
DUAL MODE AND NEW DIESEL LOCOMOTIVE DEVELOPMENTS

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Author: Janis Vitins

Affiliation: Bombardier Transportation

Address:

Brown-Boveri-Strasse 5

10 CH-8050 Zurich

Switzerland

Phone: +41 44 318 36 54

Cell: +41 79 311 22 50

Fax: +41 44 318 27 27

15 e-mail: janis.vitins@ch.transport.bombardier.com

Abstract

The integration of electric and diesel traction into a single rail vehicle is technically challenging due to weight and space restrictions, particularly for AC catenary power. By combining recent developments in power converter technology, diesel engine design and mechanical light weight structures, dual mode locomotives are now feasible for railroad applications. Apart from the different modes of traction, such locomotives must also fulfill the latest vehicle standards with regards to safety, environmental impact and interoperability. A key component is the DC-link of the traction converter which interfaces to electric and diesel power supply systems. In addition, batteries and/or super-caps can be interfaced to this DC-link. All electric power flow is bi-directional permitting a multitude of possibilities for energy savings and reduction in exhaust emissions. The performance of a dual mode locomotive is greatly enhanced using the latest high-speed diesel engines developed for off-road and industrial applications. Not only do they provide high diesel power at low weight, they also meet the new Tier3 and upcoming Tier4 exhaust emission standards. For maximum vehicle performance in both modes, the carbody and truck must be light weight. A monocoque carbody and fabricated truck are the obvious solutions hereto, as used on the dual-powered ALP-45DP and the European TRAXX AC3, which is an electric locomotive with a diesel engine for operation into non-electrified sidings and terminals. The above technologies lend themselves also to new diesel-electric locomotives, yielding a high vehicle performance at low axle loads, as required for passenger services at 125 mph.

Introduction

Passenger trains have been the traditional domain of locomotive traction. Given the necessity for new and extended passenger services, economic solutions are needed for new types of locomotives which can run beyond the existing service networks. Whereas diesel traction is wide spread in North America, there is also an electrified network, primarily in the Northeast, as well as third rail systems in many larger cities and suburban areas. Further electrification can be expected as ridership increases in the future and thus the need to haul longer and heavier trains in high density traffic. In this environment, the dual mode locomotive can play an important role allowing a one-seat ride over system borders, both electric and diesel. This is currently the situation at NJ Transit and AMT, Montreal. The ALP-45DP [1] is presently in delivery for these railroads. These locomotives have become technically feasible in the last years thanks to the advent of compact and light weight propulsion equipment and by combining this equipment with the latest diesel engine developments. Manufacturers of off-road and industrial diesel engines have invested heavily in new engine technologies, making these machines attractive also for railroad applications. These engines open up new opportunities for fuel savings and for lowering exhaust emissions in compliance to the upcoming Tier4 requirements.

The Propulsion Concept of Dual Mode Locomotives

In a dual mode locomotive, the traction converter must interface with the electric power source from the catenary (and/or third rail), as well as with the power output from the alternator. This is best accomplished with the voltage-source traction converter which has an intermediate DC-link, see Figure 1.

