Next Generation Equipment Committee NGEC

LOCOMOTIVE VEHICLE/ TECHNOLOGY OVERVIEW

**A Report Prepared by the
Locomotive Technology Task Force
of the
Next Generation Equipment Committee**

August 11, 2011

Tasking

The Locomotive Technology Task Force was established in response to a concern of the Executive Board that the recently-approved diesel-locomotive specification represented "business as usual" as far as propulsion technologies are concerned. A desire was expressed to investigate what technologies might be available to "take passenger locomotives to the next stage in technology." Associated with this was interest in determining if any new technologies might be ready/feasible for commercial use in a PRIIA version of dual-mode locomotive to be used on routes in the New York City region serving Pennsylvania Station and Grand Central Terminal where internal combustion vehicles are prevented from operating in the approach tunnels.

Members for the LTTF were solicited from the PRIIA Technical Subcommittee. Over two dozen representatives of operators and manufacturers volunteered; a complete list of LTTF members is included later in this document.

The LTTF effort was not intended to present new and independent research efforts, but rather provide a literature search of "what's out there now." One of the first tasks of the members was to submit ideas technologies and/or vehicles about which information would be gathered. One limitation on the information reported is that some manufacturers noted certain developmental projects were proprietary; these obviously are not included in this report.

General Guidelines for the Vehicle/Technology reports were to include the following:

A. Vehicle/Technology:
B. Application (e.g., switcher, linehaul freight/passenger, experimental, etc.)
C. Manufacturer
D. Year Placed in Service (or testing began)
E. Summary Description
F. Advantages (over conventional equipment)
H. Disadvantages (over conventional equipment)
I. Sources

Not all reports submitted exactly followed this structure.

Contents

This document presents sixteen reports on various vehicles and technologies. In broad terms, the reports fall into three categories:

A. Operational Vehicles—current or series production, mature technology.
B. Experimental/Operating—currently operating vehicles, generally a unique, one-off design, intended to evaluate a technology application, or an under-design/construction vehicle clearly intended for future series production

C. Research—past projects or current projects under design/construction to evaluate a technology application.

The author of each report is listed alongside the title.

Operational

A. P32AC-DM (Graciela Trillanes)
B. DM30AC (Phil Strong)
C. ALP45DP (Lutz Schwendt)
D. Hybrid Switchers (Bruce Wolff)
E. Hybrid DMU (Lutz Schwendt)
F. Genset Locomotives (Bobby Doyle)

Experimental/Operating

A. Plathee Switcher (Bruce Wolff)
B. Traxx (Lutz Schwendt)
C. Hydrogen Fuel Cell (Melissa Shurland)
D. ES44AC Hybrid Locomotive (Graciela Trillanes)
E. Battery Electric Locomotive (Melissa Shurland)
F. Biodiesel (B20) Fuel (Melissa Shurland)

Research

A. Natural Gas Locomotive (Jack Madden/Bobby Doyle)
B. Tier IV Diesel Engine (Graciela Trillanes/Bruce Wolff)
C. Dual Fuel (Natural Gas/Diesel) Locomotive (Graciela Trillanes)
D. JetTrain/Flywheel Energy Storage (Mike Coltman/Al Bieber)

References

Authors included selected references on their reports. Listed below are other documents members of the Task Force came across that contain related information, and most of these references, themselves, include additional references for interested readers.

1. Parker, E.S., "Selecting the Proper Commuter Rail Vehicle Technology for Denver RTD's FasTracks Program," Transit Finance Learning Exchange Electrification and Commuter Rail Workshop, March, 2011
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2. LTK Engineering Services, "Rolling Stock Technology Assessment for Metrolinx GO Electrification," June, 2010
http://www.getongo.ca/estudy/en/current_study/docs/Rolling_Stock_Technology_Report_FINAL080610.pdf

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6. Rader, C., "Economics of FRA-Compliant Diesel Multiple Units (DMUs)," 2003 APTA Rail Conference, June 2003.

7. Sislak, K, "Economics of Diesel Multiple Unit Operations," 1996 APTA Rapid Transit Conference, June, 1996.

8. Jacobs, D., Galbraith, A., "A Comparison of the Operating and Maintenance Costs of DMU and Locomotive-hauled Equipment for the MBTA," 1997 APTA Rapid Transit Conference, June 1997.

9. AAR, BNSF, UP and California Environmental Associates, "An Evaluation of Natural Gas Fueled Locomotives, November 2007.

10. Jaafar, A. et. Al, "Sizing and Engergy Management of a Hybrid Locomotive Based on Flywheel and Accumulators, October 2009, IEEE Transactions on Vehiclular Technology.

11. Kumar, Ajith, "Hybrid Energy Locomotive Electrical Power Storage System," U.S. Patent 6,591,758, July, 2003.

12. Thelen, R.F., Herbst, J.D. Caprio, M.T., "A 2MW Flywheel for Hybrid Locomotive Power," IEEE Vehicular Technology Conference, 2003.

13. Leading European Companies Launch Joint Technology Initiative, railway-technolgy.com, July 2011.
http://www.railway-technology.com/News/News124387.html

Members of Task Force

The following individuals were members of the PRIIA Locomotive Technology Task Force as of the date of this report.

Al Bieber (STV, Inc.)
Richard Brilz (MotivePower)
Richard Chudoba (Electro-Motive)
Michael Coltman (Volpe NTSC)
Robert Doyle (Progress Rail Services)
Steve Fretwell (CalTrans)
Greg Gagarin (Amtrak)
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Kevin Kesler (FRA-Office of Safety, R&D)
James Klaus (Cummins)
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John Madden (NYSDOT)
Jack Martinson (Bombardier Transp.)
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Jim Michel (Marsh USA)
John Pannone (EAO Corp.)
Allan Paul (NC-DOT)
Charles Poltenson (NYSDOT)
John Punwani (FRA-Office of Safety, R&D)
Lutz Schwendt (Bombardier Transp.)
Melissa Shurland (FRA-Office of Safety, R&D)
Phil Strong (P S Consulting)
Graciela Trillanes (GE Transportation Sys.)
Mike Trosino (Amtrak)
Dave Ward (Siemens AG)
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David Watson (GE Transportation Systems)
Bruce Wolff (MTU)

Disclaimer

The views, opinions, conclusions, recommendations expressed in this report are those of the authors themselves and do not represent the policy or position of their respective employers or the Section 305 Next Generation Corridor Equipment Pool Committee (NGEC) or any of its officers or members.

