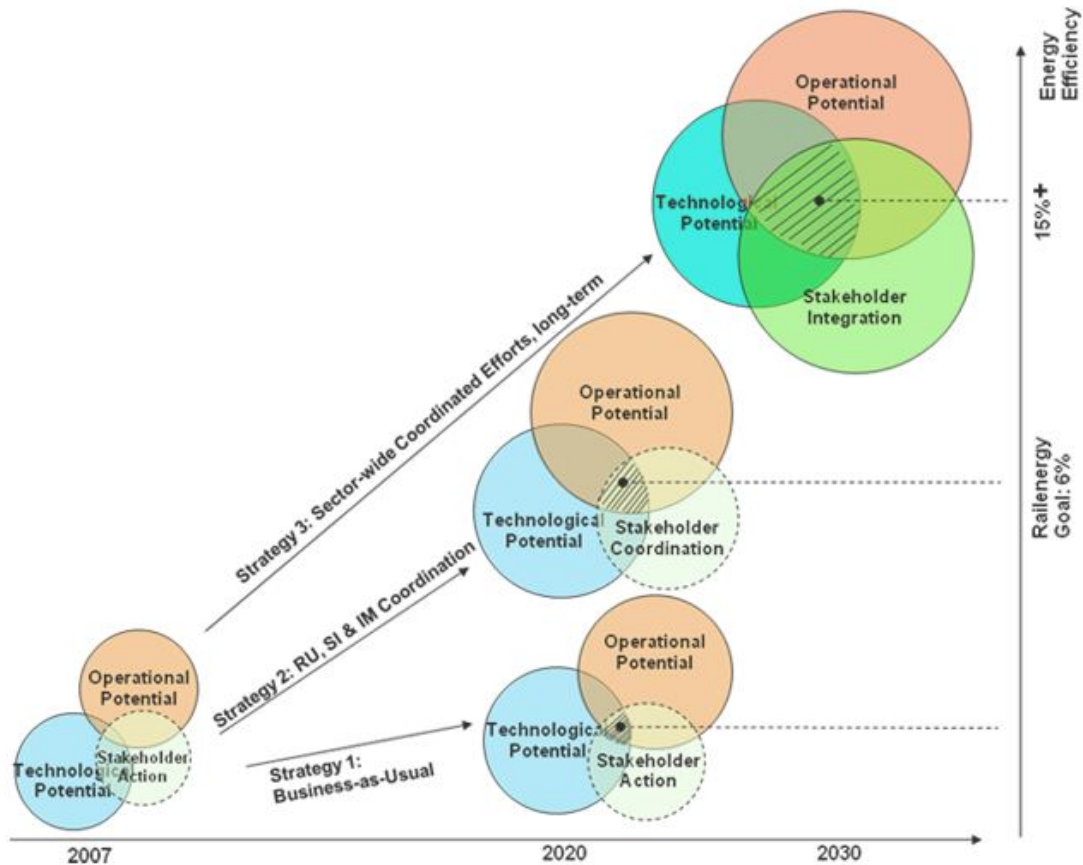


Figure 6. Strategy Approaches to Energy Efficiency²⁷

Unlike the U.S. intercity rail network (with the exception of Amtrak NEC *Acela* and several commuter railroads), European rail systems are electrified, with 85 percent of energy used directly for traction, and only 5 percent wasted in catenary losses.²⁸ The large-scale electrification and standardization of power and propulsion equipment includes regenerative braking that recovers and reuses up to 20 percent of the kinetic energy now lost as frictional heating during braking.

The UIC has compiled a database on 95 technologies ranked by their potential to improve the energy efficiency of passenger and freight rail.²⁹ UIC BPs for improved E2 per passenger-mile, or per ton-mile and the specific technologies for energy efficiency, which may be applicable to the U.S. rail industry, include:

- Standardization of infrastructure, rail propulsion, and environmental control technologies (e.g., noise barriers, cleaner fuels, upgraded power plants, nontoxic materials in maintenance);

²⁷ Figure source: <http://www.railenergy.org/>

²⁸ "Rail Transport and Environment Facts and Figures," 2008, <http://www.uic.org/homepage/FactandFig%2011-08.pdf>

²⁹ <http://www.railway-energy.org/tfee/index.php?ID=210&SEL=210&OLDSETTINGS=1>

- Light-weighting of locomotives, train cars, and consists through the use of lighter vehicle designs and materials, by eliminating dead-weight;
- Better train control and traffic dispatch and management to eliminate idling in congested bottlenecks and improve line-haul and traffic flow;
- Use of modular systems for efficient construction and maintenance, and use of distributed locomotives;
- Lower noise through better damping of vibrations, noise barriers, and aerodynamic vehicle, catenary, and pantograph designs.

Figure 7 summarizes global efforts to diversify the production of electric power for HSR systems with renewable energy resources.

High Speed Rail Systems' Sustainability & Renewable Energy Commitments

System	Sustainability Focus Areas	Regular Reporting?	Energy Details
Network Rail	3 "e"s across focus areas: Water, Materials, Waste, Stations, Biodiversity & Ecology, Energy (Carbon)	Yes	Energy load reduction & Electrification. Relying on the national grid to de-carbonize. Solar generation on some stations
SNCF	3 "e"s	Yes	Energy load reduction and electrification. France's grid is primarily fed with nuclear power Solar panels on car parks, some generation at new 'ecosustainable stations'
Deutsche Bahn	Company, Customers, Products, Employees, Environment	Yes	Direct Purchase. A program that shippers can opt into and obtain a 'carbon neutral' trip. DB's vision is for traction current to be entirely CO2-free in 2050. Currently contracted for 25 wind turbines (not on DB ROW)
Taiwan	Environment	Yes	Relies on national grid which has a .2% of renewable power Solar panels on Hsinchu station, and on equipment rooms
South Korea	Safety, Environment, Customers, Business Growth	Yes	Energy load Reduction & Electrification. SK's national grid is based on nuclear generation. Building integrated PVs on stations
Japan	Environment, Safety, Society	Yes	Energy load Reduction
China			National Grid has .4% from wind power.
Spain	3 "e"s are a management model and a brand	Yes	Energy load reduction & Electrification. Spain's grid has one of the highest percentages of solar
Italy	Environment	Yes	Focus on efficiency. National grid is aiming for 17% renewables by 2020
Belgium (Thalys)	Passenger health and safety, Connectivity, Environment Social commitments, Partnerships	<i>Carbon footprint</i>	Belgium provides a rare example of a rail system coordinating with an energy company to generate renewable power directly in the rail right of way and fed into the rail system
Eurostar	Cut carbon, Have a Plan, Carbon Neutral	Yes	Increased ridership and purchased more nuclear-generated electricity to lower GHG emissions associated with the train. Eurostar buys carbon credits
Switzerland	Customers, Environment, Employees, Economy, Safety, Management	Yes	SBB, Switzerland's largest rail operator, produces most of the power needed for train operations in its own hydroelectric power stations

Figure 7. International HSR: Sustainability and Renewable Energy Use³⁰

The British Rail Safety and Standards Board (UK/RSSB) has also conducted comparative energy efficiency studies and developed a set of practical Traction Energy Metrics for UK railroads. Adoption of such metrics would ensure the uniformity and consistency in reported E2 data so as to enable comparisons and allow quantification of E2 improvements relative to baseline.³¹

RSSB studies compared the energy efficiency and environmental emissions (CO₂) of diesel, electrically powered rail systems, and modes (buses, passenger cars, aviation). Of immediate interest to defining consistent rail performance metrics are two reports:

³⁰ Source: <http://www.cahighspeedrail.ca.gov/assets/0/152/232/325/a1a74ce4-1bb5-43a5-9a7d-a4f72011d9d0.pdf>

³¹ See RSSB postings at www.rssb.co.uk and report on "Traction Energy Metrics," December 2007 at http://www.rssb.co.uk/SiteCollectionDocuments/pdf/reports/research/T618_traction-energy-metrics_final.pdf

- 1) *T618-Traction Energy Metrics*, which defines the traction energy consumption metrics for comparative analysis and standardization of existing versus benchmarking emerging technologies; and
- 2) *T618-Improving the Efficiency of Traction Energy Use*, which focuses on intercity rail, providing technology-specific energy consumption data. Near-term strategies for energy gains for both diesel and electric traction were:
 - Improved driving techniques (operational)
 - Reduced idling (both through stop-start devices and operational practices)
 - Running shorter electric suburban trains off-peak (optimal asset management and dispatch)
 - Reducing “stabling loads” (cf., disconnect vehicles from grid when stationary, reduce idling, use wayside supply on demand versus on-board storage)

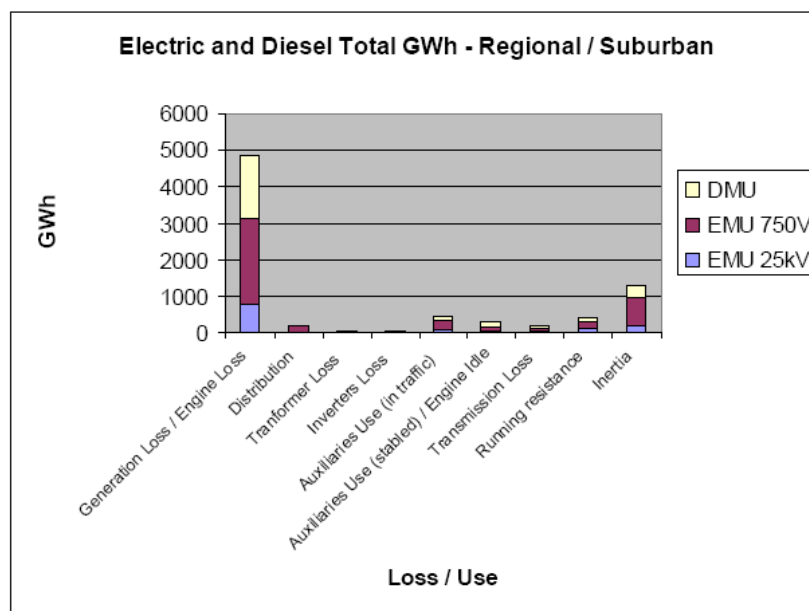
RSSB also identified several long-term strategies for additional energy savings:

- Aerodynamic drag reduction
- Train weight reduction
- Improved heating and cooling systems
- Intelligent communications and control of diesel trains
- Fuel additives that reduce emissions and improve fuel burn
- Dual power source trains
- Hybrid drives, including: electric/diesel, diesel/battery drives with regenerative braking to recharge the battery, and other on-board storage devices for energy assist

The RSSB analysis of energy efficiency and losses for urban commuter and intercity rail is probably applicable to understanding similar equipment transmission and distribution losses in U.S. rail counterparts (see Figure 8).

The ELECRAIL Spanish³² study of energy reduction strategies for electric DC-powered commuter and AC-powered HSR with regenerative braking capability found that at high-speed power return to the grid or to another train without energy storage is the best E2 strategy, saving up to 9.5 percent energy. When combined with efficient driving, 18–34 percent of total energy could be saved. For DC-powered urban commuter rail or transit with high-traffic density and many stops, wayside kinetic energy storage systems (KESS) had advantages, especially when coupled with energy-efficient driving and scheduling.

³² J.C. Martinez Acevedo and A. Mascaraque: “Energy Efficiency of Electric Traction Railways (ELECRAIL Project),” Proceedings of 2011 JRC Conference, paper no. JRC2011-56127.



Regional / Commuter	EMU 25kV	EMU 750V	DMU
Generation Loss / Engine Loss	60.0%	60.0%	68.0%
Distribution	1.4%	4.5%	0.0%
Train Transformer Loss	2.3%	0.0%	0.0%
Inverters Loss	0.7%	0.7%	0.0%
Auxiliaries Use (in traffic)	6.4%	6.3%	5.0%
Auxiliaries Use (stabled) / Engine Idle	2.8%	2.8%	5.0%
Transmission Loss	2.3%	2.3%	3.0%
Running resistance	8.1%	4.4%	6.0%
Inertia	15.9%	19.1%	13.0%

Figure 8. Total Energy Consumption with Losses in Generation for Regional and Suburban UK Rail³³

A Swedish HSR E2 study examined whether higher speeds would substantially increase energy consumption³⁴, a topic (also called “the cost of speed”) of great interest to U.S. HSR planning efforts. The key finding is that the specific energy consumption (W-h per passenger-km) for modern trains is actually reduced by 25–45 percent despite higher average speeds. The key factors for reduced energy consumed by electrified HSR or E2 gains are: reduced aerodynamic drag (25 percent cut in energy consumed); regenerative braking (11–17 percent); more efficient power supply for electric traction (3–7 percent), as well as improved use of longer trains and interior space and higher load factors.

³³ Source: Peckham, Christian, “Improving the Efficiency of Traction Energy Use,” Rail Safety and Standards Board, United Kingdom: June 13, 2007, © Rail Safety and Standards Board.

³⁴ See P. Lukaszewicz and E. Anderson: “Energy Efficiency of High Speed Rail-Will Higher Speed Cause Increased Energy Consumption?” presentation at the 6th World Congress on High Speed Rail, Amsterdam, 2008.

A more detailed 2010 UIC study³⁵ of “the cost of speed” documented only a modest increase in energy costs per seat-km as the average and maximum speed increase, compared with other cost elements (train ownership, infrastructure, direct operating costs, personnel, and maintenance). Technology and operational strategy options to reduce energy consumption for electric and conventional rail were also examined for the UK and Japan HSR systems and are also applicable to U.S.-planned HSR.³⁶

In Japan, most railroads and transit systems are electrified and have regenerative braking, so many successful applications of wayside energy storage systems (WESS) and on-board energy storage were highlighted in a 2007 status review.³⁷ Since the 1980s when EMUs with AC traction power and regenerative braking capability were introduced in Japan, the issue of poor grid receptivity to the frequency and voltage of returned power (DC to the high voltage AC grid or DC catenary) was solved using two-way power converters, instead of rectifiers, and on-board and wayside storage at the DC power substations. The Rail Technology Research Institute (RTRI) developed a simplified calculation of EMU energy consumption over all phases of rolling stock operation³⁸ (see Figure 8, similar to the UK energy tools shown in Figure 98).

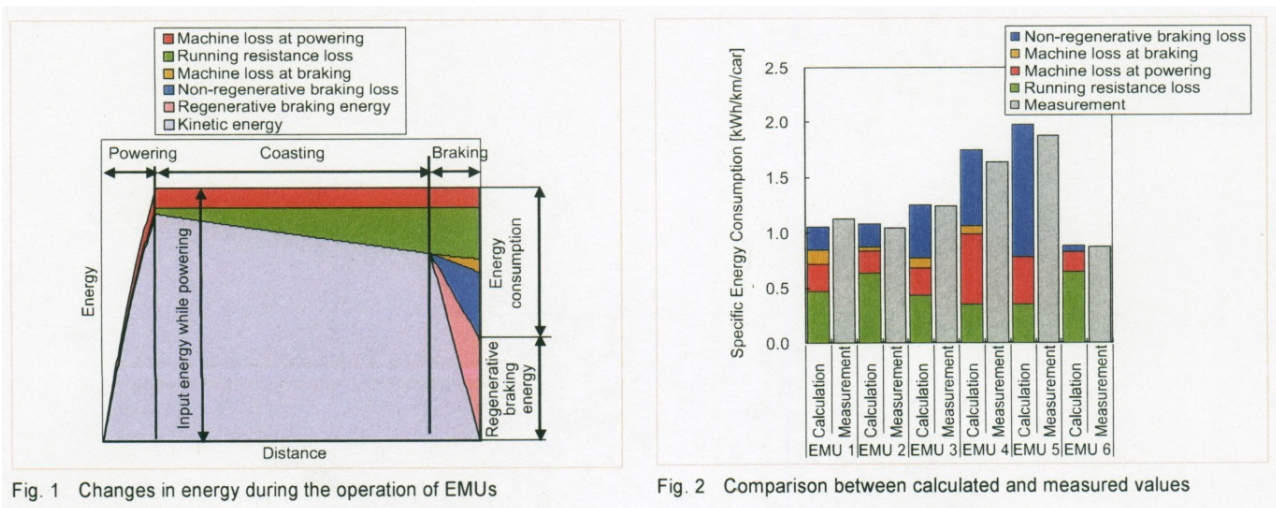


Figure 9. Actual vs. Calculated Energy Consumption of EMUs Over Duty-Cycle³⁹

RTRI and Japan’s railroads have developed and successfully implemented diverse options for wayside and on-board storage of braking energy, to enable electric and diesel trains operating

³⁵ “Relationship Between Rail Service Operating Direct Costs and Speeds,” Dec. 2010 posted at http://www.uic.org/IMG/pdf/report_costshs.pdf

³⁶ “Comparing Environmental Impact of Conventional and High Speed Rail,” NetworkRail 2009 study posted at www.networkrail.co.uk

³⁷ “Wayside and On-Board Storage Can Capture More Regenerated Energy” by Satoru Sone, Railway Gazette, July 2007 at <http://www.railwaygazette.com/news/single-view/view/wayside-and-on-board-storage-can-capture-more-regenerated-energy.html>

³⁸ Source: M. Kondo, “A Simplified Method to Calculate the Energy Consumed by Rolling Stock”, Railway Technology Avalanche, No. 38, March 21, 2012, <https://webform.rtri.or.jp/ent/entry/backnumbers/38/RTA-38-226.pdf>

³⁹ Image courtesy of Railway Technical Research Institute

more efficiently.⁴⁰ Most passenger trains in Japan are electric (EMU) or diesel multiple units (DMU) operating on electrified ROW, but many branch and trunk lines are still not electrified. On-board energy storage systems (ESS) were developed for DC and AC traction railcars and for diesel-powered locomotives that use lithium ion batteries, or Electric Double Layer Capacitors (also called ultracapacitors) to recover, store, and reuse the regenerated braking energy for peak loads (in hill climbing and acceleration), thus improving energy efficiency by 20–30 percent. However, both technologies continue to be actively improved for more rail applications: although lithium ion batteries have higher energy density and capacity for energy storage of braking energy than ultracapacitors, battery power, and cycle-life still need to be improved; ultracapacitors have higher power and longer life but insufficient capacity for on-board energy storage. The rechargeable energy storage system (RESS) architecture must be suited to the duty cycle of the train, since frequent stops allow the energy recovered from dynamic braking to be frequency-matched and returned to the grid. A high-speed intercity train with fewer stops faces greater challenges in regenerating braking energy and optimizing network receptivity.