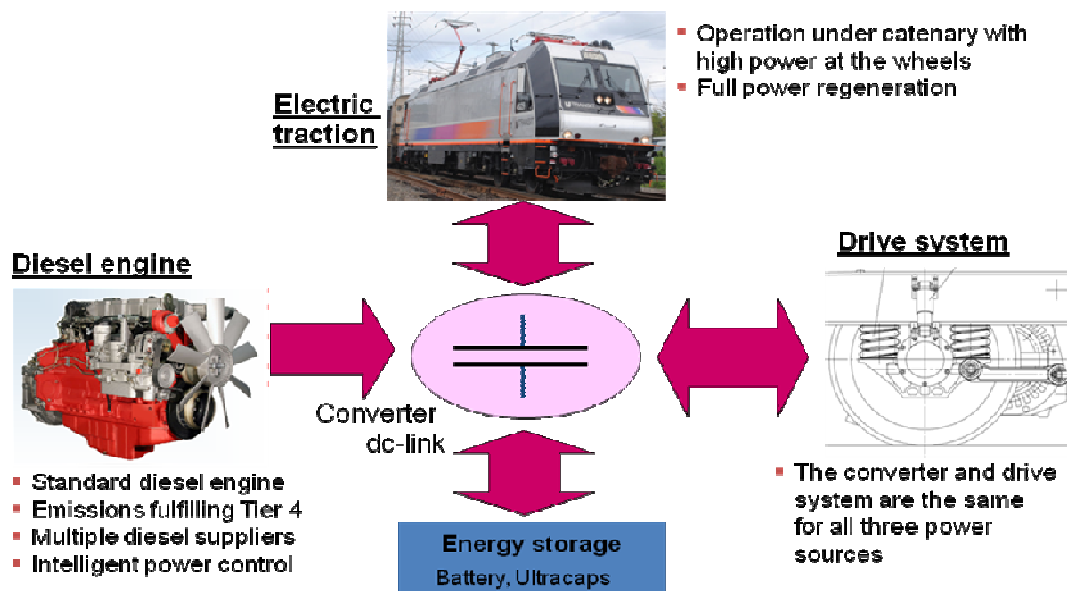


Figure 1: The DC-link of the traction converter is the common interface for the electric and diesel power flow. Also energy storage devices can interface to the DC-link.

This DC-link is comprised of a capacitor bank to which power input and output circuitry is connected. Under catenary, the line voltage is reduced by means of the traction transformer to levels compatible with the converter switching devices. The output from the secondary windings is then rectified and fed into the DC-link. In third rail applications, the power can flow directly through an input choke or via a step-up chopper into the DC-link. In diesel traction, the power output of the alternator is rectified and also fed into the same DC-link. Hence, the DC-link is the common interface to the traction motors and drive systems. The DC-link voltage is determined by the rated blocking voltage of the IGBT switching devices of the converter. For 3.3 kV IGBT devices, the DC-link voltage is typically 1'700 V and for 4.5 kV IGBTs it is approximately 2'800 V. The choice of IGBT device, and thus the DC-link voltage, depends on many design factors. In general, a high DC-link voltage is chosen for high traction power.

The DC-link can be viewed as the common *bus-bar* for power distribution within the locomotive. In the case of passenger locomotives, additional inverters can be connected to this DC-link to feed the passenger cars with head-end power, HEP. Also, the locomotive auxiliary converters draw power from the DC-link, and batteries and other electric storage devices can be added in the same way. In all cases, modern propulsion technology allows power to flow in both directions. This allows the following possibilities of power flow in traction and dynamic braking:

- Traction: Power flow from the overhead catenary or third rail to the traction motors, auxiliaries, HEP and energy storage devices.
- Traction: Power flow from the diesel engine to the traction motors, auxiliaries, HEP and energy storage devices, and if desired, also back to the catenary. In the latter case, diesel engine full load testing is possible without resistor grids for power dissipation.
- Traction: Power flow from the energy storage devices to the traction motors, HEP, auxiliaries and catenary.
- Dynamic braking: Power flow from the traction motors to the catenary (or third rail), HEP, auxiliaries and energy storage. Hence, even in diesel mode there is a non-negligible amount of power regeneration.

The power rating of each power source depends on the specific application. Typically, a high power is needed in the electric mode for fast acceleration of long, high capacity trains to high speeds. Non-electrified networks are generally less congested and often have lower maximum speeds. Therefore, the power at the wheels from the diesel engines can usually be somewhat less than in electric traction. Energy storage devices today are still not capable of providing economically sufficient traction power for reasonable travelling distances. Therefore, their application is mostly limited to smaller shunters and special purpose vehicles. However, this may soon change with the availability of new battery technologies.