(*adopted 1/3/2012*)

P32AC-DM-Genesis Dual Mode Locomotive
GE Transportation

Graciela Trillanes

Speed: 110 mph (diesel)
Dual Power: 650 VDC third rail capability
Arrangement: B-B - Trucks fitted with third rail power pick-up mechanisms
Weight: 277, 000 lbs.
Engine Model: 7FDL12, 3200 hp with EFI
Alternator: 1 - GMG195A1
Motors: 4 - GEB15 AC, axle suspended
Inverters: 4 - one per traction motor for single axle control
Head End Power: Inverter rated 800 kW, 480 V, 3 Phase, 60 Hz
Air Brake Schedule: 26L Integrated Electronic Air Brake Control by NYAB/Knorr
Users: Amtrak, Metro-North (42 locomotives produced since 1995)

Main Configuration and Features:

Aerodynamic monocoque carbody
Enhanced collision capability
Cab signal equipped - Microcabmatic by GRS
Automatic parking brake
Microcomputer-based integrated control
Engine layover system by Kim Hot Start
Compartmentalized, spill-resistant fuel tank
Remote engine starting
Retractable third rail shoes
Blended dynamic/air brake system
Dual mode with seamless transition
Hostler stand
Battery jog capability

LIRR Dual Mode Locomotives (DM 30AC) *Phil Strong*

Vehicle/Technology: Diesel/3rd Rail Line Haul Passenger Locomotive
Manufacturer: GM, EMD
Year Placed in Service: 1997/1998
Summary Description:

- **Engine:** EMD 12 cylinder 710 engine
- **Propulsion:** AC, all four axles equipped
- **Propulsion Controls:** subcontractor, Siemens
- **HEP** : supplied by main engine, converted to 3 phase 480 VAC
- **HEP Signal Conditioning**: subcontractor, Siemens
- **Truck:** subcontractor, Thyssen-Krupp
- **Length, width, height:** 75 ft, 10 ft, 14.5 ft
- **Weight:** 295,000 lbs
- **Top Speed:** 80 mph
- **Braking:** Blended dynamic and friction brake, with full service brake capability possible using friction only using combination tread and wheel cheek.
- **Power at Rail:** Higher power at rail in 3rd rail mode than in diesel mode

Advantages (over conventional equipment):
Offers one seat ride to and from Penn Station NY from and to locations on Eastern Long Island East of where track with 3rd rail is not installed.

Disadvantages (over conventional equipment):
1. Low speed acceleration performance of consists using one or two DM 30 locomotives is typically less than for the LIRR EMU fleet. Maximum horsepower available at the rails per ton of consist weight is typically less than for the LIRR EMU consists. (Note that EMU consists share track with DM consists in electrified territory.)
2. Operation in 3rd rail mode over 3rd rail gaps can cause arcing when entering and leaving, if in a high power notch.

ALP45DP Dual Power Locomotive *Lutz Schwendt*

Supplier: Bombardier, Germany

Timeline: In test and delivery to NJT (New Jersey) and AMT (Montreal, QC), Revenue Service from autumn 2011

Description and Data:

- Locomotive for commuter and regional service in North America
- Max. service speed 125mph
- Weight 284.000 lbs
- Power 4MW at wheel fore electric mode, 4,200 HP diesel engine power
- 2 high speed diesel engines

Technology:

- AC propulsion
- AC catenary supply (all three NEC systems) and diesel propulsion
- 2 engines Caterpillar 3512HD certified for Tier 3
- Asynchronous alternators with engine start function
- Line converters also used as alternator rectifiers
- Common DC link for Electric and diesel propulsion
- Light weight monocoque carbody with integrated fuel tanks
- Safe fuel tank for passing through tunnels (NY fire department)
- Fully suspended drive with integrated high capacity disc brakes

Useful Technology for PRIIA Diesel Locomotive?

- AC propulsion technology
- Engine starting system
- Multi engine concept and integration into the locomotive controls
- Lightweight monocoque carbody
- High speed trucks and drives, integrated disc brake

Railpower Technologies (and Railserve) Hybrid Locomotives: Green Goat and Green Kid

Bruce Wolff

Application: Switcher locomotive

Manufacturer: Railpower Technologies (now RJ Corman Railpower). All locomotives were built under contract by various manufacturers, including SRY (New Westminster, BC), Alstom (Calgary, AB), Railserve (Longview, TX), MPI (Boise, ID), CAD Rail (Montreal, QC) and Super Steel (Schenectady, NY). Some manufacturers (e.g. Railserve) were also the locomotive purchasers.

Year entered service: Prototype Green Goat (2000 hp) in 2001; prototype Green Kid (1000 hp) in 2003. Production units built 2004 - 2006.

Summary description: Battery-dominant hybrid switcher locomotive. Traction power is provided by lead-acid batteries, which develop up to 2000 hp (Green Goat) or 1000 hp (Green Kid) for several minutes. A 300 hp diesel genset runs as needed to recharge the batteries. The concept functions only for a switcher application, where a) the average power requirement is far lower than the peak power requirement, and b) the peak power is required only for a couple minutes at a time, allowing time for the batteries to recharge before peak power is required again. Batteries are recharged entirely by the diesel genset; braking energy is not captured due to anticipated difficulty in harnessing energy at very low track speeds.

Advantages:

- Fuel consumption savings over 50% are possible.
- Extremely low emissions compared to existing Tier 0 or uncertified single-engine switcher locomotives.
- Ability to operate in zero-emission mode (by disabling diesel genset) for a limited period of time, for example when operating inside a building.
- Very quiet and vibration-free operation.

Disadvantages:

- High capital cost compared to an operable older single-engine switcher. Acquisition can usually only be justified if government emission reduction funding is available.
- Fuel cost savings are mitigated by the inherently low fuel consumption of switcher locomotives, due to their low average duty cycle.
- Can lose power, or even suffer permanent battery damage, if the duty cycle is high enough that the batteries cannot recharge properly. Susceptible to draining batteries when operating at full power at speeds above 5 or 10 mph for more than a couple minutes.
- Battery management was not fully optimized when production began, leading to a few well-publicized battery thermal events (fires).