On-board RESS power packs may use supercapacitors, lithium ion batteries, or nickel hydrogen batteries:

- The JR Freight Railway Company introduced to Tokyo service in 2012 a mass-produced hybrid shunting locomotive storing regenerated braking energy in lithium ion batteries from GS Yuasa, improving fuel economy by 30 percent.
- Hybrid diesel-battery traction for a “battery tram” was developed by RTRI using stored energy when operating on non-electrified tracks, in tunnels, or on gap segments using the recovered energy stored in lithium ion batteries. The Kawasaki Swimo project also developed and demonstrated a nickel-hydride (NiH) Gigacell battery for on-board energy storage.
- JR Central has evaluated since 2007 EDLC systems, instead of lithium ion batteries, for on-board energy storage performance on a Series 313 DC-powered suburban EMU⁴¹.
- JR East has tested since 2000 its New Energy Train (Figure) with regenerative braking, using hybrid traction of diesel-alternator and battery, which was able to cut fuel consumption by 20 percent. The NE train has also been tested with hybrid drive that uses a fuel cell and 35 MPa (5 ksi) hydrogen tank, replacing the diesel alternator and fuel tank. Another hybrid version used instead of the diesel-alternator a fuel cell with a high-pressure hydrogen tank for hybrid traction.

Figures 10 to 13 illustrate innovative E2 equipment and technologies developed and deployed by the Japanese rail industry, with assistance from the Rail Technology Research Institute (RTRI): Figure 10 shows a typical AC Japanese electric EMU locomotive used in high-speed operations, and Figure 11 is a freight hybrid switcher locomotive using lithium ion batteries for on-board energy storage; Figure 12 is the NE hybrid train, and Figure shows the hybrid battery DMU.

⁴⁰ See <http://www.railwaygazette.com/news/single-view/view/wayside-and-on-board-storage-can-capture-more-regenerated-energy.html> (2007)

⁴¹ See “Wayside and On-Board Storage Can Capture More Regenerated Energy,” 2007 at <http://www.railwaygazette.com/news/single-view/view/wayside-and-on-board-storage-can-capture-more-regenerated-energy.html>

The *Hayabusa* hybrid rail transit system was developed by Hitachi and operated by the Eastern Japan Railway for DMU operations. It uses a stack of 48 high energy density 1 KWh (3412 Btu) lithium ion batteries, and uses regenerative braking and on-board energy management to switch off the engine in stations. It has shown up to 20 percent fuel savings and reduced particulate emissions. A more powerful hybrid drive version is being tested in the UK as well. The three Kiha E200 diesel battery hybrid units (Figure 13) were launched into service in 2007 on the Koumi line, and 10 additional hybrid DMUs were added to service in 2010. JR East data show fuel consumption savings of 10 percent and emission cuts of 60 percent and 20–30 dB noise reduction compared with standard DMUs.



Figure 6. Toshiba AC Electric Locomotive Used by Taiwan's HSR⁴²



Figure 11. Toshiba HD-300 Hybrid-Electric Shunting Locomotive⁴³

⁴² Source: <http://www.toshiba.co.jp/sis/railwaysystem/en/products/locomotive/hybrid.htm> and <http://www.toshiba.co.jp/sis/railwaysystem/en/products/locomotive/electric.htm>

⁴³ Images courtesy of Toshiba Corporation

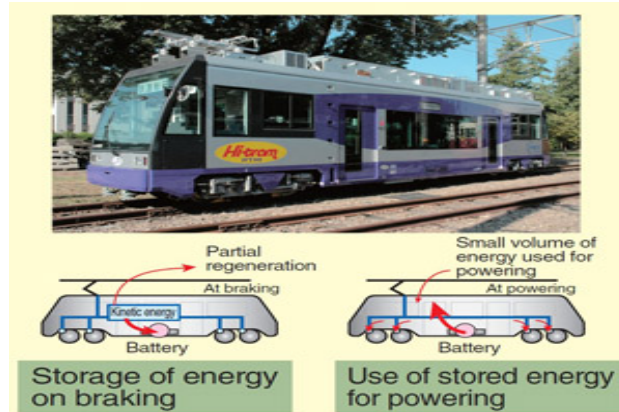


Figure 12. RTRI Hybrid Electric Locomotive with Regenerative Braking Schematics⁴⁴



Figure 13. Hybrid Battery DMU⁴⁵

2.2 U.S. Rail E2 Metrics and Performance

2.2.1 Energy and Environmental Performance of Passenger and Freight Rail

The DOT/BTS National Transportation Statistics, the National Transit Database, and the Transportation Energy Data Book 2011⁴⁶ include comparative fuel consumption trends and energy intensity data (in Btu/passenger-mile) for rail vehicles in comparison with other surfaces modes, marine, and air. The lower the energy intensity, the more energy efficient a rail system is. The AAR-posted data showing the remarkable doubling of freight rail energy efficiency over the past 3 decades, in ton-miles per gallon (see Figure 7).

As Figure 2 and Figure 3 illustrate in Section 1.2, the comparative E2 performance among rail service types (commuter, regional, and long-distance conventional versus HSR) and among modes varies with service type (passenger versus freight), route (number of stops, length, grade),

⁴⁴ Image courtesy of RTRI

⁴⁵ Image courtesy of http://tokyorailwaylabyrinth.blogspot.com/2013_02_01_archive.html

⁴⁶ See ORNL Transportation Energy Data Book 30th Edition, July 2011 at <http://cta.ornl.gov/data/index.shtml>

and technology specifics (EMU, power cars, diesel or electric), and the primary power (diesel versus electric). The metrics and units are not consistent and do not permit easy comparisons. For instance, Amtrak energy consumption is 2,435 Btus/passenger-mile, converted into 1.6 MJ/passenger-km, but also varies with the loading factor: the passenger yield is typically 60–80 percent on the Northeast Corridor.

Unit conversions are required: European passenger rail energy consumption (e.g., for the Swiss SBB in 2011) is expressed as 2,300 GWhr/yr or 0.47 MJ/passenger-km (where 1 MJ/passenger-km is equivalent to 0.33 kWhr/passenger-km). East Japan Railway Company (EJR) cites train energy efficiency per car-km at 20.6 MJ/car-km or 0.35 MJ/passenger-km. An OECD 2009⁴⁷ discussion paper cites an average of 0.5 MJ/pass-km for conventional passenger rail, but only 0.76 MJ/pass-km for HSR, noting the modest “cost-of-speed.” The energy efficiency metrics for freight rail are usually given in gallons of fuel burned per ton-mile, or ton-km, and again, do not allow for easy and meaningful comparisons with passenger rail.

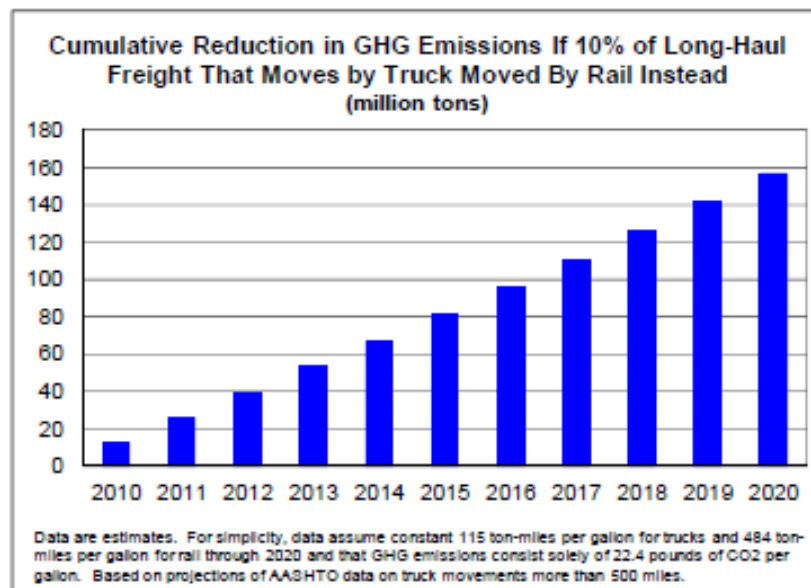


Figure 7. AAR 2010 E2 for Freight Railroads⁴⁸

⁴⁷ See C. Nash, 2009 “When to Invest in HSR Links and Networks?” OECD discussion paper at <http://www.internationaltransportforum.org/jtrc/DiscussionPapers/DP200916.pdf>

⁴⁸ See AAR 2011 brief at <http://www.fecrwy.com/sites/default/files/help-reduce-emissions.pdf>

2.2.1.1 E2 for Commuter Rail

Table 1 shows a sample of commuter rail systems energy intensity performing below and above the national average (in red). The spread in commuter rail data in Table 1 is rather narrow—within a factor of 2—and reflects differences in technology (electric or diesel), route, duty cycle, and load factors compared with a national average (in 2007).

Table 1. Energy Intensity of Commuter Rail Systems, 2007⁴⁹

City/State	Btu per Passenger-mile
Chesterton, IN	1,638
Boston, MA	2,117
Newark, NJ	2,538
Chicago, IL	2,634
All Commuter Rail Systems	2,679
Jamaica, NY	2,786
New York, NY	2,818
Philadelphia, PA	4,223

⁴⁹ Source: Department of Transportation (National Transit Database, April 2009).

Table 2 reproduces more recent data on commuter rail and heavy rail energy intensity from the 2011 ORNL Transportation Energy Data Book and shows a wider range reflecting their diverse technologies, ages, routes, duty cycles, and load factors. Currently, few commuter rail systems are electrified in the United States due to the high cost of electrification infrastructure; most regional heavy rail systems are still diesel-powered. Promising system-wide E2 improvements through fleet equipment, infrastructure, and operations modernization are illustrated in Section 4.2 for passenger railroads (Amtrak and commuter rail).

Table 2. Energy Intensity of Commuter Railroads, 2010^{50 51}

	Btu per Passenger-mile
Stockton, CA	1,907
Los Angeles, CA	1,917
San Carlos, CA	1,984
Alexandria, VA	2,037
Chesterton, IN	2,448
Boston, MA	2,487
Baltimore, MD	2,556
Seattle, WA	2,591
Albuquerque, NM	2,769
Portland, ME	2,830
New York, NY	2,837
Chicago, IL	2,884
Oceanside, CA	2,897
Jamaica, NY	2,919
All Commuter Rail Systems	2,923
Newark, NJ	3,205
Pompano Beach, FL	3,252
Fort Worth, TX	3,279
Minneapolis, MN	3,327
Austin, TX	3,686
Philadelphia, PA	3,865
Salt Lake City, UT	5,152
Portland, OR	5,961
Harrisburg, PA	8,167
Newington, CT	16,505

Source: U.S. Department of Transportation, National Transit Database, May 2012. (Additional resources: www.ntdprogram.gov).

⁵⁰ From the ORNL Transportation Energy Data Book at <http://cta.ornl.gov/data/index.shtml>.

⁵¹ See [Energy Intensity of Commuter Rail](#) Systems, 2011, Ch. 2, Figure 2.4 at <http://cta.ornl.gov/data/chapter2.shtml>

2.2.1.2 Energy Efficiency for High-Speed Rail

An APTA 2011 report⁵² on the business case for HSIPR systems provided strong support for Federal and private investments and identified major economic productivity and benefits. Investment in modern rail technologies for infrastructure and equipment would also enable environmental and energy-efficiency gains. The APTA report cited UIC data that high-speed trains get 106 mi (170 km) per KW-hour of energy, versus 13 mi (21 km) for airplanes, 24 mi (39 km) for cars and 34 mi (55 km) for buses. It also cited findings of a Center for Clean Air Policy/Center of Neighborhood Technology 2006 study⁵³ highlighting HSR and maglev air quality and sustainability advantages versus conventional rail, highway, and air modes: CO₂ emissions for HSR operations are substantially lower (0.1- 0.3 lb/passenger-mile or 0.03-0.08 kg/passenger-km) than those for cars (0.5 lb/p-mi or 0.14 kg/p-km) and for airplanes (0.6 lb/p-mi or 0.17 kg/p-km). The introductory overview in Section 1.1 discussed freight versus passenger rail. The 2006 study compared the CO₂ emissions by corridor for current U.S. conventional rail and future planned HSR along the 12 potential HSR corridors identified by FRA, including emissions saved relative to highway and air modes, with largest impacts for the NEC and California corridors. A recent Lifecycle Analysis of HSR and conventional rail versus air and highway modes⁵⁴ indicated that a comprehensive system-wide comparison must include building and operation of rail infrastructure, maintenance and fuel, high occupancy/load factors, and a clean supply for electric power from renewable sources, rather than coal-fueled power plants. Freight rail consumes more than 90 percent of the energy used by the domestic rail sector; it merits specific focus.

2.2.1.3 Efficiency for U.S. Freight Rail

The rail mode represents only a modest 4.1 percent of the energy consumed for heavy duty transportation, amounting to 0.54 quadrillion Btus in 2009. The majority of the rail sector's freight revenue is accounted for by Class I freight railroads (93 percent in 2007), which carry more than 90 percent of rail freight volume. The Class I railroads have become remarkably more energy efficient over the past three decades and continue to improve. Overall, the U.S. freight railroads have implemented in the past decade a wide range of successful efforts to improve E3 performance, with sizeable economic gains. Whereas passenger rail consumed about 20,000 barrels of oil per day in 2010, freight rail has consumed 10 times more, up to 250,000 barrels per day. For comparison⁵⁵, in 2010 the 4.8 million heavy trucks on the road consumed more than 1.6 million barrels of diesel oil per day, or 5.1 quadrillion Btu in 2010, for an average fuel economy of only about 6 miles per gallon (2.55 km/l).

⁵² "APTA report: "The Case for Business Investment in High Speed and Intercity Rail" at http://www.apta.com/resources/reportsandpublications/documents/HSRPub_final.pdf

⁵³ "High Speed Rail and Greenhouse Gas Emissions in the US," 2006 at <http://www.cnt.org/repository/HighSpeedRailEmissions.pdf>

⁵⁴ "Life-cycle Assessment of High-Speed Rail: The Case of California" by M. Chester and A. Horvath, 2010 *Environ. Res. Lett.* **5**, 014003 doi:10.1088/1748-9326/5/1/014003 and <http://stacks.iop.org/ERL/5/014003>

⁵⁵ See EIA transportation sector data in the AEO 2012 Forecast at [http://www.eia.gov/forecasts/aeo/er/pdf/0383er\(2012\).pdf](http://www.eia.gov/forecasts/aeo/er/pdf/0383er(2012).pdf)

The AAR has posted relevant findings, resources, and statistics on rail Energy and Environmental performance⁵⁶ indicating that freight rail is currently the greenest and most fuel-efficient ground transportation option. The findings are summarized below:

- Of more than 560 U.S. freight railroads, the 7 Class I railroads account for 68 percent of ton-mileage, 89 percent of employees, and 93 percent of revenues.
- The freight railroads transport 43 percent more ton-miles of freight than any other mode.
- On average, freight trains are 4 times more fuel efficient than trucks, moving a ton of freight for 484 mi per gallon (206 km/l) of fuel.
- Each ton-mile of freight moved by rail rather than highway reduces greenhouse gases (GHG) emitted by 75 percent.
- A loaded freight train is equivalent to removing about 280 trucks, or 1,100 cars, from roads, thereby providing both emissions reduction, as well as congestion relief.
- Switching 10 percent of freight from highway to rail can save 1 billion gallons of fuel and 12 million tons GHG per year.

A 2011 AAR white paper listed the most effective strategies for freight railroads to both reduce GHG emissions and improve fuel efficiency.⁵⁷ It documented a dramatic doubling of fuel efficiency from 235 mi/gal (100 km/l) fuel in 1980, to 469 mi/gal (200 km/l) in 2011 to move a ton of freight. The AAR summarized the wide range of E3 BPs in technology deployment and operational changes for improved FE and environmental gains:

- Redesign freight cars to increase the average tonnage capacity;
- Overhaul to upgrade fuel efficiency, or renew the fleet of switchers, short-haul, and long-haul locomotives;
- Reduce idling through “stop-start” and other (e.g., Auxiliary Power Units—APU) equipment upgrades;
- Provide engineers with training on advanced engine control systems to save fuel and reward savings;
- Adopt computer control software and hardware for route optimization, speed profile for peak fuel efficiency, to monitor and control locomotive operations;
- Implement incremental, but synergistic, fuel and equipment improvements such as: better wheel and gear lubricants, use of fuel additives for improved combustion, low-torque railcar bearings that reduce weight and save fuel, optimal placement of locomotives in long consists for more efficient distributed power (DP), etc.

These strategies, as well as related fuel efficiency options for passenger rail (commuter and higher speed intercity), will be illustrated below with successful Best Practices (BPs). There are other options for rail system E2 improvements, although this report focused primarily on opportunities related to equipment and operations. For instance, lighter rail cars, aerodynamic shapes, top-of-rail (TOR) lubricants to reduce wheel-to-rail and internal friction, use of steerable

⁵⁶ See AAR postings at www.aar.org/KeyIssues/Energy-Environment.aspx and resources on North American Freight Railroad Statistics, 2010; An Overview of America’s Freight Railroads; and Class I Railroad statistics, 2011.

⁵⁷ See AAR “Freight Railroads Help Reduce GHG Emissions” at <https://www.aar.org/keyissues/Documents/Background-Papers/Freight-RR-Help-Reduce-Emissions.pdf>

or radial trucks and of electronically controlled pneumatic (ECP) brakes, as well as PTC, provide incremental and synergistic E2 benefits.⁵⁸

2.3 Existing and Emerging Fuel Efficient Locomotives

2.3.1 Equipment Technologies and E2 Strategies

An American Society of Mechanical Engineers (ASME) Joint Rail Conference 2012 presentation reviewed proven and promising E2 technology options for deployment in new rail systems, retrofits, or upgrades for system-wide E2 gains.⁵⁹ It identified modernization of the traction and propulsion system to be the most important factor for improving E2.

Additional system-wide E2 gains may also be achieved by modernizing the heat, ventilation, and air conditioning (HVAC) system controllers for railcars, focusing on integrating:

- Variable speed motor drives for refrigerant compressor that can save up to 70 percent of energy for ventilation and heating;
- Variable dampers or fans;
- Permanent magnet motors that increase efficiency and reduce size and weight of compressors and pumps;
- CO₂ sensors.

Lighting system options with superior efficiency for both rail cars and facilities (multimodal terminals, stations, depots, and railyards) include day-lighting, automatic ambient light sensors, and motion detectors, as well as replacing incandescent and fluorescent lighting with long-lived, low-power, light-emitting diodes (LEDs).