The ALP-45DP Dual-Powered Locomotive

This locomotive, see Figure 2, was developed initially for NJ Transit and the Montreal based railroad AMT (Agence Métropolitaine de Transport) to operate their passenger trains on routes which are only partly equipped with overhead catenary. The objective is to provide passengers

with a *one-seat ride* on services with mixed diesel and electric traction. It also enables railroads to switch off diesel traction under catenary, where diesel locomotives have previously been used. The ALP-45DP thus allows substantial fuel savings, diesel traction being substantially more expensive in overall than electric traction under catenary.



Figure 2: The ALP-45DP for AMT (left) and NJT (right).

The challenge in the design of the ALP-45DP was to provide sufficient power ratings in both electric and diesel mode under the constraint of a maximum axle load of 72'000 lbs (32.66 tons) and meeting the required FRA standards 49CFR 229&238. This was done using the latest technologies already incorporated in the electric locomotive ALP-46A for the carbody, trucks, propulsion and control & communication. Also, the operators cab is basically identical to that of the ALP-46A, with additional functions for diesel traction. The fuel tank has a capacity of 1'800 US gal and is an integral part of the carbody structure. It consists of four separate compartments of 450 US gal each in order to fulfill the stringent requirements of fire safety in tunnels. The trucks are derived from the German locomotive BR 101 and are of the same basic design as is used on the ALP-46 locomotives, however, adapted to the higher axle load.

The major engineering challenge was to install both the diesel engines and the electric traction equipment with the space and weight restrictions of a 4-axle locomotive. Two Caterpillar 3512HD high speed engines were chosen for the diesel mode. One advantage of these engines is that they can provide high acceleration, essential to achieve short traveling times between stations. Also, they meet Tier3 exhaust emission standards. A solution is now being prepared to meet Tier4. The disposition of equipment within the locomotive is shown in Figure 3. The traction converter is positioned in the center of the locomotive with the transformer directly beneath it. This arrangement has the advantage of short power cables between them. The two diesel engines are mounted left and right of the converter providing largely a symmetric layout and thus facilitating the weight balance of the locomotive. The cooling systems are installed in the roof sections

directly above the diesel engines, thus making best use of available space. The fuel tanks are directly below the diesel engines. The rheostatic brake cubicle, the cabinets for low voltage and the auxiliary drive distributor, battery boxes and the toilet are mounted in the rear section of the locomotive.