Autorail Grand Capacite (AGC)/France – Hybrid DMU

Lutz Schwendt

Supplier: Bombardier France

Timeline: In service since 1996

Description and Data:

- Double deck Multiple Unit for regional and commuter Service
- AC catenary supply and diesel propulsion
- Service speed 160km/h (100mph)

Technology

- AC propulsion
- Asynchronous alternators
- Line converters also used as alternator rectifiers
- DC link common for Electric - and Diesel traction

Useful Features for PRIIA Diesel Locomotive?

- Propulsion principle used for ALP45 Dual Power
- The AGC is a low power multiple unit, no locomotive

Genset Industry Overview

Bobby Doyle

Vehicle Technology
Multiple high speed engines turning generators (gensets) configured through advanced computer technology, to sequence a locomotive through various power notches, providing necessary start and stopping of engine generator sets to optimize power, reduce fuel consumption and reduce emissions.

The current GenSet configurations use two (2) or three (3) smaller diesel engines and generators to replace a single primemover. Several Genset manufacturers have hybrid models that replace one or more of the engines with battery technology to further reduce fuel consumption and emissions.

Application
Short Line Operations, Short Haul, Switching Locomotives, Maintenance-of-Way Locomotives

Manufacturers
Brookville Equipment Company, National Railway Equipment, Progress Rail Service, RJ Corman/Railpower,

Current Manufacturer Platforms

1. National Railway Equipment,
    - N-ViroMotive Locomotive (2007 – Present)
        - CARB recognized/ULEL Certified
        - Tier III Compliant
        - 210 production units
            - BNSF, CP, CSX, UP, NS
            - Pacific Harbor Lines, Rail America, Fort Worth & Western
            - MBTA, SEPTA
        - 700hp Cummins QSK 19L Engines
        - 700hp to 2800hp configurations
            - 4 or 6 axle
        - Load sharing for equal duty cycle

- DC Chopper Control
- Individual traction motor control with higher adhesion efficiency
- 70 mph
- HEP 300KW to 525KW

2. R.J. Corman Railpower
    - RP Series Locomotive (Present)
        - 700 to 3000hp units
        - Deutz or Cummins Engines
        - Tier III Compliant
      - RP20BD (4-axle) & RP20CP (6-axle)
        - Three 667-hp/2000hp
        - Deutz TCD2015 V-8 diesel engine
        - 20 to 35% fuel savings
        - RPM max/min—2100/1500
        - 65 mph
        - 275,000 lbs
        - Microprocessor Controlled
        - IGBT/Individual axle drive
        - Tractive Effort (Starting) 88,000 lbs @ 30%
        - Tractive Effort (Continuous) 47,000 lbs @ 25.5 mph
      - Customer List
        - Modesto & Empire Traction Company
        - UP, NS
3. Brookville Equipment Corporation
    - CoGeneration Locomotives
        - Tier II Compliant
        - 700hp Cummins QSK 19L Engines
        - 700 to 2100hp
        - Regenerative Braking down to 0.6 mph
        - Individual traction motor control
        - Liquid-cooled IGBT controls
        - TMV Control Systems
        - Touch screen on-board diagnostics
        - Generators start engines/Fuel introduced at high speed/Smokeless
    - Optional battery, third rail or catenary input sources

4. Progress Rail Services
    - PR43C
        - Tier III Compliant
        - 2-engine 4000 hp
        - Cat C175 (3300hp) and Cat C18 (700hp)
        - 6-axle
    - PR30C

        - Tier III Compliant
        - 2-engine 1400 hp
        - Cat C18 (700hp)
        - 6-axle
    - PR22B
        - Tier III Compliant
        - 3-engine 2235 hp
        - Cat C18 (745hp)
        - 4-axle

E. Advantages of Genset Technology

- Fuel savings of more than 20%, compared to existing diesel locomotive technology in side-by-side use, have been demonstrated
- Compared to a traditional locomotive in the same application, GenSet units have been shown to reduce NOx by 58%, HC by 94%, CO by 37% and PM by 80%
- Able to adjust tractive effort to meet required task
- Modular design allows for quick engine/generator change-out

F. Conclusion

With the development of the CoGeneration, Brookville Equipment Company has advanced the concept of a multi-engine platform with the flexibility to supply electricity to the unit by catenary, third rail or batteries. This platform allows for dual-mode operation and can be considered a good candidate to test advancements in new energy storage devices.

SNCF PLATHÉE Hybrid Locomotive

Bruce Wolff

Plathée (pronounced "plah-TAY"):

- **PLA**te-forme pour **T**rains **H**ybrides économes en **E**nergie et respectueux de l'**E**nvironnement
- (Platform for energy-efficient, environmentally-friendly hybrid trains)

Application: Technology development and demonstration project, aboard a multi-purpose locomotive ("light road-switcher")

Manufacturer: Initiated by SNCF (French National Railways). Built by ALSTOM, with components from / participation by: 2HENERGY, SOCOFER, SOPRANO and ERCTEEL.

Year entered service: Testing began in 2010.

Summary description: Technology development and demonstration project, not intended as a production locomotive model. The goal was to develop the best technologies for hybrid applications, and optimize their integration into a rail vehicle. The demonstration locomotive was built on the platform of a common 1950s-vintage class BB 63000 diesel-electric switcher / branchline locomotive. It incorporates a diesel genset, hydrogen fuel cell, batteries and supercapacitors, and an energy management system to allocate the locomotive's power demands to the optimal energy source. Energy from regenerative braking is also captured and stored. The equipment configuration was optimized for performance, energy efficiency, capital cost, operating cost and maintenance cost.

Advantages:

- Fuel consumption and CO_2 emissions reduced 20% over long distances, 40% in switching and 85% when stationary and idling.
- 60% to 99% reduction in regulated exhaust emissions.
- Noise while idling at a passenger station reduced by 11.5% to 23%.

- Technologies developed in this project can be applied elsewhere, for example emergency hotel power in TGV passenger trains during overhead electric power outages.

Disadvantages:

- Project not intended for series production.
- Hybrid advantages reduced as duty cycle increases (average power demand approaches peak power demand).