Regenerative braking can be used to capture and reuse the electricity produced by dynamic braking. Dynamic braking runs the electric motor in reverse to slow the train, so that it acts like a generator producing electricity. Currently, most trains dissipate the dynamic braking energy by using banks of resistors located on top of locomotives that heat up in the process (called rheostatic braking). A cooling grill for the brake grid resistors is typically placed at the top of the locomotive. ECP (air) brakes are increasingly used, but energy savings can be realized only if all railcar brakes are connected. Regenerative braking requires an on-board RESS to store and deliver on demand the recovered kinetic energy, which is typically wasted as frictional heat. The recovered braking energy, otherwise wasted, can be returned to the grid or reused for peak load demand such as acceleration, or hill climbing.

At present, most light and heavy rail and electric commuter rail systems do not yet capture and reuse braking energy. Newer electric rail systems with regenerative braking capability (Amtrak *Acela*, international HSR, and some commuter light rail vehicles (LRVs) were able to save and reuse 10 to 20 percent of energy consumption. For commuter rail with frequent stops, regenerative braking is an attractive E2 option.

⁵⁸ *Potential for Energy Efficiency Improvement Beyond the Light-Duty Sector*, Feb. 2012, at www1.eere.energy.gov/analysis/transportationenergyfutures/index.html

⁵⁹ P.A. Alexander, LTK Engineering “Rail Transportation Energy-Efficiency Oriented Technologies.” Proceedings of Joint Rail Conference (JRC2012), April 2012, Philadelphia, PA: JRC 2012-74130.

Both WESS and on-board RESS technologies were also recently evaluated by APTA and the Electric Power Research Institute (EPRI) in a 2010 TRB/TCRP⁶⁰ report, which offers guidance to rail transit agencies. Emerging RESS system options include:

- An on-board RESS using battery packs or super capacitors (also called ultracapacitors). Advanced lithium ion batteries with diverse chemistry options, or lower cost larger and heavier nickel metal hydride (NiMH), have been evaluated, but not yet deployed in the United States.
- An on-board flywheel (FESS) or Kinetic Energy Storage System (KESS), such as that demonstrated in the FRA/DARPA Advanced Locomotive Propulsion System (ALPS) project completed in 2003.⁶¹ The ALPS demonstrator consisted of a gas turbine and synchronous alternator, combined with an induction motor coupled to a 2 MW (2682 hp) rapidly spinning FESS (Figure 15). However, the prototype failed and did not prove practical and ready for application. Related research on KESS for heavy-duty applications (rail, marine) is ongoing.
- A WESS pilot deployment by the Los Angeles Metrolink commuter rail that was funded by an FTA Transit Investments in Greenhouse Gas and Energy Reduction (TIGGER) grant in 2010.⁶² The Red Line Westlake Energy Storage System based on flywheels will capture and release regenerated braking energy at the Westlake at-grade rail station and is currently being tested and evaluated.
- Another FTA 2011 TIGGER sustainability award funded the South Eastern Pennsylvania Transit Authority (SEPTA) electric light rail system, which has regenerative braking capability, to deploy WESS in an updated substation on the Market Frankford line and evaluate energy savings. This WESS uses advanced lithium ion batteries for energy storage and reuse at peak loading.⁶³ This complements the 2010 SEPTA WESS pilot project funded by the Pennsylvania Energy Development Authority. SEPTA partnered with Viridity Energy to optimize substation energy storage for return and reuse to the grid; Saft to provide lithium ion batteries for trackside energy storage; Envitech to serve as WESS integrator and use its Vpower software for power quality; and ENVISTORE DC for the DC converter and power control system.⁶⁴

⁶⁰ 2010 TCRP report by M. Schroeder “Guiding the Selection and Application of Wayside Energy Storage Technologies for Rail Transit and Electric Utilities.”

⁶¹ See the ALPS project overview posted at <http://www.cte.tv/darpa/alps.pdf>

⁶² See WESS and other E2 technologies in “Greenhouse Gas Emissions Cost Effectiveness Study” by ICF for LACMTA, 2010 posted at http://media.metro.net/projects_studies/sustainability/images/GHGCE_2010_0818.pdf

⁶³ See SEPTA Sustainability blogs postings at <http://www.septa.org/sustain/blog/2011/07-15.html> and <http://www.septa.org/sustain/blog/2011/11-23.html>

⁶⁴ See details of SEPTA WESS project at <http://www.septa.org/sustain/pdf/viridity-faq.pdf>

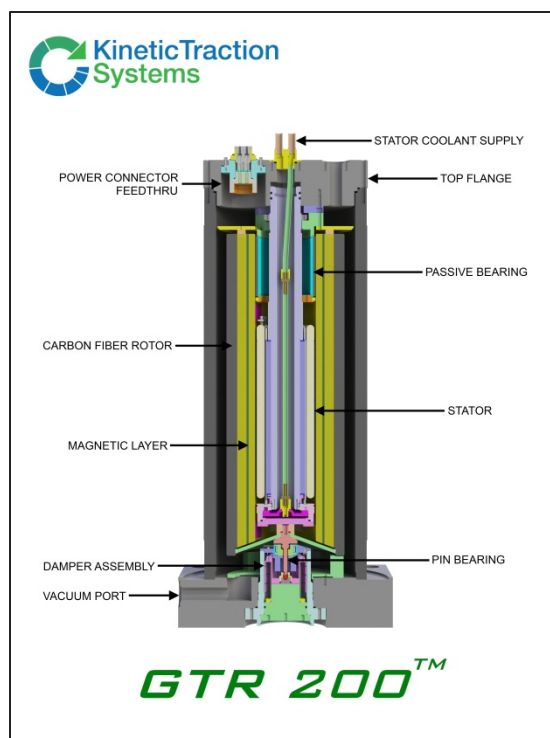


Figure 15. GTR Flywheel WECS⁶⁵

2.3.2 Gensets: Switcher Locomotives with Scalable Power

Class I freight railroads are gradually replacing the single powerful diesel locomotive engine in yard switch locomotives with fuel-efficient Genset switchers. Gensets are particularly useful for maintenance “switching activities” in and around railyards, where the locomotive often must operate at idle, usually near already noisy and congested metropolitan areas. Gensets are equipped with a diesel particulate filter (DPF) that reduces or eliminates PM locomotive emissions.

Gensets have multiple (2–4) smaller off-road diesel engines to provide scalable power on demand, using heavy-duty diesel engines from Cummins, Caterpillar, or Deutz, which comply with Tier 3 EPA emission standards. If motive power is not needed within a certain predetermined time interval, one or more engines are shut down automatically, or enter a sleep mode. Gensets also use LED lighting for better energy efficiency.

Manufacturers of Gensets include: R.J. Corman-Railpower, Caterpillar/Progress Rail, Electro Motive Diesel (EMD), Motive Power/Wabtec, and Brookville. RailPower delivered 98 Gensets to Union Pacific Railroad (UPRR) and claimed more than 40 percent fuel savings and up to 80 percent cuts in oxides of nitrogen (NOx) emissions for its Genset. The National Railway Equipment Company (NREC) Gensets have up to 3 engines of 700 hp (522 kW) each in 1, 2, or 3 engine models. The NREC N-ViroMotive™ road switcher Genset locomotive was certified by CARB in CA and by the Texas Emissions Reduction Plan (TERP) program as an ultra-low

⁶⁵ See <http://www.railwaygazette.com>

emissions locomotive (ULEL). N-Viromotive Gensets are used by CSX and UPRR in yards located in sensitive or nonconformity areas in California, Texas, Indiana, New York, Michigan, and Illinois. In addition to a growing CSX fleet of new Gensets (more than 25 in 2011), NREC has been retrofitting the entire CSX switcher fleet (Figure 16).



Figure 16. CSX New Diesel Genset Switcher Locomotives Operating in Chicago, California, New York, and Indiana Railyards⁶⁶

Gensets were proven to achieve 20–40 percent fuel savings compared with conventional switchers, although UPRR, which pioneered Genset adoption in 2004 and operates more than 165 units in California and Texas, reported fuel savings of only 15–25 percent. New Gensets may be up to six times more expensive, and retrofits during repowering of aging locomotives are more affordable.

Under a State Rail Emissions Reduction Program, the California Air Resources Board (CARB) and railroads entered in 2005 a statewide railyard emissions abatement agreement with UPRR and Burlington Northern Santa Fe (BNSF) Railroad,⁶⁷ committing them to deploy Gensets and idle reduction technologies for railyard switch locomotive fleets and for line haul locomotives operating intra-state. In 2010, BNSF owned and operated two liquefied natural gas (LNG)-powered Gensets and implemented idle-reduction and DPF equipment and training on most of its California diesel locomotive fleet.

NREC also delivered 73 Gensets to BNSF and 60 to UPRR. As of 2009, UPRR operated 70 Gensets in California, and Texas had a similar set of requirements for TERP.⁶⁸

The U.S. Army started to modernize its locomotive fleet with new, energy-efficient Genset locomotives in 2007, when it received new National Railway Equipment (NRE) 3GS-21B locomotives⁶⁹ (see Figure 17). To date, seven such Gensets are in service around various Army locations.

⁶⁶ Photographs © Tim Hurst

⁶⁷ See CARB Railyard Emission Reduction Program postings at <http://www.arb.ca.gov/railyard/railyard.htm>.

⁶⁸ See TERP program postings at http://www.tceq.texas.gov/airquality/terp/program_info.html/.

⁶⁹ See NRE Genset locomotive specifications at <http://www.trainweb.org/Gensets/nre.html>.



Figure 17. First NRE 3GS-21B Genset Locomotive Delivered to U.S. Army as USAX 6500⁷⁰

2.3.3 Diesel Multiple Units (DMUs) and Electric Multiple Units (EMUs)

The self-propelled DMUs may be diesel-electric, diesel-mechanical, or diesel-hydraulic units. DMUs with power-driven wheels are more energy efficient than locomotive-pulled trains and achieve faster acceleration, as well as shorter braking distance. They may be used in distributed power configurations (discussed in Section 2.3.9) when powered cars are linked by cable or radio link communications.

EMUs are also self-propelled railcars, which are individually powered by direct current (DC) from a third rail, or via a vehicle pantograph in contact with the alternating current (AC) overhead catenary system (OCS). EMUs can achieve higher speeds than DMUs, are more energy efficient and environmentally friendly, but cost more. EMUs also require costly OCS electrification infrastructure, traction power conditioning and transfer, as well as multiple traction power substations (TPSS) along the ROW. EMUs are considered the most energy-efficient option for electrified commuter and light rail systems.⁷¹

An AC drive EMU is more energy-efficient than DC traction, although it has an additional step-down transformer to convert the high voltage from the overhead line to a lower voltage for controlling the motors, as well as an AC to DC rectifier (the complete unit is a converter).

EMUs are currently used by commuter railroads with electrified territory, such as MTA's Metro-North Railroad (MNR) operating on three routes in New York and Connecticut, the Long Island Railroad and New Jersey Transit, which operates EMUs on several electrified routes. The NJT Coastline commuter rail locomotives are electrically powered by a 60 Hz, 12.5 kV OCS. MNR uses both newer AC drive EMUs, such as the Bombardier M-7 powered by third rail, and older DC drive EMUs. All SEPTA regional commuter rail lines are electrified with overhead catenary system (OCS) at 12 KV, 25 Hz. The SEPTA commuter rail uses a mixed fleet of EMUs consisting of older GE Silverliner IV, and newer Rotem Silverliner V.

⁷⁰ Source: <http://www.greenrailnews.com/owners/usax.html>; photograph © Mark Mautner

⁷¹ See "The Return of the EMU" in *Rail Magazine* Summer 2012 issue, p 48 at www.railmagazine.org



Figure 18. M-7 EMUs from Bombardier for use by LIRR and Metro-North⁷²

Emerging rail technology options⁷³ offer different degrees of powertrain electrification, as illustrated in Figure 18, Figure 19, and Figure 20. Options include EMUs (such as the EMD AEM-7, or the ABB ALP-44) and dual power locomotives like the Bombardier ALP45DP, which combine diesel engine with electric traction, depending on availability of track electrification infrastructure. The trend toward progressive locomotive electrification promises to improve system E2, especially when electric motors are able to store regenerated braking energy on board, or on wayside (such as Bombardier ALP equipped with EnergyStor).

In January 2013, Amtrak and the California High-Speed Rail Authority (CHSRA) with FRA participation issued a joint Request for Information⁷⁴ for purchase of next generation high-speed trainsets: EMUs are preferred for power distribution among all cars and bi-directional operation with a cab car on each end, which allows for high passenger occupancy of 400 to 600 passengers.

Amtrak's *Acela* trains have electric locomotives at each end, which are powered via pantograph by a 60 Hz, 2x25 KV catenary on its northern segment, and by an older 25 Hz, 12.5 kV catenary on its southern segment.

The SEPTA electrified commuter rail in Pennsylvania and the Chicago METRA Electric Division operate EMUs on the electrified track segments. Some commuter rail trains operate electric locomotives in push-pull configuration. The Metro-North Commuter Railroad and the Connecticut Department of Transportation have purchased and are integrating new Kawasaki Railcar M8 EMUs in their fleet. These cars will eventually replace all 240 M2, 54 M4, and 48

⁷² Photograph © Bombardier; Source: <http://www.bombardier.com/en/transportation/products-services?docID=0901260d800102a8>

⁷³ "Is Full Electric in Our Future?" *Mass Transit Magazine*, June 2012, at <http://www.masstransitmag.com/article/10715700/hybrid-update-is-full-electric-in-our-future>

⁷⁴ See press release at <http://www.amtrak.com/ccurl/620/710/Amtrak-CHSRA-Joint-RFI-HSR-Train-Sets-ATK-13-012.pdf>

M6 railcars which were built by Budd starting in the 1970s. The new M8 car is similar to the M7 car, which is used on the Metro-North Harlem Line and by Long Island Railroad and is able to pick up 750 volt direct current from third rail operation from Grand Central Terminal to Pelham, NY. The M8 is also able to switch to overhead catenary wire via pantograph from Pelham, NY, to New Haven, CT. These cars can also transfer to Amtrak 25kV AC power from New Haven to Boston, MA.



Figure 19. Kawasaki Rail Car, Inc. M8 Railcar EMU for Use by Metro-North and CDOT⁷⁵

2.3.4 Energy Use Monitoring and Idle Reduction Control Devices

The EPA SmartWay program⁷⁶ has certified several locomotive idle reduction technologies available as retrofit kits, which save fuel and reduce locomotive emissions in railyards in and near nonconformity areas. EPA-approved idle reduction technologies and products include:

- **Shore Connection Systems (SCS)** for railyards replace switcher locomotive idling needed to keep the engine warm and control cab HVAC, especially in severe weather, with electrically powered heaters and some fuel-operated heaters.
- **Auxiliary Power Units (APUs) and generator sets** verified for effectiveness by EPA are the Teleflex EcoTrans, the Kim Hotstart Manufacturing Co. products, and the Power Drives, Inc., model DWS-APU. In 2002, CSXT formed EcoTrans Technologies as a joint venture with International Road and Rail Inc., to market the K9 Auxiliary Power Unit

⁷⁵ [http://en.wikipedia.org/wiki/M8_\(railcar\)](http://en.wikipedia.org/wiki/M8_(railcar))

⁷⁶ See idle reduction technologies at www.epa.gov/smartway/technology/idling.htm

(APU). The APU consisted of a turbocharged Kubota diesel engine effectively cooled by water-glycol jacket, coupled to a generator set and shutdown timer, and used to reduce idling fuel waste and emissions. Southwest Research Institute (SwRI) evaluated the K9 effectiveness in yard switching operations in 2003. In 2006, DOE/EERE⁷⁷ considered the EcoTrans K9 technologies to be a commercialization success story for energy efficiency technologies, with more than 3,600 units installed in locomotives, which improved E2 by up to 83 percent and cut emissions (NOx by 91 percent, hydrocarbon (HC) by 94 percent, carbon monoxide (CO) by 96 percent and PMs by 84 percent).

- **Automatic Engine Stop Start (AESS)** systems available as retrofits to improve the performance of older locomotives⁷⁸ include: the GE Transportation AESS; AESS models by Motive Power-Wabtec⁷⁹; and the ZTR Control Systems/Hotstart SmartStart⁸⁰, which integrates the AESS with an Auxiliary Power System (APU) for GE and EMD locomotives. The AESS requires sophisticated control hardware and software for shutdown prevention and smooth locomotive restart in all weather. Examples of smart controllers integrated with AESS are the EMD EM20000 control system⁸¹, and the ELCON traction motor management module⁸², that reduce idle time and associated fuel waste, pollutant emissions, and noise.
- **NS Locomotive Engineer Assist Display and Event Recorder (LEADER®)** was developed by the New York Air Brake Corporation with FRA R&D funding and has been extensively tested and used by Norfolk Southern (NS) since 2004. It logs train operating conditions and monitors fuel burn to create a statistical profile for an optimal, fuel efficient run. It assists engineers to eliminate frequent braking and throttle use, in order to conserve energy. As of mid-2009, NS reported that its Locomotive Engineer Assist Display and Event Recorder (LEADER) helped achieve 25 percent fuel savings per unit coal trains and equipped more than 150 trains with LEADER hardware and software.⁸³
- **CSX Event Recorder Automated Download (ERAD)**: CSX locomotive engineers⁸⁴ are trained on locomotive simulators on the BPs for fuel-efficient train handling. CSX is utilizing the locomotive Event Recorder Automated Download (ERAD) system, leveraging GIS and communication technologies to provide feedback to locomotive

⁷⁷ See “Auxiliary Power Unit Cuts Emissions, Fuel Use in Locomotives” at http://www1.eere.energy.gov/vehiclesandfuels/pdfs/success/locomotive_apu.pdf.

⁷⁸ See Mechanical Equipment for the Eco-Minded,” March 2009 article in *Progressive Railroading*.

⁷⁹ See postings at <http://www.motivepower-wabtec.com/emissions-reduction/>

⁸⁰ See <http://www.hotstart.com/assets/PDF/epafundstestofhotstartapu.pdf>

⁸¹ See EM2000control system retrofit benefits at www.EMDiesels.com

⁸² See http://www.elconinc.net/html/traction_motor.htm

⁸³ See *Progressive Railroading* March 2010, “Class Is Employ Fuel Saving Practices that Promise Stingier Diesel Usage” at <http://www.progressiverailroading.com/mechanical/article/Class-Is-employ-fuelsaving-practices-that-promise-stingier-diesel-usage--22736#>.