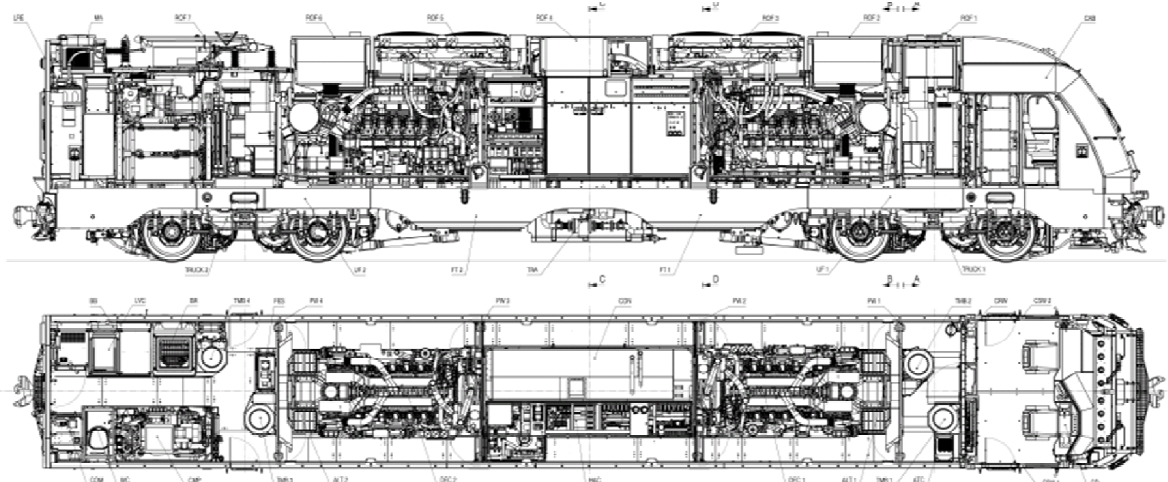


Figure 3: The equipment disposition within the ALP-45DP

The different energy flows from the catenary and diesel engines are handled by the same traction converter and drive system [2]. In the electric mode, the catenary voltages used on the Northeast Corridor of 25, 12.5 or 12kV (60 and 25 Hz) are reduced in the transformer and are rectified for the dc-link by the line converters. In diesel mode, the line converters take a new function and rectify the output voltage of the alternators and feed DC power into the traction converters. The diesel engines are turned on by the alternators, with power sourced from the line converters and batteries. The key technical data of the ALP-45DP is shown in Table 1.

ALP-45DP	Electric mode		Diesel mode
Length over coupler	71' 6 1/4" (21'000 mm)		
Axle base	9' 2 1/3" (2'800 mm)		
Wheel diameter	44" (1'118 mm), new 41 3/16" (1'046 mm), fully worn		
Total weight	284'000 lbs (128.8 tons)		
Axle load	71'000 lbs (32.2 tons)		
Service speed	125 mph (201 km/h)		100 mph (160 km/h)
Converter type	IGBT, water cooled		
Nominal power at the wheels	5360 hp (4'000 kW)		2'734 hp (2040 kW), 8 cars
Train supply (HEP) capability	1'340 hp (1'000 kW)		
Starting tractive effort	71'000 lbs (316 kN)		
Brake force (electric brake)	34'000 lbs (150 kN)		
Brake resistor power	1'742 hp (1'300 kW)		

Table 1: Key technical data of the ALP-45DP

The ALP-45DP locomotive has a low environmental impact with regards to noise and exhaust emissions as follows:

- The diesel engines can be turned off in the stationary mode under overhead lines. The locomotive is then parked with the pantograph up and it heats or cools the train with the HEP supply. This feature is important in densely populated areas.
- When the catenary is not available, noise and exhaust emissions can be significantly reduced through the use of only one diesel engine.
- The locomotive can be operated with just one diesel engine at slow speeds and at low power demand.

The above measures lead to a considerable drop in fuel consumption compared to conventional diesel locomotives, and this, in turn, permits the use of somewhat smaller fuel tanks. As the total costs (operating and maintenance) are significantly higher for diesel than for electric operation, the dual mode locomotive also results in considerable overall cost savings to the railroads. The ALP-45DP also improves operational availability. If one diesel engine fails, the locomotive still has full tractive effort and can continue operation with half power. The HEP supply is maintained and the journey continued.

As shown above, the propulsion concept of the dual mode locomotive allows to integrate also a third rail capability for services, e.g. in the New York region. The important additions needed for the ALP-45DP are the pick-up shoes, high current cabling and switches as well as input and chopper chokes. Due to the large currents drawn from third rail, such chokes add several tons of weight and require adequate space for mounting. First investigations show that it is possible to include third rail to the ALP45DP, however, only with smaller and lighter diesel engines so to remain within the axle load limits and within the existing length of the locomotive.

Dual Mode Locomotive Designed For Last Mile

Whereas the ALP-45DP was developed for the North American market, the requirements are quite different in Europe [3]. There rail networks are mostly electrified and important non-electrified lines are increasingly fitted with catenary. Thus, diesel traction is often limited to less frequented secondary routes as well as sidings and terminals. In this situation, the design objective of a dual mode locomotive in Europe is to maintain high performance for dense traffic on electrified mainline routes and to install only a small diesel engine for seamless services into sidings and terminals. Such a design concept has been implemented on the TRAXX AC3, a freight locomotive with 5'600 kW (7'500 hp) at the wheels in electric mode and 180 kW (240 hp) in diesel mode. The maximum tractive effort of 300 kN (67'400 lbs) is the same in both modes, allowing operation with the same train load also in diesel traction, although at much lower speeds, and without stopping for the switchover. All electric propulsion and auxiliary equipment are placed into a central power pack, thus providing the necessary space for the last mile diesel module, see Figure 4. This module is designed as a self- contained, replaceable unit, complete with controls and cooling equipment.