Sources:

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- http://lewebpedagogique.com/sncf/wp-content/uploads/2011/01/11-Bruno-SARENI-Conception-et-optimisation-d-une-locomotive-hybride.pdf
- http://multimedia.sncf.com/lecteurs/Clip_plathee/Clip_plathee.html

TRAXX DE Multiengine Locomotive *Lutz Schwendt*

Supplier: Bombardier, Germany

Timeline: Under design. First delivery for revenue service 2013/2014

Description and Data:

- Locomotive for regional and freight service in Europe
- Max. service speed 140mph
- Weight 84t (185,000lbs)
- Multiengine locomotive with 4 diesel engines
- Power of diesel engines 4x560kW

Technology

- AC propulsion
- Permanent magnet water cooled synchronous alternators
- 4 engines Caterpillar C18, certified for European exhaust emission rule stage IIIB
- Intelligent control concept to operate the engines optimized with regard to fuel consumption and maintenance
- Light weight monocoque carbody
- Disc brakes (wheel mounted cheek brakes)

6. Useful Technology for PRIIA Diesel Locomotive?

- AC propulsion technology
- Multi engine concept
- Engine control system for optimization of fuel consumption minimizing maintenance efforts

Hydrogen Fuel Cell Switcher

Melissa Shurland

Figure 1: Fuel cell battery hybrid switcher locomotive

The need for cheaper, cleaner locomotive energy led to the innovative development and implementation of various alternatively powered locomotive designs. In 2008, the United States saw an unprecedented rise in the cost of fossil fuel, with on-highway retail cost of #2 diesel fuel being as much as $4.10/gallon. This rise in the cost of fuel coupled with the need for a more environmentally benign fuel, led to the development and/demonstration of the following three energy technologies for railroad applications: fuel cell, biodiesel and lead-acid battery.

A zero-emission fuel cell power for locomotives combines the environmental benefits of a catenary-electric locomotive with the higher overall energy efficiency and lower infrastructure costs of a diesel-electric. Vehicles Project Inc., BNSF Railroad and US Army Corp of Engineers Construction Engineering Research Laboratory (CERL) collaborated on the development of a fuel cell locomotive that: (1) reduces air pollution in urban railyards, (2) reduces atmospheric greenhouse-gas emissions, and (3) serves as a mobile backup power source ("power-to-grid") for critical infrastructure on military bases and for civilian disaster relief efforts.

The fuel cell locomotive was built on the Green Goat™ switch engine platform. At 127 tons (280,000 lb), the locomotive produces continuous power of 250 kW from its prototype exchange membrane (PEM)) fuel cell power plant, and transient power in excess of 1 MW. This translates into approximately 335 hp and 1340.48 hp, respectively. Integration of the complete fuel cell system in the locomotive is shown in Figure 2, below.

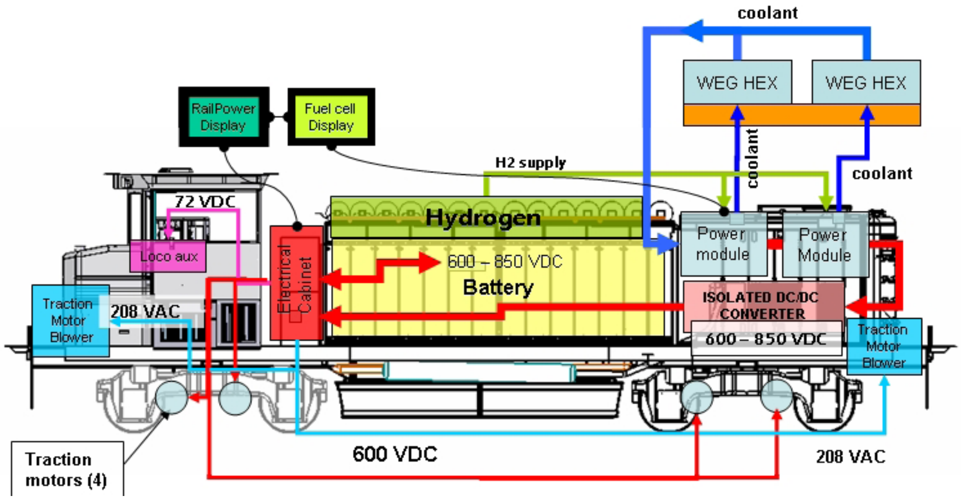

Figure 2: System layout of the fuelcell hybrid locomotive including 250 kW net fuel cell power plant, DC-to-DC converter, hydrogen storage and control interface

The rear compartment houses the fuel cell power plant, the cooling system and power converter. Fourteen carbon-fiber composite tanks, located above the battery, store a total of 70 kg of hydrogen at 350 bar (~5076 psi). Both the fuel cell power converter and the traction battery supply power to a single high-voltage bus that then distributes power to the existing locomotive systems as well as the 600 VDC traction motors. The fuel cell prototype locomotive consists of five bolt-in modules: fuel cell power plant, DC/DC power converter, cooling module, and two hydrogen storage modules. Each of the five modules were independently tested, tested as an integrated system, and then installed in the locomotive. The fuel cell prototype locomotive was tested in service in BNSF LA yard successfully. It was also tested as a mobile back-up unit on a military base in Ogden, Utah.

Currently, preliminary designs for a 2700 hp commuter rail locomotive are under consideration. One of the concepts being considered is based on Motive Power's MP36 diesel locomotive shown in Figure 3.

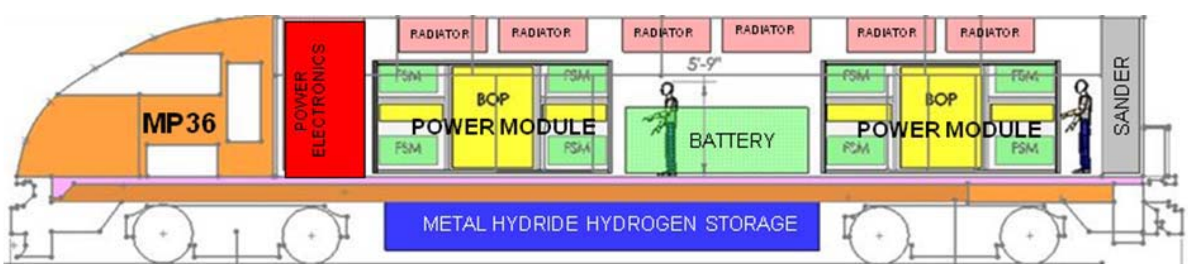

Figure 3: Motive Power MP36 fuel cell powered commuter locomotive concept

The demonstrations showed that the use of hydrogen fuel cell technology to provide tractive power, in the railroad environment is technically feasible.