⁸⁴ See CSX sustainability BPs listed at <http://corporate-social-responsibility.csx.com/>

engineers on how to improve fuel efficiency, performance, and safety in operations. A scorecard produced by ERAD tracks operational habits (starting/stopping/braking) to optimize performance, and thus improves efficiency. In 4 years, ERAD has contributed to CSX saving more than 20 million gallons (75 million liters) of fuel.

2.3.5 Dual Power Hybrid Locomotives

Bombardier developed the ALP-45DP dual powered (diesel and electric) hybrid locomotive,⁸⁵ which is now being deployed and operated by New Jersey Transit commuter rail. NJT ordered 35 locomotives with an option for more. Two diesel engines are complemented in electrified territory by power from the overhead catenary system. The DP locomotive can reach a speed of 160 km/h (100 mph) under diesel power and up to 200 km/h (124 mph) for electric runs. It will be used in push-pull operation with double deck coaches; for greater efficiency and on-time performance, it can switch from diesel to all-electric operation when the engineer presses a button.



Figure 20. NJ Transit DP Locomotive⁸⁶

2.3.6 Hybrid Electric Locomotives

The future for hybrid electric locomotives using battery stacks to recover braking energy and store it for on-demand delivery looks bright: Pike's Research predicted that by the year 2020 hybrid locomotives will be readily available for the industry, utilizing lead acid or lithium ion large-capacity batteries. This low-cost hybrid technology could reduce emissions by 80 percent over standard locomotives and reduce noise levels and maintenance costs.⁸⁷

RailPower Technologies Corp. (now RJ Corman RailPower) introduced its GG20B hybrid switching locomotive in 2002. The GG20B, marketed as the "Green Goat," was a yard switching

⁸⁵ See <http://www.bombardier.com/en/transportation/products-services/rail-vehicles.html#1365795278211>

⁸⁶ Photograph courtesy of Bombardier

⁸⁷ "Hybrid Electric Locomotives Will Utilize 514 Megawatt Hours of Battery Capacity by 2020." Pikeresearch.com. 9 Aug. 2011. 20 Dec. 2011. <http://www.pikeresearch.com/newsroom/hybrid-electric-locomotives-will-utilize-514-megawatt-hours-of-battery-capacity-by-2020>

locomotive and used three sets of lead acid battery packs capable of generating up to 1,200 hp (895 kW) (see Figure). The batteries were charged using an on-board 300 hp (224 kW) diesel engine manufactured by Deutz. The GG20B locomotive was EPA-certified as Tier 3 compliant and had relatively low acoustic emissions. The Green Goat hybrid electric switcher locomotive had a small diesel engine and a large battery pack consisting of 330 rechargeable lead acid batteries on-board to supply peak power on demand while the diesel engine recharged the batteries. This configuration eliminated idling energy waste, which amounts to 75 percent of operational time and wastes approximately 30 percent of fuel in conventional switchers.

In 2007, 59 units were recalled in Fort Worth, TX, following the on-board fire of a Green Goat yard switcher after a lightning strike. Railpower repaired all Green Goats, or converted some to Genset switchers. As of 2009, there were 12 Green Goats operating in California.

The Green Goat hybrid-electric switcher locomotives showed fuel savings of 30–80 percent, with commensurate environmental benefits due to lower fuel burn, an efficient catalytic converter, and particulate reduction technologies. These hybrids also achieved lower operating costs as well as lower noise. Hybrid locomotives are expensive, with an average payback of more than 8 years. Fuel-efficient, battery-assisted diesel hybrid switcher locomotives will be used increasingly in railyards to meet EPA emission standards. The advanced storage battery and power control electronics are widely applicable.



Figure 21. RailPower-RJ Corman Green Goat (GG) Hybrid Switcher Locomotive⁸⁸

GE Transportation developed and released in 2010 the demonstrator ES44HAC Evolution hybrid locomotive,⁸⁹ which captures braking energy and stores up to 2,000 hp in rechargeable heavy-duty, sodium nickel chloride batteries for reuse on demand, thus reducing fuel consumption up to 15 percent and emissions by up to 50 percent compared with conventional freight locomotives (Figure 22–24). GE also announced a \$100 million program to build large capacity sodium sulfur batteries (which operate at high temperature) for the energy storage systems of its own hybrid locomotive. This prototype meets the EPA 2015 Tier 4 emissions standard. Other Tier 4 locomotives are available: EMD released a prototype in November 2011.

⁸⁸ Source: <http://www.reuters.com/article/idUSN0144320620070601>; photograph © Bob Lehmuth

⁸⁹ <http://www.ge.com/about-us/ecomagination>

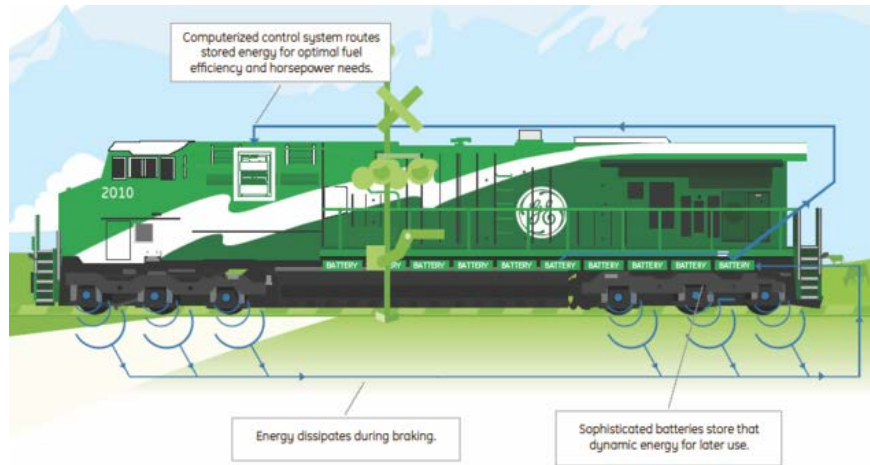


Figure 22. GE Hybrid Electric Locomotive Schematic and Battery Module⁹⁰

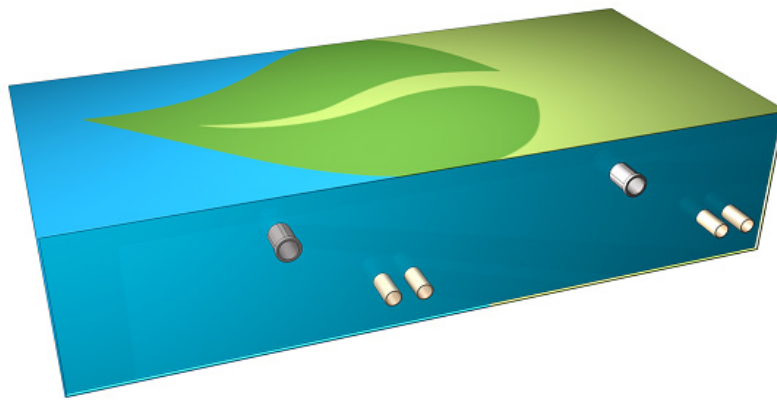


Figure 23. GE Battery Module for Hybrid Electric Locomotive⁹¹



Figure 24. GE Evolution Hybrid Locomotive Demonstrator

⁹⁰ Source: [ES44HAC GE Demonstrator Side.jpg](#) and <http://www.railwayage.com/index.php/mechanical/locomotives/ge-unveils-prototype-for-next-evolution@-series-locomotive.html#.UEdSIbKPXyA>; courtesy of General Electric Company

⁹¹ Source for Figures 24, 25: [ES44HAC GE Demonstrator Side.jpg](#) and <http://www.getransportation.com/rail/rail-products/locomotives/hybrid-locomotive.html>, courtesy of General Electric Company

2.3.7 Battery Electric Locomotive

The experimental NS all-electric switcher locomotive NS999⁹² is a 1,500 hp (1,118 kW) battery-electric prototype, developed with DOE and FRA support in partnership with Pennsylvania State University (Figure 25). It was tested and evaluated in Altoona, PA, in 2009 for yard operations and demonstrated in California in 2010. The RESS consists of 1,080 12 Volt advanced Absorbent Glass Mat (AGM) lead-acid batteries that store the regenerated braking energy from its dynamic braking system. In 2010, Axion Power International (API) developed a battery management system (BMS) to improve the charge/discharge cycling of battery-powered switcher locomotives for urban railyard operations. The original 999 battery was a very large advanced lead acid AGM model. Since then, NS hired Axion Power⁹³ to develop advanced lead carbon (PbC) batteries and a BMS for a refurbished NS999, which would be capable of efficiently storing and delivering regenerated braking energy. In 2012, NS ordered from Axion its higher performance PbC batteries for use in NS999 and future retrofits. The new batteries were delivered to NS in January 2013 to undergo integration and performance testing.⁹⁴ Currently, NS and Axion are partnering to develop battery power for a larger and twice as powerful electric, long-haul locomotive.



Figure 25. NS999 Prototype 1500 HP Battery Electric Switcher Locomotive⁹⁵

2.3.8 Efficient and Ultra-Clean Diesel-Electric Locomotives and Repower Kits

Several new locomotive prototypes in test and evaluation are able to meet the EPA Tier 4 emission limits being phased in by 2015, which will reduce by approximately 70 percent NO_x and particulate emissions, relative to 2005 emission values. GE describes its Evolution series diesel-electric locomotive with 12 cylinder engine as its most technologically advanced, fuel-

⁹² See “Batteries Are Included” at <http://www.nscorp.com/nscportal/nscorp/Media/News%20Releases/2009/batteries.html>

⁹³ <http://seekingalpha.com/article/540501-battery-powered-locomotives-compellingly-green-economics> and <http://www.prnewswire.com/news-releases/axion-power-tm-to-work-with-norfolk-southern-on-battery-driven-locomotive-project-95943869.html>

⁹⁴ See <http://www.prnewswire.com/news-releases/axion-power-pbc-batteries-continue-to-demonstrate-effectiveness-for-railroad-applications-186452901.html> and <http://seekingalpha.com/article/540501-battery-powered-locomotives-compellingly-green-economics>

⁹⁵ Photograph courtesy Norfolk Southern

efficient, and environmentally compatible (Tier 2 and 3), with over 3,700 locomotives operating in 10 countries. It is more efficient than the GE 16 cylinder PowerHaul diesel electric locomotive, also part of Evolution series.

Since 2003, more than 5,000 GE Evolution series locomotives, designed to save 9 percent fuel compared with current fleet average and meet the Tier 2 EPA standards, are operating in the United States and globally. The latest GE Evolution heavy-haul locomotive prototype that meets Tier 4 standards was unveiled in August 2012.⁹⁶ Its advantage over competing clean Tier 4 locomotives is that it does not require urea additives to the Selective Catalytic Reduction (SCR) used to reduce exhaust NO_x emissions and therefore requires no expensive infrastructure upgrades to store and supply urea. Alternatives include the Progress Rail and SwRI Ultra Clean Diesel Locomotive (UCDL) using urea-based SCR after-treatment certified by SwRI in Texas; and the UP 9900 experimental Tier 4 lower power EMD locomotive with three after-treatment systems being evaluated for 18 months near Sacramento, CA.

Since locomotives have a typical life of 40 years, and new locomotives are costly, the more cost-effective option to achieve E2 and E3 improvements is to retrofit aging locomotives with **repower kits** that reduce emissions and fuel burn. In 2010, Progress Rail Services (PRS), a Caterpillar division, purchased Electro Motive Diesel (EMD) which has long been manufacturing locomotives, with the goal of repowering switcher low power, medium power regional, and powerful long-haul locomotives with cleaner operation and efficient traction.

For instance, the 8,500 EMD 710 engines and 10,000 AR-10 alternators would be reconditioned into the 710ECO or EM22ECO by adding the EM2000 digital control system for optimized burn and an integrated AESS for idle reduction. The 710ECO™ Repower locomotives (Figure 26) minimize fuel consumption while maintaining emissions compliance; they achieve up to 25 percent fuel savings and 50 percent lube oil reductions, which are important benefits for railroads facing rapidly escalating fuel costs. Similar kits for repowering Gensets are also available.

Demonstrated 70 percent reduction in emissions makes these EPA certified kits eligible for both State and Federal funding as clean air projects, able to meet Tier 2 and 3 criteria cost-effectively.

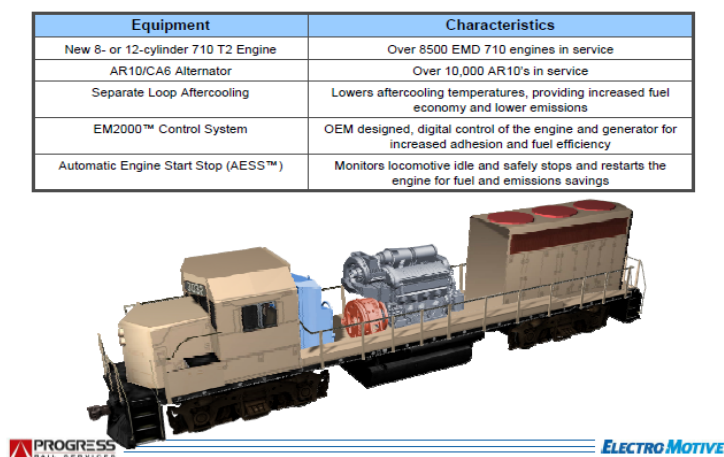


Figure 26. 710ECO Repower⁹⁷

⁹⁶ See www.genewcenter.com/Press-Releases/GE-Unveils-the-First-Tier-4-Heavy-Haullocomotive-3aa1.aspx

⁹⁷ Source: <http://www.progressrail.com/repowered-locomotives-710ECO.asp>; © Progress Rail Services

At the 2011 APTA Expo, EMD announced a 125 mph (201 km/h) Tier 4 diesel passenger locomotive demonstrator powered by Caterpillar engines, microprocessor controlled, and scheduled for release in 2014.

The Brookville Equipment Corporation⁹⁸ has developed new passenger and multipurpose locomotives that will operate cleaner and with less fuel than their predecessors. Pictured below are units for South Florida Regional Transportation Authority and MNR.

- **Brookville BL36PH** – A next generation 4-axle diesel-electric passenger locomotive featuring a Tier 4 ready main engine and separate head end power (HEP) package. The locomotive is constructed with a modern all-steel aerodynamic nose and semi-monocoque frame providing a safe and lightweight unit built to operate efficiently (Figure 27).
- **Multipurpose BL20GH** – A multipurpose locomotive that can be used for both passenger and freight applications. This unit is designed with a separate HEP generator so it can be used as a freight switcher or a passenger locomotive for small passenger lines (Figure 28).



Figure 27. Brookville Passenger BL36PH



Figure 28. Brookville Multipurpose BL20GH

⁹⁸ See <http://www.brookvillecorp.com/locomotive-passenger.asp>; images courtesy of Brookville Equipment Corp.

2.3.9 Distributed Power Management and Control Technologies for Freight Rail Consist Fuel Savings

Distributed power places locomotives in the middle, as well as at ends of trains instead of the traditional push-pull configuration. Distributed locomotive power along a heavy and long train consist is increasingly used by freight trains, since it offers greater E2 (by approximately 5 percent) than push-pull configurations. In a distributed power configuration, several locomotives are physically spaced along the train consist and controlled remotely (by radio control from the leading, or both head-end units).

Distributed power also increases safety because it makes a train less prone to derailments by reducing the physical braking and turning forces on a train, thereby evenly distributing the force on rail-car couplers. Distributed power facilitates more even braking and can potentially reduce wheel and track wear and shorten the stopping distance. Freight railroads have realized 4–6 percent fuel savings on distributed power trains versus trains using conventional power.

Distributed power management and control software enables optimization of power distribution for a desired speed curve. For instance, the GE Transportation Locotrol-distributed power management device and software are widely used by CSX and UP for heavy freight, like coal trains. Other providers, such as Canac and Wabtec, offer competing products for the distributed power market. The BAE Systems HybriDrive for hybrid locomotives and LTK also offer power management products tailored to specific rail technologies.

For instance, NS has achieved up to 30 percent fuel savings with distributed power, by combining ECP brakes that communicate along the consist with GE's Locotrol, with the LEADER train management and control system. UP has successfully used distributed power for fuel savings, with multiple locomotives placed by optimizing tons-per-equivalent-powered-axle (TPA) instead of horsepower/ton. UP has also installed AESS devices on its locomotives fleet and deployed Gensets.

2.4 Software Tools for Streamlined Operations to Enhance E2

2.4.1 Trip Logistics and Optimization Software

The GE Evolution series diesel electric locomotives for Class I freight railroads can be integrated for better fuel efficiency with the GE Locotrol distributed-power and Trip Optimizer energy management software for operational optimization and engine control. The Trip Optimizer (Figure 29) automated throttle controller automatically optimizes the locomotive speed profile and minimizes braking, based on train length, weight, grade and track conditions, and weather. It has been implemented successfully on 200 Canadian Pacific (CP) freight locomotives since 2009, achieving up to 6–10 percent annual fuel savings on certain routes. Although the Trip Optimizer improves fuel efficiency by only 1 percent for the average mainline locomotive, this translates into annual fuel savings of 32,000 gallons (121,600 liters), 365 tons (328,500 kg) of GHG, 5 tons (4500 kg) NO_x, and 0.2 tons (180 kg) of PM cuts. This software is also compatible with the GE LOCOTROL distributed power controller and the GE's RailEdge Trip Planner to secure further fuel savings of 3–15 percent, depending on the territory.