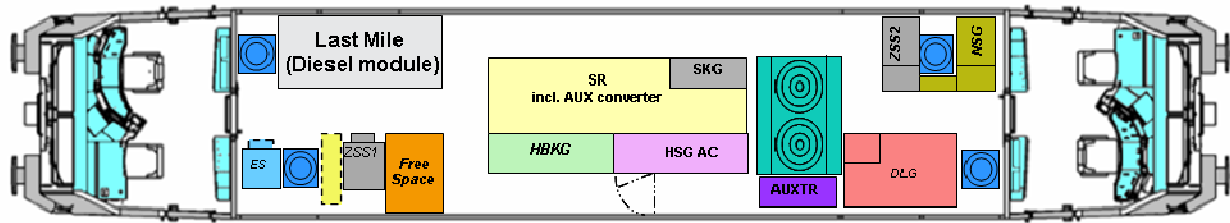


Figure 4: The equipment disposition within the TRAXX AC3.

The TRAXX AC3 locomotive has, in addition, a boost function which provides supplementary power from batteries, see Figure 1. The diesel engine is a Deutz BR 2013 4V with a power rating at the shaft of 230 kW (310 hp). It fulfills the exhaust emission standard of Stage IIIB (similar to Tier4), which is required in Europe starting January 2012.

New Diesel Locomotive Developments

Principally, it is possible to apply the concepts of multi-engine propulsion, as used on the ALP-45DP, also in diesel-electric locomotives. It was found that a four-engine solution with heavy-duty industrial engines is the most favorable for lowest initial and life-cycle costs. This led to the corresponding design of the TRAXX DE ME (BR 246) for the German railroad, which will use this locomotive for regional passenger services. The locomotive is shown in Figure 5. It has four Caterpillar C18 diesel engines compliant to the European Stage IIIB exhaust emission requirements. All engines feed into the DC-link. It features an elaborate start/stop functionality so that engines can be powered selectively, according to the power requirements of the locomotive.

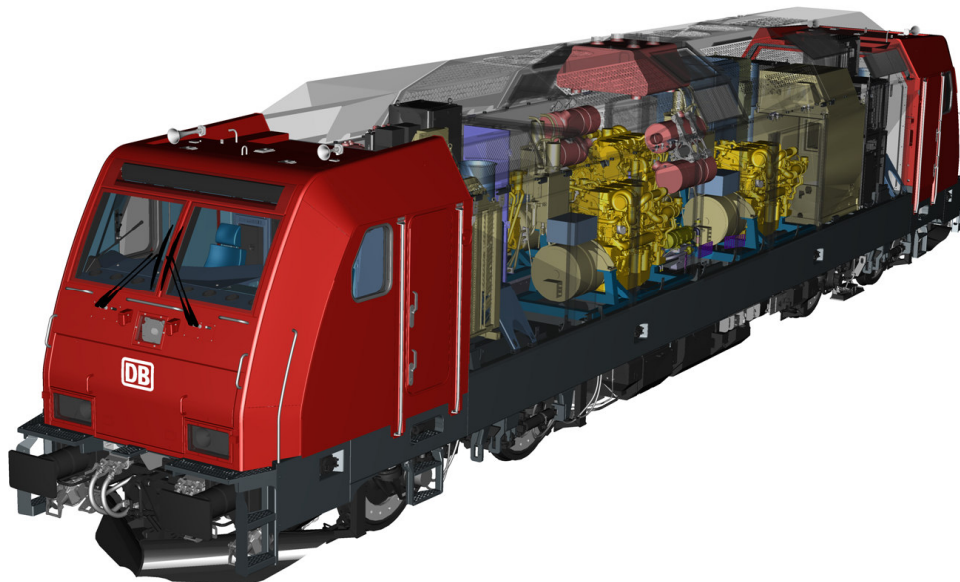


Figure 5: The new TRAXX DE ME (multi-engine) locomotive for the German Railroad DB Regio. It is powered by four heavy-duty C18 industrial engines.