Evolution Series Model ES44AC Hybrid Locomotive
GE Transportation

Graciela Trillanes

Speed: 79 mph
Arrangement: C - C
Weight: 432,000 lbs,
Engine Model: EVO 12, 4,400 hp , EPA Compliant
Motors: 6 GE AC axle suspended
Inverters: 6- one per traction motor for single axle control
Main Configuration and Features:

Aerodynamic carbody
Enhanced collision capability, FRA Compliant
Cab signal equipped (Customer Option)
Electronic parking brake
Microcomputer-based integrated control
Engine layover system
Segmented, spill-resistant fuel tank
Remote engine starting
Blended dynamic/air brake system
Low idle system
Jog capability
ARR Stand
Remote diagnostics
PTC compatible
Electronic brake system
ECP (optional)
Dynamic Weigh Management (ES44C4)
Distributed power (Optional)
Trip Optimizer (Optional)
Advance adhesion system (Optional)
GeoFance (Optional)
Advance Fuel optimization(Optional) GE

Hybrid system proof of concept completed May 2007

Battery-Powered Switcher *Melissa Shurland*

Norfolk Southern Railroad (NS) developed and demonstrated a 1500 hp locomotive that was 100% battery-powered, using lead-acid batteries. The battery-powered locomotive consists of 20 strings of 54 lead acid batteries. 1080 12-V valve regulated lead acid batteries were installed on the platform of an EMD GP38 locomotive in place of the original diesel engine and fuel tank. The nominal voltage on the strings of batteries is 648 volts. Its batteries are charged via shore power and regenerative braking energy.

The batteries are carefully monitored and controlled through an elaborate battery management control system (BMS) to assure safety and maximum battery life. The BMS system has the ability to isolate batteries, if parameters exceed preset thresholds. The charge/discharge characteristics of the batteries in large strings are currently being studied at Penn State. NS is considering several advanced battery technologies for the switch engine and ultimately a battery road locomotive.

The most promising technology is the energy storage system based on lead-carbon battery technology, being developed by Axion Power International Inc. The emerging PbC battery technology appears to offer a greater opportunity to capture the dynamic brake energy with less energy fade and longer projected service life. Axion's PbC® battery technology appears more tolerant of variation across a string of batteries which have reduced the expected life of conventional lead acid batteries on the NS switcher to-date.

Once the laboratory testing of the batteries in long strings is finalized, NS will focus on the system safety requirements of a battery-powered locomotive. The prototype battery-powered switch engine will be used as the baseline for a battery-powered road engine. The underlying strategy is to pair a conventional diesel locomotive with the battery road Locomotive to minimize on line road failure risks. Trip optimizer software, such as LEADER, would be used to automatically switch between diesel and battery locomotive to provide the required tractive effort, while reducing the overall amount of fuel utilized for the trip.

B20 Biodiesel Fuel Demonstration

Melissa Shurland

Biodiesel fuel is a feasible alternative source of fuel for diesel locomotives. B20 biodiesel blended fuel (20% beef tallow-based biodiesel, 80% ultra low sulfur diesel) was successfully demonstrated in the passenger locomotive of the Amtrak Heartland Flyer train. The locomotive was fueled with B20 fuel for a period of 12-months while the train was operated in revenue passenger service. Following the 12-month trial, the locomotive underwent emissions testing and tear-down inspection of three of its power assemblies to assess the wear of the engine components under the influence of the biodiesel.

An Amtrak GE P-32 12-cyclinder locomotive (photo) was selected for the revenue service trial. The locomotive hauled 4 passenger coaches and 1 baggage car daily from Oklahoma City, OK to Fort Worth, TX, during the trial, for a total of 410 miles. The biodiesel fuel was tested monthly to ensure that it met the ASTM standards for B100 and B20. The engine oil was tested every 10 days to monitor its acidity level and degradation. Throughout the 12-month trial, there were no complications to the engine due to the biodiesel use. The emissions testing of the locomotive engine by GE Transportation Services showed that the engine emissions were in compliant with the EPA Tier 0 emissions standards.

The tear down inspection of the power assemblies showed that there were no abnormal wear on the engine components as a result of the biodiesel used. The locomotive consumed 500 gallons of fuel per roundtrip; therefore, during the biodiesel trial, the engine consumed about 200,000 gallons of B20 which was 160,000 gallons of ultra low sulfur diesel and 40,000 gallons of biodiesel. The locomotive traveled approximately 150,000 miles while using B20 biodiesel, and maintained its high level of customer satisfaction and on-time performance.

- Heavy-duty truck natural gas engine rather than a diesel engine retrofitted to burn natural gas
- Self-contained (on-board locomotive), cryogenic storage of LNG; conversion into CNG; and injection as natural gas into the engine
- High-Pressure Direct Injection (HPDI) of small amount of diesel fuel prior to injection of natural gas, at compression stroke, for auto-ignition rather than spark ignition

Application: Line haul freight locomotive in high fuel consumption service

Manufacturer: Development will be conducted by a consortium of:
- Gaz Metro Transportation Solutions, a subsidiary of Gaz Metro will provide its LNG expertise during the testing and will be responsible for the logistics of fuel supply
- Westport Innovations will provide the Westport HD natural gas engine, using HPDI technology, possibly using a Cummins engine as the base unit
- Canadian National Railway will provide railroad locomotive engineering and operating expertise and will operate the demonstration locomotive on selected routes during the trial period
- [Sustainable Development Technology Canada, a non-profit Canadian federal government corporation, will provide C$2.3 million in funding]

Year Testing to Begin: A demonstration unit should be in service by 2013.

Summary Description: The project aims to demonstrate the technical, economic and environmental viability of LNG engine technology for locomotives, from design to supply.