Figure 29. GE Trip Optimizer Software Used for Status Display in Locomotive Cab⁹⁹

The GE Trip Optimizer can be coupled to other GPS tracking and scheduling software in the GE Evolution series of energy efficient, eco-friendly railroad products: auto-engine start-stop; automated Notch 8 Fuel Economy to adjust the power; the AccuFuel gage measuring fuel level for improved monitoring and management; and the engine Smart Burn optimizer to balance engine performance over the duty cycle. Implementation of the full suite of GE Fuel Savings Solutions can improve locomotive efficiency by up to 10 percent. CSX uses LEADER, an Event Recorder Automatic Download (ERAD), and locomotive and engineer operations monitoring software,¹⁰⁰ which is enabled by GIS, GPS, and communication capabilities. Software tools require operator training to save fuel: for instance, the UP Fuel Masters program, which monitors engineers' fuel consumption performance by territory, promotes idle reduction, and rewards conservation, is an industry model. The BNSF Fuel Most Valuable Player (MVP) program¹⁰¹, introduced in 2007, rewards locomotive engineers using fuel-efficient train handling practices and measures their performance with a fuel-efficiency scorecard. By agreement with the Brotherhood of Locomotive Engineers (BLE), BNSF has trained and rewarded with gift cards those engineers who (1) reduced locomotive idling, which burns an average of 5 gallons (19 liters) of fuel per hour; (2) avoided stretch braking, which consumes on average 5 gallons (19 liters) of fuel per braking; and (3) promoted consistent wheel lubrication to reduce wheel-rail friction by 40 percent. Many TOR lubrication products and friction management options offer both friction reduction and fuel savings.¹⁰²

2.4.2 Efficient Rail Operations on Shared Track

The Northeast Corridor is the busiest rail corridor in the United States, with 2,200 trains operating daily on shared track and ROW. Fifty freight trains a day from the major Class I and regional railroads (CSX, NS) and regional (Connecticut Southern, Conrail, Pan Am Southern)

⁹⁹ Source: <http://www.gereports.com/ges-fuel-autopilot-software-set-for-200-locomotives/>; photograph courtesy General Electric Company

¹⁰⁰ CSX Fuel Efficiency postings at <http://www.csx.com/index.cfm/about-csx/projects-and-partnerships/fuel-efficiency/>

¹⁰¹ See 2008 news release at <http://www.teradata.com/newsrelease.aspx?id=84>

¹⁰² See April 2012 article at <http://www.progressiverailroading.com/mow/article/Maintenance-of-way-technology-Topofrail-lubrication-and-friction-modifiers--30591>

share track with the Amtrak *Acela* high-speed express and regionals trains. In addition to the Amtrak and freight trains, commuter rail services operated by transit agencies Massachusetts Bay Transportation Authority (MBTA), New York Metro-North, Long Island Railroad, South East Pennsylvania Transit Authority-SEPTA, New Jersey Transit-NJT, Maryland Transit Administration Commuter Rail-MARC, and Virginia Railway Express-VRE also share the right of way along the Northeast Corridor. Fuel efficiency improvements can be achieved through more efficient asset management operations, scheduling, tracking, and dispatch, as well as by maintaining an optimal speed profile for fuel burn and reducing idling on sidings while waiting for other trains to pass. Northeast Corridor infrastructure upgrades and repairs currently underway, thanks to ARRA and Passenger Rail Investment and Improvement Act (PRIIA) of 2008 funding, will improve the shared rail infrastructure for operational and E3 gains, as detailed in the cooperatively developed 2010 “Northeast Corridor Infrastructure Master Plan.”¹⁰³

Although HSR systems abroad operate on dedicated ROW and tracks for high-speed efficient and safe operations, the same is not possible or practical in the United States, where the legacy infrastructure that must be shared and maintained slows both passenger and freight rail operations. As the *Acela* has proven, the shared-use HSR system can be improved incrementally by building more dedicated segments over time as ridership increases and benefits become clear.

Major benefits of shared-use of rail network infrastructure are:

- Lower costs for all partners as a result of sharing maintenance costs of tracks and facilities;
- Reduced economic, environmental, and social impacts;
- Improved accessibility since shared-use enables HSR trains to use rail stations in city centers;
- Network utilization benefits since transit and commuter rail lines feed passengers to HSR hubs and lines.

Adoption of PTC and GPS or radio communications, navigation, tracking, and control systems are enabling safer shared operations and more efficient routing, scheduling, and dispatch. However, as discussed in a recent NCHRP report,¹⁰⁴ rail operations on shared ROW for passenger, freight, and commuter railroads may pose major challenges to speed optimization for on-time arrivals and to achieving further energy-efficiency gains.

¹⁰³ See NEC Infrastructure Master Plan posted at <http://www.amtrak.com/ccurl/870/270/Northeast-Corridor-Infrastructure-Master-Plan.pdf>

¹⁰⁴ TRB/NCHRP Report 657 *Guidebook for Implementing Passenger Rail Service on Shared Passenger and Freight Corridors*, 2010 at http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_657.pdf

3. Alternative Fuels for Environmental Sustainability

3.1 Hydrogen Fuel for Fuel Cell Hybrid Locomotives

In order to pursue environmental improvements in the rail industry for compliance with current Tier 3 and the 2015 Tier 4 EPA standards, alternative fuels for locomotives are a necessary stepping-stone. Several options for emerging locomotive fuels are discussed below.

Use of hydrogen fuel cells in locomotives can reduce the amount of particulate pollution around rail lines and reduce the amount of GHG expelled into the atmosphere. Hydrogen fuel cell locomotives can also reduce railroad dependency on fossil fuels.

A partnership between BNSF, the U.S. Army, and Vehicle Projects, LLC as designer and leader has developed and demonstrated a fuel cell hydrogen locomotive prototype for railyard switching operations. The goal was to reduce dependence on fossil fuel and improve energy security, as well as minimize the environmental impact of locomotive engines.¹⁰⁵ BNSF partners included RailPower Hybrid Technologies (the Montreal manufacturer of the basic Green Goat locomotive); Dynetek Industries of Calgary, Alberta (provider of pressurized hydrogen tanks); General Atomics of San Diego, CA, a developer of power electronics; the University of Nevada, Reno, as designer of the refueling system; and others. The prototype was unveiled in Topeka, KS, in January 2009. It then traveled to Transportation Technology Center in Pueblo, CO, for additional testing, and then was sent to California in 2010. It was tested in the Los Angeles railyards in Commerce and Hobart through 2010 and 2011. In 2012, BNSF was awarded Patent No. 8,117,969 for the fuel cell locomotive design.¹⁰⁶

The hydrogen hybrid locomotive design is based on a commercial diesel hybrid platform: the locomotive cab includes batteries to drive electric traction motors, which are recharged by a Ballard fuel cell stack rated at 240 kW (322 hp) (continuous), with light composite hydrogen fuel tanks storing 70 kg (154 lb) of hydrogen at 350 bar (5,076 psi) on the roof, associated power electronics, and battery ventilation. If battery temperatures become excessive, as in the event of a fire, temperature sensors would activate pressure relief devices to ventilate the batteries as well as the hydrogen fuel cells.¹⁰⁷

The locomotive also had 9,000 kg (19,842 lb) of ballast added, displacing the traditional diesel fuel tanks. This design was said to reduce both air and noise pollution in railyards and provide a contingency for mobile backup power of up to 200 kW (268 hp). The primary technology concern is the hydrogen storage capacity and the limited range between refuelings. The fuel cell recharges the battery, which drives the electric motors. The locomotive includes 9,000 kg (19,842 lb) of ballast added to provide sufficient traction between wheels and tracks.

The hydrogen-fueled switch locomotive was unveiled by BNSF in a Los Angeles yard in January 2010, where its operation was evaluated and the technology refined.¹⁰⁸ (See Figure 30 and Figure 8.)

¹⁰⁵ http://www.energy.ca.gov/2009-ALT-1/documents/2009-09-29_workshop/presentations/Vehicle_Projects_presentation.pdf and <http://www.hydrogencarsnow.com/blog2/index.php/hydrail/jr-east-demonstrates-worlds-first-commuter-hydrogen-train/>

¹⁰⁶ See www.fuelcellpropulsion.org/projects.html

¹⁰⁷ Miller, A. "System Design of a Large Fuel Cell Hybrid Locomotive." 2007
http://www.vehicleprojects.com/docs/System%20design_Manuscript%2006%20Sep%2007_.pdf

¹⁰⁸ "Hydrogen fueled locomotive unveiled," <http://www.oregister.com/news/-231592--.html>



Figure 30. BNSF Hydrogen Fuel Cell Hybrid Switcher Locomotive Demonstrated in 2010¹⁰⁹

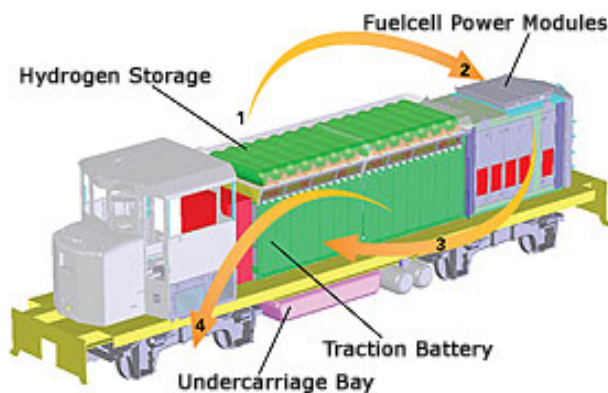


Figure 8. Schematic of the BNSF Fuel Cell Locomotive Prototype¹¹⁰

The International Union of Railways (UIC) HyRail Consortium, funded by the European Commission 6th Framework Programme (FP6, 2002 to 2006), conducted a technology feasibility study of fuel cell locomotive platforms and hydrogen supply for rail operations and established the Hydrogen Railway Applications Lighthouse.¹¹¹ International conferences were conducted to establish a vision, define the R&D agenda, and coordinate globally a deployment strategy for the Hydrail technology initiative. Korea, USA, Canada, Italy, and Japan are considering using or are already using the fuel cell for rail propulsion. The 2009 International Hydrail Conference, held at UNC-Charlotte,¹¹² featured emerging applications of hydrogen fuel cells for both transit and rail. By 2012, fuel cell mining locomotives were tested in South Africa, FC-powered light rail trains entered service in China and Aruba, and FCs for rail infrastructure were used in the UK.¹¹³

¹⁰⁹ See <http://www.hydrogencarsnow.com/blog2/index.php/hydrail/bnsf-hydrogen-hybrid-train-meets-gov-arnold-schwarzenegger/>

¹¹⁰ See <https://www.bnsf.com/communities/environmental/fuel.html>; image courtesy BNSF

¹¹¹ <http://www.hyrrail.eu/pages/introduction.html>

¹¹² www.hydrail.org

¹¹³ See news posted at <http://hydrail.org/>

3.2 Natural Gas (CNG, LNG) Locomotives



Figure 32. Burlington Northern LNG Locomotive with Tender Car Attached¹¹⁴

Natural gas has a rather short past as an alternative fuel with the railroad industry, including just 18 years of LNG locomotive service in California. In the 1980s, the former Burlington Northern Railroad utilized natural gas-powered locomotives (Figure 32). Morrison Knudsen, now Motive Power Inc., built four LNG switch locomotives in the early 1990s. UP owned two of the LNG switch locomotives, but transferred ownership to BNSF in the mid-1990s. As a result, all four of the LNG switch locomotives are operated by BNSF in the Los Angeles area. BNSF's four LNG switch locomotives are the only active operating LNG switch locomotives in the United States. In 1999, the Napa Valley Wine Train installed a 60 percent compressed natural gas (CNG) locomotive; a full 100 percent CNG locomotive was put into service in 2008. (See Figure 33.)

¹¹⁴ Image courtesy BNSF



Figure 33. Napa Valley Wine Train Locomotive #73¹¹⁵

In 2007, a coalition of BNSF, UP, AAR, and California Environmental Associates completed an evaluation of the reliability and operational efficiency of natural gas-fueled locomotives. Dealing mostly with retrofitting freight locomotives with a natural gas conversion system and developing new high-horsepower natural gas-fueled locomotives, it was found that there is no NOx or particulate emissions benefit to using a natural gas fueled locomotive. The locomotives were less energy efficient and produced more GHG than their diesel-powered locomotive counterparts. It was proven that natural gas locomotives are not more cost effective either. The North American natural gas market is too unstable and the investment necessary in new infrastructure is too great to be cost effective.¹¹⁶

In October 2012, FRA hosted a Natural Gas Locomotive Technology Workshop at the DOE Argonne National Lab (ANL), which highlighted success stories and BPs in the field of natural gas technology advancement. Topics ranged from modern combustion technology for dual fuel (diesel and natural gas) locomotives to the need for regulatory review of standards for natural gas equipment and emissions. Presentations were made from around the rail industry, highlighting not only the usefulness of natural gas, but the substantial obstacles in the way of large-scale adoption.

Westport Innovations is collaborating with Caterpillar to develop natural gas fuel systems for locomotives and certain mining trucks. This project will use high-pressure direct injection technology for combustion and should be ready in approximately 5 years. The main goals are to create full horse powered, emissions-compliant, mainline locomotives with interchangeable tender cars. This technology will require the use of only 5 percent of diesel fuel for combustion; therefore, 95 percent of the diesel fuel will be replaced with natural gas that will allow the locomotive to maintain full horsepower. Funded by Sustainable Technology Development Canada, Westport Innovations in partnership with Canadian National (CN) Railway, EMD, and Gaz Metro, plans to unveil a fully functioning LNG high-pressure direct-injection fuel system (HDPI) in 2014, with testing of in-revenue-service of two LNG fueled mainline diesel-electric

¹¹⁵ Photograph © Steve Hoffman

¹¹⁶ Caretto, L., Fritz, S., Hedrick, J., Iden, M., Schmid, L., Stehly, M., Trump, A., Wheelles, D., Weldon, S. "An Evaluation of Natural Gas-Fueled Locomotives." November 2007.

locomotives currently underway in Alberta, Canada.¹¹⁷ For demonstrations, Westport plans to utilize a multipurpose LNG tender car equipped with a pump and vaporizer to inject high-pressure compressed natural gas (HPDI) into the locomotive.¹¹⁸ (See Figure 34.)

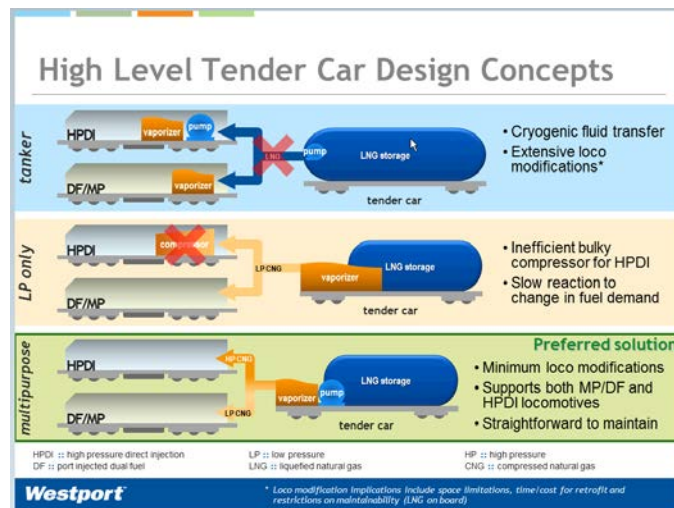


Figure 34. High-Level Tender Car Design Concepts by Westport¹¹⁹

Energy Conversions, Inc. is also working in collaboration with BNSF and others to create convertible engines with dual fuel systems. This system allows for up to 92 percent diesel replacement, while also being nonintrusive and easy to install. It utilizes low-pressure direct injection (LPDI), without need for a pump, and reduces NO_x emissions caused by premixed combustion. However, thermal efficiency is a potential issue with LPDI technology—4 to 6 percent energy loss. This system could save up to 300,000 gallons (1.1 million liters) of diesel fuel per year per locomotive.¹²⁰ In 2013, BNSF will begin its testing of LNG on a small number of locomotives. BNSF believes that the economics and technology have improved enough to make natural gas in long-haul locomotives operationally feasible.¹²¹

Biofuels and Blends with Petrodiesel

Biofuels are liquid fuels derived from renewable and, fundamentally, nonexhaustive energy sources. Their production involves the conversion of biological materials into liquid fuel where the feedstock is plant or animal products or organic wastes, rather than fossil fuels. Biodiesel fuel (also known as mono-alkyl ester) is a byproduct of a chemical process, transesterification, in which glycerin is separated from fat or vegetable oil, usually using a base-catalyzed technique. Biodiesel is manufactured from vegetable oils, animal fats, or recycled restaurant greases and reacted with alcohol to produce fatty acid mono-alkyl ester. Currently, biodiesel is made primarily from soybean oil, but other raw materials, such as vegetable or animal fats, may also be used.

¹¹⁷ See <http://www.railwayage.com/index.php/mechanical/locomotives/cn-testing-lng-fueled-main-line-locomotive.html>

¹¹⁸ Westport Innovations. "Research and Development Priorities Natural Gas Locomotive and Tender Car." October 2, 2012.

¹¹⁹ Ibid; image © Westport Innovations

¹²⁰ Energy Conversions Inc. "Locomotive Natural Gas Conversions." October 3, 2012.

¹²¹ <http://www.progressiverailroading.com/prdailynews/news.asp?id=35446>

Biodiesel can be blended with petroleum diesel in any percentage to create a biodiesel blend. Blended biodiesel is denoted by the percentage of biodiesel it contains. For example, B20 contains 20 percent biodiesel and 80 percent petroleum diesel, while pure biodiesel is known as B100. Conventional diesel can contain up to 5 percent biodiesel and be used in any diesel engine applications. Blends of 6 to 20 percent (B6 to B20) can be used in many applications that use petroleum diesel with a few minor or no modifications to the equipment. Blends over 20 percent require special handling and may require equipment modifications.

The following are some general properties of biodiesel as an alternative transportation fuel:

- Nontoxic, biodegradable, and reduces serious air pollutants (i.e., PM);
- B20 can generally be used in unmodified diesel engines;
- Can be used in pure form (B100) but may require engine modifications;
- Has a higher cetane number and provides more lubricity;
- B20 contains 8 percent less energy content per gallon than does #2 diesel fuel.

For on-road use of B20, this 8 percent decrease in energy content equates to a 1 to 2 percent loss in fuel economy. However, on-road users of B20 report no noticeable difference in torque or power.¹²² The American Society for Testing and Materials (ASTM) defines the fuel standard for biodiesel. The ASTM biodiesel standard represents the minimum accepted values for properties of the fuel needed to provide adequate customer satisfaction and/or protection. The ASTM standard for biodiesel in blends of B6 to B20 is ASTM D7467-09A.

The general conclusions of the EPA's analysis on biodiesel showed that the B20 blend of biodiesel reduced fuel economy by 1 to 2 percent. Also, while emissions of CO, HC, and PM all showed a net decrease compared with diesel fuel, NO_x emissions increased by approximately 2 percent over traditional diesel fuel measurements.¹²³ To date, there has been limited testing of biodiesel use in locomotive engines. In 2000, SwRI conducted a test of several blends of biodiesel on a 2,000 horsepower General Motors Electro-Motive Diesel, Incorporated (EMD) GP 38-2 Tier II passenger locomotive engine. The findings of the study concluded that the locomotive engine was able to produce around 98 percent of full rated power when using the biodiesel blends. This result is similar to the fuel economy reduction that was observed in EPA's analysis for other diesel engines. SwRI also observed that there was a 4 to 6 percent NO_x increase for the B20 blend compared with the EPA-certified diesel fuel.¹²⁴

In 2012, Amtrak, with FRA support, completed emissions testing on a locomotive using B20 biodiesel-blended fuel. The emissions test was performed by GE Transportation Services. Prior to the emissions test, the locomotive, a GE P-32, was used in revenue passenger service on Amtrak's route from Fort Worth, TX, to Oklahoma City, OK. The revenue service test lasted 12

¹²² National Renewable Energy Laboratory (NREL). *Biodiesel Handling and Use Guide*. Golden, CO: U.S. Department of Energy.

¹²³ EPA, *Comprehensive Analysis of Biodiesel Impacts on Exhaust Emissions*, EPA420-P-02-001, October 2002.

¹²⁴ S.G. Fritz, *Evaluation of Biodiesel Fuel in an EMD GP38-2 Locomotive*, Southwest Research Institute, NREL/SR-510-33436, May 2004. Note: FRA will release in 2013 a new emission testing report conducted by SwRI with 5 percent and 20 percent biodiesel with EPA certified fuel and CARB diesel. The report is being edited by FRA and should be released in 2013.

months. The biodiesel fuel was derived from animal fat through the transesterification process. This test demonstrated that the B20 biodiesel fuel does not adversely affect the locomotive. The emissions, powering, and fuel-consumption performance results were all comparable to locomotives using regular diesel fuel.¹²⁵

In the industry, biofuels have been slow to be adopted, but there have been some success stories. The Dynamic Fuels project, started by biofuels developer Syntroleum Corp. and Tyson Foods Inc., has partnered with Mansfield Oil Co. and NS to integrate “renewable diesel,” or fuel that comes from recycled sources, into NS’s fleet. This biofuel, consisting of animal fat, vegetable oil, and other renewable sources, will be used as a replacement for petroleum diesel, with no modifications to the locomotives. The U.S. Navy has also purchased 450,000 gallons (1.7 million liters) of biofuel.¹²⁶

BNSF also signed on for a trial, using B20 in a diesel locomotive in northern Montana. Locally sourced biodiesel, made up of alternative feedstock sources, was used. Oxidation, fuel stability, acid content, degradation, and emissions were measured during trips. The results were promising and have led BNSF to believe that biofuels are the future of the railroad industry’s fuel.¹²⁷

Fischer-Tropsch fuels are synthetic alternatives to petroleum fuel. The Fischer-Tropsch process was developed in 1923 by German scientists Dr. Franz Fischer and Dr. Hans Tropsch. Fischer-Tropsch is a liquefaction process that converts gas or coal to liquid fuel. The United States Air Force Research Laboratory has conducted an analysis of a natural gas derived Fischer-Tropsch fuel that was blended at various volumes with JP-8 aviation fuel that was used to power a T63 turbo shaft engine. The results of the analysis showed that the synthetic fuel blend significantly reduced PM emissions which can be attributed to the reduced aromatic content of the synthetic fuel.¹²⁸

Currently, Fischer-Tropsch diesel fuel is not designated as a Federally defined alternative fuel under Energy Policy Act of 1992 (EPA 1992). In order to achieve this designation, DOE must find that the fuel is (a) substantially nonpetroleum based, (b) yields substantial energy security benefits, and (c) offers substantial environmental benefits. Upon its last review, DOE has verified the first two requirements, but was unable to find that Fischer-Tropsch diesel is likely to yield net environmental benefits. However, DOE has been petitioned by industry to pass rulemaking approving Fischer-Tropsch diesel as an alternative fuel under EPA 1992 (section 301(2)), and an open docket is now maintained on the rulemaking issue.¹²⁹

¹²⁵ Deitchman, Roy, Shurland, Melissa, Smith, Wade. “Emissions Testing of An Intercity Passenger Locomotive Operating on B20 Biodiesel Fuel.” JRC2012-74061. Philadelphia, PA. 17 Apr. 2012.

¹²⁶ Walton, Rod. “Dynamic Fuel Signs on Norfolk Southern.” February 15, 2012. http://www.tulsaworld.com/business/article.aspx?subjectid=49&articleid=20120215_49_E1_Tulsab667660

¹²⁷ Voegelé, Erin. “Steaming ahead to a Better Fuel.” June 14, 2011. <http://biodieselmagazine.com/articles/7859/steaming-ahead-to-a-better-fuel>

¹²⁸ Corporan, E., DeWitt, M., Belovich, V., Pawlik, R., Lynch, A., Gord, J., Meyer, T., Emissions Characteristics of a Turbine Engine and Research Combustor Burning a Fischer-Tropsch Jet Fuel. *Energy & Fuels*, 2007, 21, 2615-2626.

¹²⁹ Proposed Rules, Federal Register. “Alternative Fuel Transportation Program; Fischer-Tropsch Diesel Fuels (Docket number EE-RM-02-200).” February 14, 2005. <http://edocket.access.gpo.gov/2005/pdf/05-2779.pdf>

The Coalition for Sustainable Rail (CSR), a new partnership between the University of Minnesota and Sustainable Rail International (SRI)¹³⁰, is also researching cleaner rail technology. By utilizing torrefied biomass, or biocoal, as an alternative to regular coal, emissions can be reduced on a steam engine. This technology would theoretically be more powerful than the diesel electric locomotives, reaching speeds up to 130 miles per hour (209 km/h). Although this new biocoal is not as cheap as regular coal, it is still less expensive than the current diesel electric locomotives. The CSR is currently working on converting an old steam engine from 1937 to run on biocoal, hopefully showing that steam engines can be operated and maintained economically and are environmentally friendly. These claims for a powerful, carbon-neutral locomotive powered by biocoal are under active research and are as yet unproven.

¹³⁰ See Marchetti, Nino. "Biofuel Steam Locomotive Tomorrow's Cleaner Mass Transit?" <http://www.tgdaily.com/sustainability-features/63647-biofuel-steam-locomotive-tomorrow-s-cleaner-mass-transit>

4. U.S. Railroads E2 Best Practices (BP) and Success Stories

4.1 Freight Railroads BPs

4.1.1 Class I Railroads

The seven large Class I railroads with long-haul operations in the United States and part of Canada lead in the implementation of system-wide fuel savings to improve operational efficiency and environmental performance at reduced cost. An overview of fuel saving BPs of Class I railroads in the 2010 *Progressive Railroading*¹³¹ included a wide range of technologies and strategies (DP, TOR lubricators, throttle control software, etc.), in addition to traditional conservation. The examples below illustrate successful BPs of selected Class I freight railroads obtained from the literature and railroad managers' inputs.

- **BNSF:** As discussed above, BNSF, in partnership with the U.S. Department of Defense, FRA, and private entities, was the first railroad to design, develop, demonstrate, and evaluate the feasibility of hydrogen fuel cell motive power for switchyard locomotives. Since 2000, BNSF has modernized its locomotive fleet with more than 2,500 new fuel-efficient locomotives. Although the volume and mileage of freight moved over the past decade increased more than 30 percent, fuel consumption increased by only 14 percent. BNSF acquired more than 85 ULEL; each has three low-power engines (instead of a large one) which burn fuel on demand, thus reducing emissions and saving fuel. The ULEL emissions of NOx and particulates are 80 percent lower than for a standard diesel switcher locomotive, and its fuel efficiency is 25 percent higher.
- **CSX:** CSX has employed a cross-functional fuel Process Improvement Team (PIT) to identify options for reducing by 1 percent per year the fuel intensity (gallons/ton-miles) for cost savings and environmental gains. CSX was the first Class I railroad to join the Climate Leaders Program and was named the "Greenest Railroad" by Newsweek's 2009 and 2010 Green Rankings. In 2011, CSX joined the Environmental Defense Fund Climate Corps program. CSX has improved its fuel efficiency by 80 percent since the 1980s, voluntarily reduced GHG emissions by 8 percent from 2006 to 2011, and invested more than \$1.5 billion to upgrade its fleet with GE Evolution Tier II and III locomotives. CSX has installed AESS to reduce locomotive idling, the GE Trip Optimizer for route and logistics improvements, and deployed 25 Gensets in railyards in or near EPA noncompliance and sensitive urban areas, such as Chicago, New York City, New Orleans, and several Northeast cities.
- **NS:** According to the NS 2011 Sustainability Report¹³², GHG emissions were cut by 3.9 percent per revenue ton-mile of freight in 2010. NS estimates that approximately \$10 million in the last 4 years has been saved—energy and fuel cost savings. NS, along with other freight railroads, joined the Carbon Disclosure Project, an independent nonprofit

¹³¹ See March 2010 *Progressive Railroading* at <http://www.progressiverailroading.com/mechanical/article/Class-Is-employ-fuelsaving-practices-that-promise-stingier-diesel-usage--22736>

¹³² See 2011 Norfolk Southern Sustainability Report at <http://nssustainability.com/reports/2011-sustainability-report/>

organization working to reduce emissions and promote accountability.¹³³ Because of the Clean Air Act, NS has been buying newer locomotives and retrofitting 50 to 100 locomotives to enhance fuel efficiency. As mentioned in Section 2.3.9, NS has achieved approximately 30 percent fuel savings with distributed power by combining ECP brakes communicating along the consist with implementation of both the GE's Locotrol software and the New York Air Brake LEADER. Currently, NS has approximately 20 projects ongoing to further improve fuel efficiency in their locomotives:

- The NS locomotive fleet improved its fuel efficiency by more than 2.2 percent in 2010, saving 10.2 million gallons (38.8 million liters) of diesel fuel and 104,924 metric tons (231 million pounds) of CO₂ equivalents emissions. NS has about 10 Genset locomotives in operation, as well as the NS999 battery-powered locomotive that is still in the experimental test and evaluation phase, as discussed above.
 - To help engineers monitor and control the in-service locomotive fuel consumption, a computer dashboard for cab engineers displays real-time speed, fuel consumption rate, and other real-time data. Use of GE's Locotrol with LEADER required staff training and incentives to save fuel. LEADER has been implemented and installed in approximately 60 percent of the NS locomotive fleet, with projected completion by 2014. Training for this technology is ongoing.
 - In addition, NS has also installed AESS idle reduction kits on 1,797 fleet locomotives which have substantially reduced fuel burn due to engine idling time. NS also installed a Wireless Event Recorder Information Systems (WERIS) in approximately 1,400 locomotives to wirelessly and automatically monitor train performance.¹³⁴
 - NS is also researching alternative fuels. NS is substituting petroleum for biodiesel (both synthetic and from animal waste) to lower emissions at a fueling station in Meridian, MS. More than 800,000 gallons (3 million liters) of biodiesel a month are used. In 2012, NS agreed to purchase diesel fuel produced by Dynamic Fuels, a 50/50 venture owned by Tyson Foods, Inc. and Syntroleum Corporation. NS has been testing the blended fuel in a Meridian, MS, railyard with positive results.
- **Union Pacific (UPRR):** As part of a \$20 million investment in clean locomotives, UP unveiled in August 2012 an advanced system that will use three different technologies to cut emissions to required Tier 4 levels: Exhaust Gas Recirculation (EGR), diesel oxidation catalysts (DOC), and diesel particulate filter (DPF). The UP 9900¹³⁶ is one of a series of 25 new technology locomotives developed with funds from the California Air Resources Board's (CARB) Air Quality Improvement Program (AQIP) mandated by the Assembly Bill (AB) 118 initiative¹³⁷ and coordinated by the Sacramento Metropolitan

¹³³ <https://www.cdproject.net/en-US/Pages/HomePage.aspx>

¹³⁴ See http://www.progressiverailroading.com/norfolk_southern/article/Norfolk-Southern39s-technology-embrace--24996

¹³⁵ See <http://www.prnewswire.com/news-releases/union-pacific-railroad-unveils-experimental-locomotive-to-test-emissions-reduction-technology-167069835.html>

¹³⁶ See Fall 2012 AIRlines AMAQMD newsletter at <http://www.airquality.org/communicationsoffice/2012/2012Fall.pdf>

¹³⁷ See <http://www.arb.ca.gov/msprog/aqip/aqip.htm>

Air Quality Management District. It was designed to reduce diesel PM emissions by more than 80 percent, and UP and CARB are now testing and will jointly analyze its performance over the next 18 months. UP won the 2010 EPA Clean Air Excellence Award for its Ultra-Low Emissions Genset locomotive (see Figure 35).¹³⁸



Figure 35. UP 9900 Prototype Uses Three After-Treatment Technologies to Cut Emissions¹³⁹

At the Roseville railyard UP showed how to effectively reduce locomotive idling time for the 400 locomotives retrofitted with AESS. UP is evaluating the energy efficiency and emission reduction benefits of consists reconfigured for reduced fuel consumption, when combined with engineers training. UP's "Fuel Masters Unlimited" is a training program that measures and compares locomotive engineers' fuel consumption when running a train and tracks the gallons of diesel fuel saved each month. This program helped UP lower its fuel consumption rate by 3 percent in 2010.

4.1.2 Regional (Class II) and Short Line (Class III) Freight Railroads

E3 BPs are especially valuable to regional and short line freight RRs that operate on a narrower profit margin than the seven Class I railroads. A 2010 *Progressive Railroading* article¹⁴⁰ highlighted several efforts to shrink the short-line RR environmental footprint, while saving both fuel and capital.

- **The American Short Line and Regional Railroads Association (ASLRRA)** posts information resources and success stories¹⁴¹ on energy efficiency and environmental gains of its members, and its regional annual conferences offer the opportunity to share BPs. In addition, State clusters operating in a common environment, like the California Short Line Railroad Association,¹⁴² also share experience with fuel-efficient technologies.

¹³⁸ See <http://www.epa.gov/air/cleanairawards/winners-cleanairtech.html>

¹³⁹ © Sacramento Bee/ZUMAPress.com

¹⁴⁰ See "Green short lines: Short Line Railroads and Environmental Stewardship" in Aug. 2010 *Progressive Railroading* at http://www.progressiverailroading.com/short_lines_regionals/article/Green-short-lines-Shortline-railroads-and-environmental-stewardship--24055

¹⁴¹ See www.aslrra.org

¹⁴² See www.cslra.org

- The **EPA West Coast Collaborative**¹⁴³ annual meetings feature summaries of regional Clean Locomotive Activities.
- **The Genesee and Wyoming, Inc. (GWI)**,¹⁴⁴ which owns 60 regionals and short line railroads, has repowered more than 20 percent of its locomotive fleet, installed Gensets on 3 locomotives, and introduced 14 mother-mate, or mother-slug, dual locomotive configurations. The Mother is a conventional diesel locomotive sending via large cables excess electrical power to the Slug; the latter has only traction motors, but no diesel engine, generator, or other components of a “stand alone” locomotive. The “mate” adds tractive power to the “mother” without burning diesel and adding emissions. GWI also installed on many of its locomotives APUs, AESS, and plug-in electric warming devices to reduce idling, pollution, and noise while saving fuel.
- The **Iowa Interstate Railroad**, a 500 mi (800 km) regional railroad, has been using renewable biodiesel (blends of 10–20 percent), biodegradable soybean grease, to reduce wheel-track wear on curves and has also installed AESS units on its locomotives to save fuel. It also acquired new GE locomotives that are 25 percent more fuel efficient than older ones.
- The **Alaska Railroad Corporation (ARRC)** operates passenger sightseeing services, as well as freight trains, on scenic routes over its 470 mi (752 km) of track between Seward and Fairbanks. Its Environmental page posts “Green Railroading” highlights, such as the fact that it takes only 1 gallon of fuel to move 1 ton of freight along its entire route. Since 1993, ARRC has held a Green Star Award;¹⁴⁵ in 2007, it received a Green Star Air Quality Award, and in 2011, a Supernova Award for upgrading its track, equipment, and operations to conserve energy and reduce emissions and waste. A BP of note is the use of wind and solar photovoltaic energy production along its ROW to power the new PTC system. Another success story is progress achieved through a recently launched Idle Reduction Program (IRP).¹⁴⁶
- The **Providence and Worcester (P&W) Railroad Company** is a Northeast Regional operator with 545 mi (872 km) of track that opted for idle reduction Auxiliary Power Units (APUs) manufactured by Power Drives on 17 locomotives, as well as AESS from GE Transportation on 13 locomotives, which saves 10 percent of fuel on switchers and 3 percent on road locomotives.

¹⁴³ See May 31, 2012 Seattle, WA presentation “Cleaner Locomotive Activities in Western US” at http://westcoastcollaborative.org/files/meetings/Partners2012/Day%20May%2031/03_AM%20Breakouts/TM_%20Locomotive/03_Pat%20Kerr.pdf

¹⁴⁴ See http://www.gwrr.com/about_us/community_and_environment/gwi_green/motherslug_locomotives

¹⁴⁵ See Louis, Julie St. “Alaska Railroad Tapping into Wind and Solar Power: New Technology Being Utilized on Turnagain Arm.” *Turnagain Times*. 17 Apr. 2008. 4 Jan. 2012. <http://www.turnagaintimes.com/current%20issue/4-17-08/solarwind.html>

¹⁴⁶ See “Idle Reduction Initiative Pays Dividends for Alaska Railroad” on 12.3.2012 at www.progressiverailroading.com/prdailynews/news.asp?id=33510

- The **California Short Line Railroad Association (CSLRA)** also has members that are pushing environmental and sustainable agendas. The Modesto & Empire Traction Company (METC) recently converted its entire fleet from 1950s diesel engines to all 100 percent Genset locomotives. It is using the old frames with brand new interiors for the Genset locomotives. In-house training is provided for all Genset locomotives, as well as maintenance classes off site. With this new overhaul, the locomotives have used 35 percent less fuel. The METC facility also utilizes idle reduction processes as well as switches on the tracks for less stopping and starting.
- A partnership of the **New York State DOT (NYSDOT), NYS Energy R&D Authority (NYSERDA), and suppliers (Power Drives, Inc. and New West Technologies)** of the electric plug-in Diesel-Warming System (DWS-120) idle reduction technology demonstrated real world, in-service operational benefits on 11 locomotives for 7 NYS short line railroads.¹⁴⁷ The environmental (noise and emissions) benefits, as well as fuel and cost savings of the DWS models (powered by electricity or a small diesel engine) were quantified between November 2011 and January 2012) for 7 short line railroads, and the DWS-120 and DWS-APU (diesel) systems were certified by EPA to have an average payback period of 6.7 months in fuel savings.