Advantages (over conventional equipment):
- Improve life cycle cost structure for locomotive operation in high fuel consumption service
- Achieve compliance with increasingly stringent emissions requirements
- Reduce greenhouse gas (GHG) emissions by up to 25%
- HPDI of pilot diesel fuel prior to injection of natural gas

Disadvantages (over conventional equipment):
- Will have to overcome previous problems with loss of useable fuel during refueling operations and through venting of natural gas from on-board LNG fuel tank

- Local fire jurisdictions or States may either impose stringent and unreasonable restrictions on time and location of LNG refueling operations or completely prohibit LNG refueling within their jurisdiction
- Because of the high-pressure cryogenic LNG fuel tank, local fire jurisdictions may prohibit operation of LNG-powered locomotives in tunnels
- Previous LNG-powered locomotives used either pre-mixed natural gas with air using spark-ignition, or low pressure injection of natural gas with pilot diesel fuel injection on compression stroke for compression ignition. To avoid pre-ignition, the engine compression was reduced, resulting in a loss of rated power and efficiency of an engine powered by LNG as compared to the same engine powered by diesel fuel
- Previous LNG-powered locomotives resulted in lower emissions of NOx but higher emissions of HC and CO
- HPDI of diesel fuel prior to injection of natural gas at compression stroke for compression ignition may address both the power and emissions issues seen in previous LNG-powered locomotives

Sources

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Locomotive Tier 4 Development Status

Graciela Trillanes/ Bruce Wolff

A summary of e-mailed responses from four engine manufacturers provided to Walter Weart, and published in *Progressive Railroading* (January 2011) http://www.progressiverailroading.com/mechanical/article/Today39s-diesel-engine-technology--25453

EMD

- Completed an emissions verification program for Tier 3-compliant engines and launched field tests.
- Plans to begin shipping Tier 3-certified locomotives in January 2012.
- Tier 4 is a "major challenge" - is engaged in a multi-year emissions development and validation program to meet it.
- EMD has reached Tier 4 levels in its research facilities.

GE

- Plan to deliver Tier 3-compliant locomotives in 2012 and Tier 4-compliant locomotives in 2015
- The introduction of a Tier 3-compliant locomotive in 2012 will prompt the next major modifications to the Evolution® Series.
- To meet Tier 4, GE is evaluating various technologies to provide the lowest engine emissions and minimize after-treatment requirements.
- The company is "aggressively" working on after-treatment solutions that do not use urea.

MTU

- MTU Detroit Diesel is "making larger expenditures" on research and development to comply with emission requirements and needs to balance compliance with value for customers.
- To meet Tier 4 emissions, MTU plans to release a "range of technologies" on engines from the Series 900 rated at 100 horsepower through the Series 4000 rated at 4,000. They recently unveiled the latest generation, the S4000 R84, which features two-stage turbocharging, intercooling and cooled Exhaust Gas Recirculation (EGR)
- Also plans to introduce SCR to control NOx emissions on engines generating less than 1,000 hp, subject to the EPA's Tier 4 standards.

Cummins Rail

- 2011: Tier 3-compliant engines 750 – 2700 hp
- 2012: Production release of Tier 4 600 hp for gen-set switchers (non-urea)
- 2013: Field test Tier 4 switch/line haul 750->>2700hp
- 2014: Production release of T4/SIIIB 750 hp rail car
- 2015: Production release of T4/SIIIB 750->>2700 hp switcher/road