4.2 Passenger Railroads BPs and Success Stories

4.2.1 Amtrak E2 BPs for Higher Speed Operations

The Amtrak *Acela* on the Northeast Corridor is the only HSR in the United States, and Amtrak has instituted system-wide E2 improvements. Amtrak posts information on its energy and environmental performance on the Web and reports annually on plans and progress in improving E2 and E3 performance. The Amtrak Web site, “Travel Green with Amtrak,”¹⁴⁸ posts information on energy-efficient travel, details energy efficiency and environmental benefits, such as “Going Green on *Acela*,” a rail carbon footprint calculator for passengers, and publishes its ClimateCounts.org scorecard.

In November 2012, Amtrak launched regional high-speed 110 mph (177 km/h) services, an increase from its current 79 mph (127 km/h), in:

- Illinois, on a portion of the Chicago to St. Louis route—a 15-mile (24 km) stretch of the Amtrak Lincoln Service route between Dwight and Pontiac, MI; 75 percent of the corridor is slated to achieve high-speed service by 2015.¹⁴⁹
- From 95 mph (153 km/h) to 110 mph (177 km/h) on the Amtrak Wolverine Service route in western Michigan and northern Indiana, currently on 80 mi (128 km) of track between Kalamazoo, MI, and Porter, IN.

¹⁴⁷ “Demonstration of Locomotive Idle Reduction Technology for NYS Short Line Railroads,” 2011 at <http://www.dieselwarming.com/nyserda/docs/Short%20line%20DWS%20Demonstration%20Project%20Summary%20and%20Case%20Studies.pdf>

¹⁴⁸ See <http://www.amtrak.com/travel-green-with-amtrak> and “Amtrak Means Energy Efficiency” at http://www.amtrak.com/servlet/ContentServer?c=AM_Content_C&pagename=am%2FLayout&cid=1241245661727

¹⁴⁹ See details at <http://www.idothsr.org/faqs/>

System-wide energy and fuel conservation measures listed in the 2011 “Environmental Health and Safety Report”¹⁵⁰ include:

- The successful completion of a 20 percent biodiesel-fuel intercity passenger train test (with FRA collaboration);
- Measures to reduce fuel usage by 1 percent a year by 2015, including:
 - Installing regenerative braking in 80 percent of NEC locomotives and other electrified territory, to recover and reuse 8 percent of power consumed;
 - Aerodynamic improvements of rolling stock;
 - Installing locomotive anti-idling retrofits, such as automatic stop-start technologies, reducing locomotives diesel engine idling by shut-down within 1 hour of arrival and departure, and using 480V ground power at layovers for HVAC and lighting;
 - Implementing simulator training of locomotive engineers to help conserve fuel;
 - Increasing use of dynamic braking (which uses electric traction motors to provide resistance to rotating wheel axles in diesel-electric locomotives), rather than braking with power applied;
 - Demonstrating the benefits of Trip Optimizer and cruise control locomotive technologies;
 - Upgrading fuel management systems for deliveries and consumption tracking;
 - Increasing seat miles/kW-hour for electric traction power, while reducing electricity consumption for stations and facilities;
 - Conducting annual environmental compliance audits and reporting GHG inventories;
 - Seeking grant support from Federal and State agencies to replace aging switcher locomotive fleet in railyards with Gensets, as done in California, Illinois, New York, Virginia, Maryland, and District of Columbia;
 - Seeking equipment upgrades for E2 and E3: a 2010 order of 70 new Siemens Amtrak Cities Sprinter ACS-64 electric locomotives and ARRA-funded upgrades in power and propulsion substations and infrastructure on the Northeast Corridor (see Figure 36).

¹⁵⁰ “2011 Environmental Health and Safety Report- Connecting with Amtrak Vision” at www.Amtrak.com/ccurl/294/246/Environmental-Health-Safety-Annual-Report-2011.pdf



Figure 36. Amtrak Cities Sprinter Based on the Popular EuroSprinter Will Travel at 125 mph (201 km/h)¹⁵¹

4.2.2 Commuter RR Best Practices

Commuter rail E3 BPs highlighted below were selected because they were successfully implemented and illustrate the wide range of technology options and system-wide strategies that have saved fuel or power and led to both environmental and financial gains:

- In June 2012, FRA approved the first alternative design waiver¹⁵² for the **Denton County Transportation Authority** to purchase and operate 11 new diesel-electric DMU lightweight unit cars. The DMUs will be used on the A-Train, serving a 21-mile (34 km) commuter rail line shared with freight trains, and linked to Dallas Area Rapid Transit. These lightweight railcars are expected to be more fuel efficient by 30–70 percent, operate up to 75 mph (120 km/h) with less noise, and feature a Tier 1 crash energy management system.
- In April 2012, the **MNR**, in partnership with the New York Power Authority (NYPA), announced major upgrades for energy efficiency.¹⁵³ Metro North/NYPA upgrades in heating and cooling equipment in Grand Central Terminal, along with replacement of wasteful incandescent bulbs with LED lighting, will reduce its energy use by 30 percent and attain Leadership in Energy and Environmental Design (LEED) certification. This \$22 million outlay will be completed by the end of 2013, with anticipated energy savings over 11 years of approximately \$3 million a year in energy cost. NYPA-MTA recently completed E2 enhancements of four Metro-North train yard facilities to lower by 20 percent energy consumption—through the use of energy efficient lighting, wireless remotely controlled and monitored HVAC, high-efficiency motors, and chillers.
- In March 2012, the **Bay Area Transportation Authority** agreed to fund with State HSR bonds the electrification of Caltrain commuter rail.¹⁵⁴ Operation of lightweight energy-efficient EMUs on a hybrid line shared with the planned California HSR and equipped with PTC for safe operations.

¹⁵¹ Image courtesy of Siemens

¹⁵² See “Commuter rail Lightens Up” in ASCE Civil Engineering Magazine at <http://www.asce.org/CEMagazine/Articlen.aspx?id=25769811158>

¹⁵³ See <http://thetransitwire.com/2012/04/26/metro-north-and-chicago-transit-authority-announce-energy-upgrades/>

¹⁵⁴ See www.sfgate.com/cgi-bin/article.cgi?f=/c/a/2012/03/21/BAPS1NOFAV.DTL

- **METRA**, operated by the Chicago Transit Authority (CTA), is a commuter rail agency that serves more than 100 communities with 241 stations on 11 lines running from Chicago's downtown. It too committed to "green" operations.¹⁵⁵ Metra Electric Line operates electric-powered EMU cars over 32 miles (51 km) and is the only Metra line that uses electric, self-propelled coaches powered from an overhead catenary wire system. In 2010, METRA contracted with Sumitomo Corporation of America to buy 160 new and more energy efficient Nippon Sharyo Highliner bilevel cars for its electric commuter rail, due by 2015. These rail cars are more expensive (totaling \$560 million) because they are self-propelled, not pulled by a diesel locomotive.¹⁵⁶ Metra Electric does not share equipment with the other 10 Metra lines, which have diesel locomotives, but it does share parts with diesel bi-level cars. METRA diesel locomotives are all equipped with AESS controls to reduce idling and save fuel.
- The **Massachusetts Bay Transportation Authority (MBTA)**¹⁵⁷ commuter rail, operated under contract by the Massachusetts Bay Commuter Railroad Company (MBCR), is the fifth largest in the United States (after New York, New Jersey, and Chicago area systems). MCBR is a partnership of Veolia Transportation, Bombardier Transportation, and Alternate Concepts, Inc. The MBCR commuter rail network is shared with several freight rail operators: over 12 CSXT mainline freight trains per day operate on the Worcester Line, a part of CSXT's Boston Line.
 - Partnering BPs: MBCR, the state of Massachusetts, and CSX entered a public-private partnership to plan a multiyear sustainable rail transportation plan for shared infrastructure.¹⁵⁸ Streamlined scheduling and operations will allow commuter rail expansion on the Worcester line, as well as freight operations growth, establishing the first double-stack rail route in New England and a major intermodal terminal in Worcester. There will also be fewer CSX trains impeding commuter rail traffic and thus reduced idling and delays.
 - Facility BPs: The three MBCR railroad mechanical facilities and 11 layover yard facilities have ground power to shut down the locomotives, while keeping them warm in cold weather and eliminating idling that consumes fuel and generates air pollution. The MBTA is procuring solar power arrays for two of its facilities to generate about 2.7 MW (3620 hp) of electricity and is purchasing under Solar Power Purchase Agreements (SPPA) 20 percent of its power from renewable solar power. Additionally, a 100 KW (134 hp) wind turbine was installed at the Kingston Commuter Rail Station and Layover Facility that will generate 65 percent of the facility energy needs. MBTA is also building a 250 KW (335 hp) wind turbine at the Bridgewater site.

¹⁵⁵ See http://metrarail.com/content/dam/metra/documents/RTA_GreenTransitPlan.pdf

¹⁵⁶ <http://www.chicagobusiness.com/article/20120327/NEWS05/120329821/japanese-manufacturer-to-open-factory-hire-workers-for-metra>

¹⁵⁷ See http://www.mbta.com/about_the_mbta/environment/

¹⁵⁸ See <http://www.metrowestdailynews.com/news/x21085477/State-finalizes-100-million-deal-to-buy-tracks-from-CSX#ixzz2Pc72VRAF>

- **Equipment BPs:** The MBCR fleet currently consists of 90 diesel locomotives equipped with HEP, placed at both ends of push-pull trains, using both passenger and rebuilt freight locomotives for passenger use. Twenty new four-axle AC-traction Motive Power, Inc. AC MPI HSP46 diesel-electric locomotives are on order, able to meet applicable EPA Tier 3 emissions standards. New National Railway Equipment Corporation ULEL NRE 3GS-21B switcher locomotives were acquired to reduce yard emissions in the Boston metropolitan area. Seventy-five new energy efficient bilevel passenger coaches were ordered from Hyundai Rotem: the first four were delivered and put into service in April 2013; fifteen will be in service by fall 2013.
- **METROLINK**¹⁵⁹ is governed by the Southern California Regional Rail Authority (SCRRA), comprises 5 county agencies, and links 6 counties with 7 service lines, 55 stations, and 40,000 daily passengers over a 512 route-mile network. The fuel efficiency and environmental BPs being implemented include:
 - In April 2012, Metrolink initiated a ground power plug-in program at its Central Maintenance Facility. This technology enables its trains to run on electricity during times of service and inspection, reducing locomotives idling noise and emissions by 33 percent.
 - Metrolink will become the first rail system in the country to achieve Tier 4 status in revenue service. It is replacing or rebuilding/repowering locomotives to comply early with the 2015 Tier 4 emission standards¹⁶⁰. The Board authorized Metrolink to acquire 10 Tier 4-compliant locomotives, with an option to purchase up to 10 additional locomotives, under a contract with Electro-Motive Diesel, Inc. The first three demonstration locomotives will be completed in fall 2015. The new locomotives will be more fuel efficient and reduce PM by 86 percent and NOx by 84 percent relative to Tier 2.
 - In December 2012, the Board also committed Metrolink to testing in future operations emerging alternative fuel sources and technologies, such as liquefied natural gas and battery technology.
- **Southeastern Pennsylvania Transportation Authority (SEPTA):**¹⁶¹ SEPTA operates the only fully electrified commuter railroad in the United States, thus improving the regional air quality by offsetting localized emissions. In 2012, SEPTA was honored with the APTA Sustainability award, recognizing it as a national leader in improved sustainability practice, from advanced energy production and storage systems to improved facilities and recycling. SEPTA operates all forms of public transit, including commuter rail, to serve six counties in the greater Philadelphia area. SEPTA also serves counties in Delaware and New Jersey. It controls 280 active stations, over 450 miles (720 km) of track, 295 revenue vehicles, and 196 routes. SEPTA commuter rail equipment includes: 231 GE Silverliner IV EMUs (see Figure

¹⁵⁹ See <http://metrolinktrains.com/agency/page/title/sustainability>

¹⁶⁰ See http://www.metrolinktrains.com/news/news_item/news_id/836.html

¹⁶¹ See <http://www.septa.org/sustain/index.html> and <http://www.septa.org/sustain/blog/2011/03-11.html>

37); 120 Silverliner V EMUs from Hyundai Rotem, see Figure 38); 6 Pullman Standard Comet 1 Coaches/Cab Cars; 10 Bombardier Cab Cars/25 Trailer Coaches; 10 Bombardier Center Door Push-Pull Coaches; 7 AEM-7 Electric Locomotives; and 1 Bombardier ALP-44 Electric Locomotive.



Figure 37. GE Silverliner IV EMU¹⁶²

The purchase of 120 new “Silverliner V” railcars from Hyundai Rotem USA for its regional rail fleet, featuring an energy-efficient propulsion system, will reduce energy consumed while providing improved acceleration and braking. Regenerative braking energy is converted to electrical energy to be used by other cars on the line, or returned to the power company. The first three Silverliner V cars just started operation. These EMUs were also designed with day-lighting (bright and large windows, mid-car doorways) and digital flat-panel screens displaying trip details, as well as energy-efficient climate-control systems.



Figure 38. Silverliner V¹⁶³

¹⁶² Source: http://www.philadelphiatransitvehicles.info/Specs/General_Electric_Silverliner_IV.php

SEPTA also received a \$1.2 million grant from the Environmental Protection Agency (EPA) National Clean Diesel Campaign to significantly reduce air emissions from one of its six diesel-powered maintenance locomotives, by repowering it with state-of-the-art engine technology: the ULEL “dual Genset” with DPF. This technology improves both the fuel economy and emissions performance by providing power on an as-needed basis. Repowering will also reduce noise pollution, an additional benefit for surrounding communities.

¹⁶³ Source: www.septa.org/silverliner; photograph courtesy of SEPTA

5. Findings and Recommendations for Improved E2

5.1 General Study Findings and Conclusions

The material presented above shows that the wide range of rail industry BPs has led to substantial system-wide reductions in fuel consumption, resulting in sizeable environmental and financial gains. Though no single “silver bullet” solution exists for reducing energy consumption and cost, or for ensuring compliance with upcoming EPA Tier 4 locomotive emissions standards, railroad industry segments have made great progress toward these goals.

A recent DOE Transportation Energy Futures evaluation¹⁶⁴ analysis of modal energy efficiency projects a Class I freight fleet average E2 increase of 15–20 percent by 2030, if the historical rate of E2 progress over the past two decades continues. It is clear that each individual E2 technology opportunity—or the adoption of asset and fleet management software tools, or improvements in car and consist aerodynamics and in Operations and Maintenance (O&M)—offers only incremental E2 and fuel saving benefits. However, bundling of E2 options (e.g., idling reduction through both Automated Stop-Start devices and improved scheduling optimization software) offers synergistic higher gains.

Multiple rail technologies, best operational practices, and success stories were illustrated above, based on literature and interviews with selected railroad industry experts. The examples cited for best-in-class industry leaders offer suitable and cost-effective energy-saving options and initiatives across all rail industry segments, including OEMs, suppliers, international and U.S. rail trade associations, railroad owners, and operators.

As leaders of industry showed in the success stories cited, large rail system-wide E2 improvement can result from the cumulative impacts of upgraded equipment, tracking, and operations management software, maintenance of state of good repair for both equipment and track and signaling infrastructure, combined with operations optimization and staff training. Furthermore, adoption of PTC on shared tracks would afford multiple benefits, including safety, mobility and congestion management, as well as fuel savings from improved operations.

It is also apparent that the E2 and E3 technologies and strategies selected and implemented must be tailored to the rail industry segment and application needs in order to yield the desired energy and environmental benefits and to ensure optimal integration with legacy systems. To achieve system-wide E2 and E3 gains, synergistic and parallel changes must be made in equipment, operations, infrastructure, and human factors.

FRA does and could continue to serve as a catalyst for and resource on BPs to the rail industry in order to accelerate E2 and E3 improvements. An excellent example of a multimodal P3 partnership to enable and advance the national rail system is the American Association of State Highway Officials (AASHTO) Standing Committee on Rail Transportation (SCORT).¹⁶⁵ FRA has actively participated in SCORT and its subcommittee on HSR,¹⁶⁶ as well as the PRIIA

¹⁶⁴ *Potential for Energy Efficiency Improvement Beyond the Light-Duty Sector* at <http://www1.eere.energy.gov/analysis/transportationenergyfutures/index.html>

¹⁶⁵ See AASHTO postings at <http://rail.transportation.org/Pages/default.aspx>

¹⁶⁶ See <http://www.highspeed-rail.org/Pages/default.aspx>

Section 305 Next Generation Equipment Committee (NGEC).¹⁶⁷ NGEC has reviewed locomotive technology options and developed common passenger rail equipment specifications for Next Generation Corridor Equipment Pool to enable large-scale orders and affordability of state-of-the-art passenger rail equipment. Specifications were developed for DMUs, EMUs, and bi-level coaches that promise fuel-efficiency improvements.

Public-Private-Partnerships (P3) are a promising BP for further improving E2 of rail equipment, facilities and operations: FRA could partner with rail E2 stakeholders, including trade associations, industry, and Federal (EPA, DOE) and State agencies (NYSERDA, Caltrans). Such partnerships could leverage not only funding, but also knowledge: university and business researchers under an umbrella initiative such as this could inform State and regional transportation agencies. It is desirable that an E2 and E3 Strategic Action Plan be outlined and evaluated in the framework of the National Rail Plan¹⁶⁸. A P3 dedicated to industry-wide Energy Efficiency gains could include the FRA, AAR and, AASHTO, and TRB. This plan would explicitly address rail system energy efficiency and sustainability goals and constraints, as well as ensure that gradual progress is made and measured. Locomotive and railcar fleet renewal with new or retrofit campaigns should be carefully evaluated and selected based on the company, State, or regional E3 goals. Realistic E2 targets must be defined, based on rail system characteristics and on financial, environmental, or infrastructure capacity constraints, and progress over time should be monitored using quantifiable metrics.

Key E2 and E3 Strategic Plan implementation considerations include the following:

- In-service fleet age and performance;
- The state of good repair of equipment, track, and signaling infrastructure;
- Network congestion management and optimal scheduling, driver and asset management for specific route, loading, and duty-cycle;
- Ability to simultaneously minimize capital and operations and maintenance costs, fuel consumption, and emissions;
- Compatibility of new technology tool, equipment, and fuels with the legacy fleet and infrastructure;
- Market readiness of new equipment;
- Adoption of proven technologies for operational safety, maintainability, reliability, and affordability.