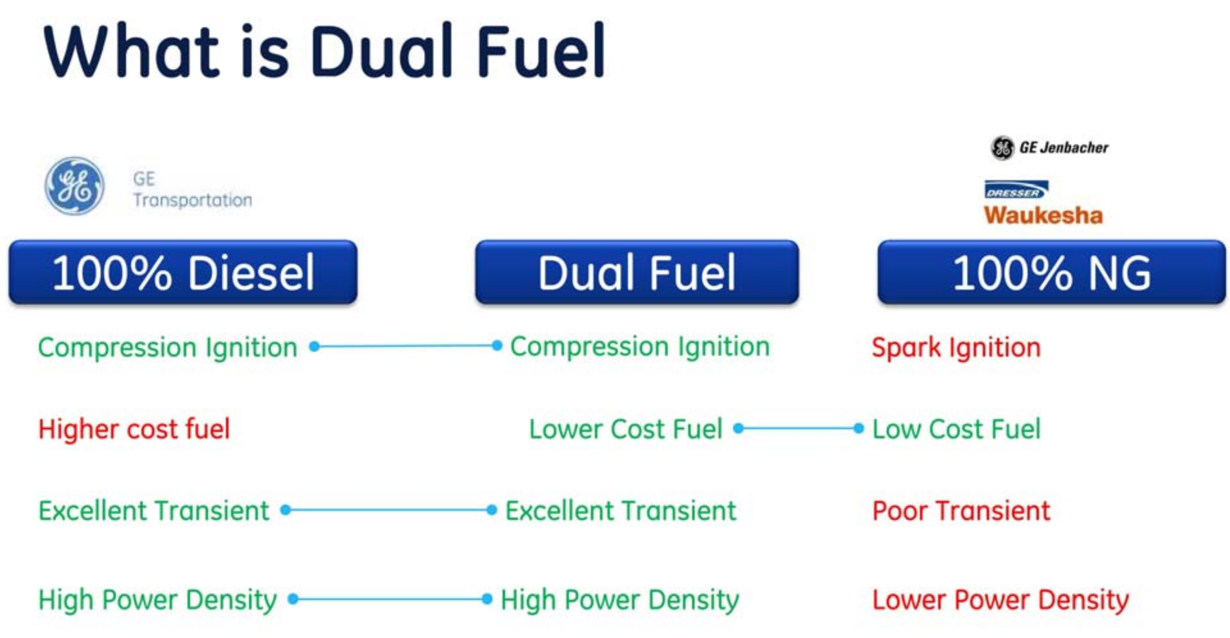
Tier 4 Advantages

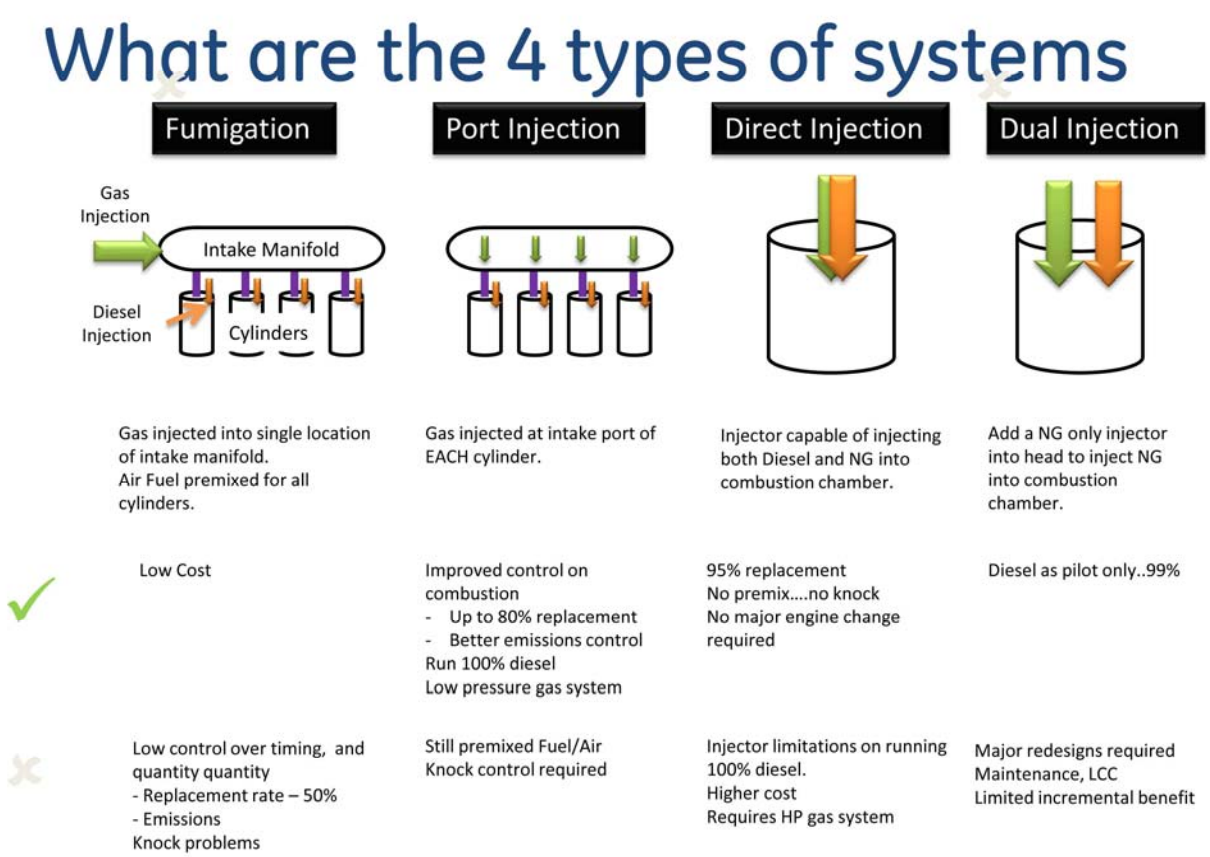
- A Tier 4 certification on an engine or a locomotive will allow that engine or locomotive to be produced for railroad use in the United States from 2015 on.
- Meeting the Tier 4 limits reduces the environmental and health impacts from the four regulated pollutants (nitrogen oxides, particulate matter, unburned hydrocarbons and carbon monoxide).
- Tier 4 certification includes a requirement for locomotives to be equipped with an idle shutdown device, potentially reducing fuel consumption, emissions and engine maintenance.
- Many emission-reduction technologies have already been proven in on-highway applications.

Tier 4 Disadvantages

- Emission-reduction technologies increase:
  - Capital cost
  - Complexity
  - Weight
  - Space requirements
  - Maintenance costs

  of the engine and exhaust system.
- Possible increased fuel consumption and carbon dioxide (greenhouse gas) emissions.
- Possible increased cooling system (radiator / charge air cooler) requirements.
- Depending on the technology chosen, possible requirement for an additional fluid (urea solution) to be procured, dispensed and carried onboard the locomotive.
- Possible difficulties in scaling up on-highway emission-reduction technologies for use in locomotives.


What is Dual Fuel
GE Transportation
GE Jenbacher
DRESSER Waukesha
100% Diesel
Dual Fuel
100% NG
Compression Ignition
Compression Ignition
Spark Ignition
Higher cost fuel
Lower Cost Fuel
Low Cost Fuel
Excellent Transient
Excellent Transient
Poor Transient
High Power Density
High Power Density
Lower Power Density


What are the 4 types of systems
Fumigation
Port Injection
Direct Injection
Dual Injection
Gas Injection
Intake Manifold
Diesel Injection
Cylinders
Gas injected into single location of intake manifold. Air Fuel premixed for all cylinders.
Gas injected at intake port of EACH cylinder.
Injector capable of injecting both Diesel and NG into combustion chamber.
Add a NG only injector into head to inject NG into combustion chamber.
Low Cost
Improved control on combustion
- Up to 80% replacement
- Better emissions control
Run 100% diesel
Low pressure gas system
95% replacement
No premix....no knock
No major engine change required
Diesel as pilot only..99%
Low control over timing, and quantity quantity
- Replacement rate – 50%
- Emissions
Knock problems
Still premixed Fuel/Air
Knock control required
Injector limitations on running 100% diesel.
Higher cost
Requires HP gas system
Major redesigns required
Maintenance, LCC
Limited incremental benefit

ADVANCED LOCOMOTIVE PROPULSION SYSTEM/ BOMBARDIER JETTRAIN

Mike Coltman/Al Bieber

The Advanced Locomotive propulsion System (ALPS) was originally a coordinated project with the Bombardier JetTrain Project. Turbine engines, running on diesel fuel, can provide very high power at very low weight (and space). The idea was that the ~5000 hp turbine engine and fuel would replace the pantograph and transformer in a high horsepower locomotive The turbine used alternators produce power that would be rectified supplying a DC bus. This bus would supply power to a bi-directional power converter that would supply the AC traction motors and the train's hotel power requirements. In braking, the motors would be turned to generators and the power converted back to the DC bus supplying either a dynamic braking grid or another converter driving a motor generator driving a flywheel. Other energy storage systems could work here as well.

The Advanced Locomotive Propulsion System project at the University of Texas was intended to design and build several critical components required to implement this concept, notably the flywheel, high rotating speed alternators (needed for both the flywheel and the gas turbine) and the bi-directional power converters. Both the flywheel and the gas turbine have rotating speeds in the range of 15000 rpm (at peak energy for the flywheel) requiring alternators that can operate at high rotating speed.

The Bombardier JetTrain used a reduction gear between the gas turbine and the alternators allowing the use of off-the-shelf alternators a small weight and efficiency penalty.

The flywheel energy storage system built by University of Texas Center for Electromechanics was a 450-600 Mjoule machine that was never fully operational. A big issue was the containment system around the flywheel that weighed over 5000 lbs. It also had to be gimbled to allow for the gyroscopic effects. The flywheel was originally intended to be housed in the locomotive along with the gas turbine, but later concepts had it in a tender car as space and weight became an issue on the vehicle containing the turbine.

The flywheel was coupled to a motor generator capable of extracting 2 to 2.5 Mw providing supplemental power for 2 to 3 minutes for acceleration. The entire system, flywheel, gas turbine, high speed alternators, and power conditioning modules were never operated together.

For more information on the flywheel contact John Herbst at UT.

The JetTrain was completed and tested at the Transportation Technology Center in the summer of 2001. During the successful test program, approximately 21,000 miles were completed at speeds up to 156 mph. The vehicle exhibited reliable, quiet and smokeless operation.

Some emissions estimates for the engine:

Based on information provided by the manufacturer of the turbine engine, an analysis had been performed by Bombardier of the expected emissions over a representative passenger route in regular service, with the following results:

Toronto to Montreal Estimated Emissions - 1 Train, 1-Way			
	HC (kg)	CO (kg)	NOx (kg)
EPA - Tier 2 diesel standard compliant locomotive	2.74	13.48	52.64
Turbine Electric - Estimated	1.75	5.32	38.97
Reduction	36%	61%	26%
Conditions: 1 locomotive, 4 cars, 125 mph maximum speed, 239 seats, 350 kW head-end-power load			

Unlike most diesel locomotives, the JetTrain was designed to be shut down when not in use and could easily be restarted even under very cold conditions, and thus the engine would not be idled when the locomotive was not in use.

Conclusions

In summary, a diesel electric locomotive ordered today that must meet the requirements of the PRIIA specification would look very much like diesel-electric locomotives presently in service. The same can be said for a dual mode locomotive based on the requirements contained in the proposed dual mode requirements document. The electrical propulsion duty cycle and low acceleration limitations of current dual mode locomotives can be resolved with larger capacity cabling. Without an onboard electrical storage capability, the issues raised of arcing under load remain an inherent design/operational problem.

Independent of the top speed of a vehicle is the EPA Tier Level of the engine. Most of the locomotive manufacturers have Tier III-compliant engines in production, or will soon, to support the January 2012 deadline. A commercial Tier IV railroad locomotive engine is still a developmental technology. The requirements documents call for a Tier IV engine, but with the order of PRIIA-funded locomotives imminent, is it reasonable to require a Tier IV engine? The answer to that question is beyond the scope of the Task Force. Requirements of 40CFR1033 (Control of Emissions From Locomotives) do not, out of hand, require ultimate upgrading of a Tier III engine to a Tier IV during the expected 20-25 year life of a locomotive, but careful reading of and compliance with the regulations will be needed by the owning and operating authorities.

There are some promising technologies and solutions when looking ahead several years. Most of the successful, advanced technologies uncovered in the preparation of this report have been successfully applied on switch locomotives. These are low speed, relatively low power applications where the vehicles remain in a controlled environment, i.e., a rail yard. But, there is movement in the line-haul locomotive field. GE has successfully tested a hybrid locomotive for use in freight service. If the technology can be transferred to a passenger application, this could represent an improvement from the "traditional" design of diesel locomotives. A reasonable scenario would involve the development of a passenger train-specific design, and then a few years of testing.

In the early days of passenger railroad diesel locomotives, a "locomotive" often consisted of two or three permanently coupled vehicles in order to provide enough tractive effort. As engines became more powerful and smaller, enough tractive effort could be provided in one vehicle. Perhaps it is time to go back to the two-unit concept, with one vehicle containing the main diesel engine with the other unit containing fuel cells, batteries or other power storage device. Research would be required to determine the economic feasibility of this kind of solution. Particularly for high-speed passenger operations, would carrying around the weight of two locomotives "make the financials work." Then again, some of the analyses performed by manufacturers have suggested that for 125 mph vehicle operation, two locomotives will be required. If that is the case, the diesel/electric storage combo locomotive might look more attractive.

The “genset” concept of several small diesel engines being used to provide “as needed” power has made a debut in the North American passenger rail market in the form of the Bombardier ALP-45DP. These vehicles have been ordered by New Jersey Transit and Agence Métropolitaine de Transport (AMT) in Montreal, QC. The multi-engine concept for a pure diesel engine version is in development in Europe, and the company has stated it plans to design a vehicle based on the TRAXX multiengine vehicles for the U.S. market.

It is less clear if the CNG and or LNG fuel technologies will eventually be useful in passenger locomotives. Indeed, even the freight railroads may find limitations when operating through tunnels. While public safety authorities have accepted the use of natural gas on transit buses, that doesn’t necessarily translate to railroads. The same concerns hold for the hydrogen used in the fuel cell vehicle. On the other hand the use of B-05 biofuel is something feasible to implement today. Using B-20 still requires additional research its impact on engine conditions, as well as further economic analyses.

Ultimately, the “next” widely-used technologies to be used on passenger locomotives will be determined by the market. Some of the vehicles discussed in this report exist because the manufacturers believed there was a potential market. Can PRIIA’s Next Generation Equipment Committee assist in developing technologies? Rather than perform its own research, the NGEC should work with the FRA to identify a promising technology (or technologies) for the Rail Energy, Environment and Engine Technology Subprogram in the FRA’s Office of Research and Development to fund and develop. A better model for developing new technologies was recently announced in Europe. A Joint Technology Initiative was established with nearly a dozen major manufacturers jointly committing to provide €600-€800 million over the next several years. http://www.railway-technology.com/News/News124387.html