Based on this study's findings and BPs illustrated above, tailored E2 and E3 solutions are suggested below for each rail industry segment. Recommendations that apply to both FRA and the rail industry sector are to:

- Join and actively participate in rail and environmental trade associations, as well as interest groups and nonprofits dedicated to sustainable mobility in their committees for specific E2 and E3 initiatives.
- Foster and participate in Research, Development, Test, and Evaluation (RDT&E) of new locomotives, alternative fuels, and devices to improve E2 or reduce emissions. An

¹⁶⁷ See postings at <http://www.highspeed-rail.org/Pages/Section305Committee.aspx>

¹⁶⁸ See NRSP and state guidance posted at <http://www.fra.dot.gov/Page/P0522>

excellent example is the joint FRA-industry effort to demonstrate, test, and evaluate biodiesel (B20 blend) locomotive fuel efficiency, emissions, and engine wear.¹⁶⁹

- Publicize E2 and E3 Efforts and Successes of U.S. Railroads: Freight railroads can benefit from AAR's environmental and energy efficiency initiatives and activities.¹⁷⁰ AAR lists Environmentally Friendly railroads as a key issue on its legislative agenda and publicizes the successful environmental initiatives of its members.¹⁷¹ Recently, AAR showcased its carbon calculator at the 2nd annual Sustainability Symposium hosted by NS and featuring industry E3 BPs.¹⁷²
- Participate in International HSR E3 Initiatives: UIC's annual Sustainability Symposium features rail successes in reducing energy consumed and environmental emissions, confers Sustainability awards in several categories, and offers information and solutions, such as the UIC/Unife NRG project and the 4-year Railenergy modeling and analysis tools.¹⁷³
- FRA Leadership in a multiyear E2 and E3 Research, Development, Demonstration, Test and Evaluation (RD2T&E) efforts: FRA could initiate a multiyear effort similar to the EU's and the UIC NRG-Railenergy Programme discussed above, which successfully focused on energy efficient and environmentally sustainable rail systems and operations specific to the U.S. environment. This could be a cost-shared effort with rail trade associations (APTA, AAR, AREMA), partner Federal agencies (DOE, EPA), States, research organizations (TRB), and leading rail industry stakeholders.
- Join and Implement Climate Mitigation Efforts: Join the nonprofit ClimateCounts.org, as Amtrak did, to reduce emissions and modify practices that speed up climate change. Amtrak's ClimateCounts scorecard¹⁷⁴ is a model for the industry. FRA could also join and present its E3 research accomplishments and R&D plans for emissions reduction and climate mitigation projects. The TRB National Cooperative Rail Research Program (NCRRP), co-funded by FRA jointly with AAR, APTA, AASHTO, and NARP rail passengers, is an excellent showcase opportunity. FRA-funded TRB-IDEA and ITS projects that also contribute to E2 and E3 could also be publicized and continued.
- Commit to Cross-Enterprise Sustainability Best Practice: Passenger railroads could subscribe to and implement the APTA Sustainability Commitment.¹⁷⁵ Signatories are

¹⁶⁹ See M. Shurland presentation at 2012 R&D Review posted at <http://www.fra.dot.gov/eLib/Details/L01673>

¹⁷⁰ See postings at <http://www.aar.org/Environment.aspx>

¹⁷¹ See <http://www.aar.org/KeyIssues.aspx> and member initiatives list at <http://www.aar.org/Environment/Member-Environmental-Initiatives.aspx>

¹⁷² See story at <http://blogs.edf.org/texascleanairmatters/2012/09/27/railroad-sustainability-symposium-highlights-environmental-opportunities-for-rail-sector/>

¹⁷³ See latest at <http://www.uic-sustainability.org/spip.php?article80>

¹⁷⁴ See Amtrak ClimateCounts scorecard at http://climatecounts.org/scorecard_overview.php

¹⁷⁵ See postings at <http://www.apta.com/resources/hottopics/sustainability/Pages/default.aspx>

ranked from entry level to bronze, silver, and gold level for which they must qualify by meeting multiple energy and environmental criteria. Attendance at annual APTA sustainability workshops for transit and commuter rail also affords valuable peer-to-peer information exchanges, and winning the annual Sustainability Award as recognition for sustained E3 gains is a great honor (SEPTA won it in 2012).

- **Join Rail Industry Trade Associations and Standards Developing Organizations (SDOs):** Active participation and use of other rail and research associations and SDOs (e.g., AREMA-American Railway Engineering and Maintenance-of way Association, HSRA-High-Speed Rail Association, and the Society of Automotive Engineers-SAE and IEEE Rail committees) to develop standards for emerging technologies and fuels, share BPs, and learn from peers. A good illustration of this successful strategy is FRA's E3 program managers' active participation in the SAE TC7 Subcommittee on Biodiesel in Railroad Applications, in the Committee on PRIIA Next Generation Equipment, and in the AASHTO/SCORT. Joint FRA test and evaluation of biodiesel B20 emissions and performance by Amtrak in-service locomotives involved partnering with GE Transportation Services, Chevron-Oronite, and OK DOT.
- **Continue Industry Partnerships with State DOT authorities, Federal, regional, and State environmental agencies:** States in nonconformity or air quality management regions have incentive programs to reduce rail equipment emissions. State programs offer co-funding opportunities for RD&T, demonstrations, and the deployment of equipment retrofits or upgrades and of related alternative fuels and infrastructure E3 improvements.

5.2 Commuter Railroads

Though FRA monitors the safety of commuter railroads operated by transit authorities, the commuter railroads benefit from FTA funding of new starts, or capital improvement programs, as well as dedicated "green" programs, such as Clean Fuels, TIGGER, and CMAQ Grants, to reduce emissions and improve energy efficiency. Applicable and transferrable BPs and success stories were discussed above for SEPTA, METRA, LIRR, and other commuter railroads. Several new and/or expansion projects for commuter rail (e.g., RailRunner in Albuquerque, NM, Orlando's SunRail, Northern Lights Express, MN, the Trinity Railway Express (TRE) linking Dallas to Ft. Worth, TX, and four Colorado and Utah new starts) benefit from available fuel efficient equipment. For instance, more than 100 Motive Power (MPXpress) diesel-electric commuter locomotives have been delivered or ordered by eight different transit agencies since 2003, making it the proven and preferred choice for commuter rail agencies. More than 1,100 Bombardier M-7 EMUs were delivered to the Long Island Railroad (LIRR) and Metro-North for use on electrified territory. These new M-7 cars feature state-of-the-art technology, including energy efficient IGBT propulsion and dynamic braking and on-board monitoring and diagnostic systems. Equipped as married pairs, the M-7 EMUs have stainless steel car-bodies for long life and low maintenance. The Bombardier Bi-level coaches, which offer 70 percent more capacity, are now ordered or in operation in more than a dozen U.S. city railroads, including the Seattle Sounder, the Minneapolis-St. Paul Northstar; the Albuquerque New Mexico Rail Runner Express, the North San Diego County Coaster, the San Francisco-San Jose Caltrain, the Los Angeles Metrolink, and SunRail in Florida.

5.3 Freight Rail (Class I-III)

Class I railroads have entered and benefited from State and regional public-private partnerships to retrofit or upgrade equipment for emissions reduction, especially in EPA noncompliance metropolitan areas. A recent example¹⁷⁶ is the partnership of CSX with the Southeast Louisiana Clean Fuel Partnership and the New Orleans Regional Planning Commission (RPC), which was partially funded by an EPA Diesel Emissions Reduction Act (DERA) grant. The effort has retrofitted an existing locomotive into a ULEL Genset switcher locomotive for operation in the Gentilly Yard in New Orleans. This modification reduced CO₂ emissions by 25 percent and nitrous oxide and particulates emissions by 80 percent. This is the latest (July 2012) of three DERA-funded CSX locomotives and more than 30 operating on the CSX network. In cooperation with FRA, NS has conducted R&D on a battery-powered locomotive. A yard switcher has been evaluated and plans have been made to build a road unit to store and reuse braking energy once the battery technology is ready.

State funding and private-public partnerships are essential for short line railroads that operate on narrower profit margins and benefit the most from energy saving technologies, but may be unable to afford them. A model partnership in New York State was the demonstration and implementation of locomotive idle reduction with funding support (loans and subsidies) from New York State Department of Transportation (NYSDOT) and New York State Energy Research and Development Authority (NYSERDA), and with cost sharing from New West Technologies and Power Drives, Inc. The Powerhouse™ Diesel Warming System (DWS) was installed on 11 different locomotives utilized by 7 short line railroads operating in New York State, with an average system payback of 7 months.¹⁷⁷

- By cost sharing in the implementation of clean rail initiatives with Metropolitan Planning Organizations, State Transportation Improvement programs, and local/regional or port authorities (e.g., CARB, Calstart, Port of Tacoma, Port of Long Beach-Los Angeles), railroads can afford new equipment or retrofit campaigns to assist local agencies in nonconformity metropolitan areas to meet air quality standards for mutual benefit. Chapter 2 discussed success stories for BNSF and UPRR railyard emissions reduction and locomotive fleet upgrades funded by CARB and Texas incentive programs to comply with EPA Tier 4 emission requirements.
- The CARB Carl Moyer¹⁷⁸ Memorial Air Quality Standards Attainment Program has provided since 2004 grants to Class I–III railroads and heavy duty fleets to reduce air pollution emissions. Each CA Air Quality Management region (Bay Area, Sacramento, Southern California) offers guidance and funding incentives to reduce switchers and road locomotive fuel consumption and emissions for repower or retrofit kits (idle limiters), Gensets, or HEP unit purchases. The San Joaquin Valley Air Pollution Control District has offered since 2000 substantial funding incentives for repowering with heavy duty

¹⁷⁶ See <http://www.csx.com/index.cfm/media/press-releases/csx-and-regional-partners-reduce-emissions-to-help-bring-cleaner-air-to-louisiana/>

¹⁷⁷ See Demonstration of Locomotive Idle Reduction Technology for NYS Short line Railroads <http://www.dieselwarming.com/nyserda/docs/Short%20line%20DWS%20Demonstration%20Project%20Summary%20and%20Case%20Studies.pdf>

¹⁷⁸ See <http://www.arb.ca.gov/msprog/moyer/guidelines/supplemental-docs.htm>

clean engines or purchasing new locomotives, both passenger rail and freight fleets, for line haul, short line, or switch yard service.¹⁷⁹

¹⁷⁹ See <http://www.valleyair.org/transportation/Internet%20Locomotive%20handout.pdf>

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Appendix 2: Interview Guide for Informational Calls to Subject Matter Experts (SMEs)

I. General and Background Information

- Introduce ourselves (name, Volpe Center) and our FRA study objectives: to obtain information from RR experts and program managers on BPs, success stories and initiatives underway to improve Railroad E3 performance
- Ask the SME for his/her name, affiliation and role: ask if the SME is willing to spare 15 minutes and share insights? (if now is not a good time, when?)
- Pledge to:
 - Protect full confidentiality for the SME's inputs
 - Ask for preference for oral or email inputs
 - Promise no identification by name of the company/person if so desired
 - Promise to share study findings when completed

II. Tailored questions regarding E2 improvement initiatives

- Ask the SME to share specific initiatives, with associated cost, timetable, metrics and success, focusing on:
 - Engine and Equipment technology selected and implemented, e.g.:
 - Repowering of existing switcher and long-haul locomotive fleet
 - New acquisitions, fleet renewal rate, number, compliance with EPA Tier II or higher
 - If new, which type was the greenest and most cost-effective locomotive? How well did it perform?
 - Alt fuels (biodiesel? Blends? Other: fuel cells? LNG/LPG? Electricity for commuter and passenger RRs?)
 - Software Tools for optimal operations and logistics/route and fuel burning savings?
 - Staff training programs needed (depot maintenance and cab engineers)
 - Open ended: any other E2 or E3 topics and insights the SME would like to share, any news item or article he/she would like to email us?

Appendix 3: Energy Unit Conversions

1 Btu	= 778.2 ft-lb		1 kWhr	= 3412 Btu ^a
	= 107.6 kg-m			= 2.655 x 10 ⁶ ft-lb
	= 1055 J			= 3.671 x 10 ⁵ kg-m
	= 39.30 x 10 ⁻⁵ hp-h			= 3.600 x 10 ⁶ J
	= 39.85 x 10 ⁻⁵ metric hp-h			= 1.341 hp-h
	= 29.31 x 10 ⁻⁵ kWhr			= 1.360 metric hp-h
1 kg-m	= 92.95 x 10 ⁻⁴ Btu		1 Joule	= 94.78 x 10 ⁻⁵ Btu
	= 7.233 ft-lb			= 0.7376 ft-lb
	= 9.806 J			= 0.1020 kg-m
	= 36.53 x 10 ⁻⁷ hp-h			= 37.25 x 10 ⁻⁸ hp-h
	= 37.04 x 10 ⁻⁷ metric hp-h			= 37.77 x 10 ⁻⁸ metric hp-h
	= 27.24 x 10 ⁻⁷ kWhr			= 27.78 x 10 ⁻⁸ kWhr
1 hp-h	= 2544 Btu		1 metric hp-h	= 2510 Btu
	= 1.98 x 10 ⁶ ft-lb			= 1.953 x 10 ⁶ ft-lb
	= 2.738 x 10 ⁶ kgm			= 27.00 x 10 ⁴ kg-m
	= 2.685 x 10 ⁶ J			= 2.648 x 10 ⁶ J
	= 1.014 metric hp-h			= 0.9863 hp-h
	= 0.7475 kWhr			= 0.7355 kWhr

^aThis figure does not take into account the fact that electricity generation and distribution efficiency is approximately 33%. If generation and distribution efficiency are taken into account, 1 kWhr = 10,339 Btu.

Abbreviations and Acronyms

AAR	Association of American Railroads
AESS	Automatic Engine Stop Start
APTA	American Public Transportation Association
APU	Auxiliary Power Unit
AREMA	American Railway Engineering and Maintenance-of-Way Association
ARRA	American Recovery and Reinvestment Act
ARRC	Alaska Railroad Corporation
ASLRRA	American Short Line Regional Railroads Association
ASTM	American Society for Testing and Materials
BNSF	Burlington Northern Santa Fe
BP	Best Practice
BTS	Bureau of Transportation Statistics, part of the DOT Research and Innovative Technology Administration (RITA)
CARB	California Air Resources Board
CEM	Crash Energy Management
CENELEC	European Committee for Electrotechnical Standardization
CHSRA	California High-Speed Rail Authority
CNG	Compressed Natural Gas
CP	Canadian Pacific Railway Company
CSLRA	California Short Line Railroad Association
CSR	Coalition for Sustainable Rail
CTA	Chicago Transit Authority
DCTA	Denton County Transportation Authority
DMU	Diesel Multiple Units
DOC	Diesel Oxidation Catalysts
DOE	Department of Energy
DOT	Department of Transportation
DPF	Diesel Particulate Filter
DWS	Diesel Warming System
E2	Energy Efficiency
E3	Energy, Environment, and Engine FRA research program

ECP	Electronically Controlled Pneumatic
EDF	Environmental Defense Fund
EDLC	Electric Double Layer Capacitors
EERE	Energy Efficiency and Renewable Energy
EGR	Exhaust Gas Recirculation
EJR	East Japan Railway
EISA	Energy Independence and Security Act
EMD	Electro Motive Diesel
EMS	Environmental Management System
EMU	Electric Multiple Units
EPA	Environmental Protection Agency
EPRI	Electric Power Research Institute
ERAD	Event Recorder Automated Download
ESD	Energy Storage Devices
EU	European Union
FE	Fuel Efficiency
FESS	Flywheel Energy Storage System
FRA	Federal Railroad Administration
GAO	U.S. Government Accountability Office
GE	General Electric
GHG	Greenhouse Gas
GIS	Geographic Information System
GPS	Global Positioning System
GS	Generator Set
HEP	Head End Power
HPDI	High Pressure Direct Injection
HrSR	Higher Speed Rail
HSIPR	High-Speed Intercity Passenger Rail
HSR	High-Speed Rail
HVAC	Heat, Ventilation, and Air Conditioning
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IRP	Idle Reduction Program

KESS	Kinetic Energy Storage System
LEADER	Locomotive Engineer Assist Display and Event Recorder
LED	Light Emitting Diodes
LEED	Leadership in Energy and Environmental Design
LIRR	Long Island Railroad
LNG	Liquefied Natural Gas
LPDI	Low Pressure Direct Injection
LRV	Light Rail Vehicle
MARC	Maryland Area Regional Commuter
MBCR	Massachusetts Bay Commuter Railroad
MBTA	Massachusetts Bay Transportation Authority
METC	Modesto & Empire Traction Company
MNR	Metro-North Railroad
NEC	Northeast Corridor
NJT	New Jersey Transit
NREC	National Railway Equipment Company
NRP	National Rail Plan
NS	Norfolk Southern
NYPA	New York Power Authority
NYSDOT	New York State Department of Transportation
NYSERDA	New York State Energy Research and Development Authority
OCS	Overhead Catenary System
OECD	Organization for Economic Cooperation and Development
ORNL	Oak Ridge National Laboratory
P3	Public-Private Partnership
PEDA	Pennsylvania Energy Development Authority
PIT	Process Improvement Team
PM	Particulate Matter
PRIIA	Passenger Rail Investment and Improvement Act
PRS	Progress Rail Services
PTC	Positive Train Control
RESS	Rechargeable Energy Storage System
ROW	Right-of-Way

RSSB	Rail Safety and Standards Board
RTRI	Rail Technology Research Institute
SCR	Silicon-Controlled Rectifier
SCRRA	Southern California Regional Rail Authority
SCS	Shore Connection Systems
SEPTA	South Eastern Pennsylvania Transit Authority
SME	Subject Matter Expert
SRI	Sustainable Rail International
SWRI	Southwest Research Institute
TCRP	Transit Cooperative Research Program
TERP	Texas Emissions Reduction Plan
TIGGER	Transit Investments in Greenhouse Gas and Energy Reduction
TOR	Top-of-Rail
TPA	Tons-per-equivalent-Powered Axle
TPSS	Traction Power Substation
TRB	Transportation Review Board
UCDL	Ultra Clean Diesel Locomotive
UIC	International Union of Railways
ULEL	Ultra-Low Emissions Locomotive
UNIFE	Association of the European Rail Industry
UPRR	Union Pacific Railroad
VRE	Virginia Railway Express
WERIS	Wireless Event Recorder Information Systems
WESS	Wayside Energy Storage System