Such a solution can also fulfill the upcoming traction needs for new passenger services in North America on existing and future high speed routes with 125 mph. The basic requirements for such high-speed locomotives and coaches have been specified by the PRIIA committee and are:

- Service speed of max 125 mph
- 5 • High traction power for fast train acceleration
- Lowest possible weight to reduce fuel consumption
- Low unsprung mass to reduce rail forces particularly at high speed
- Exhaust emission standard of Tier4 (required starting 2015)
- Low overall fuel and lube oil consumption
- 10 • Train supply (HEP) of minimum 600 kVA

From the above, it is evident that a passenger diesel locomotive for high speed services up to 125 mph has very different design requirements from a heavy freight locomotive. Light weight designs with low axle loads, low unsprung mass and high traction power are necessary to enable cost-efficient passenger operations. As benchmark, axle loads in Europe for speeds up to 125 mph are limited to maximum 22.5 tons. A design example of such a weight truck is given below, see Figure 6. Key design features are: light weight fabricated frame, primary and secondary coil springs, fully suspended drives including suspended brake discs, short axle base, flexible wheelset guidance vertically and laterally, and push/pull rod for transmitting traction and brake forces between the truck and carbody.

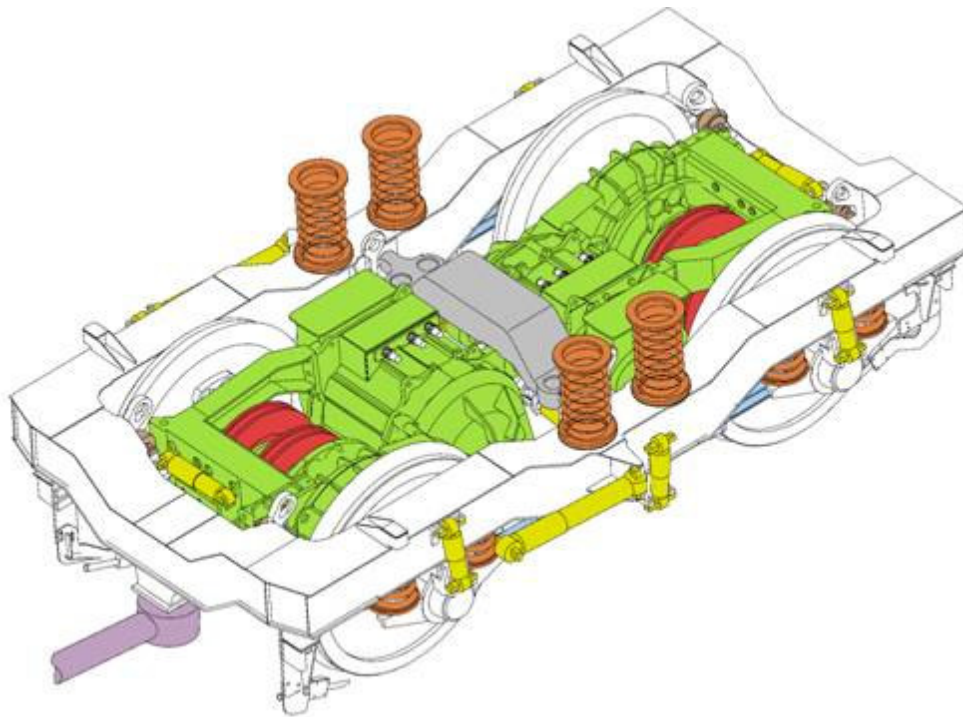


Figure 6: Design example of a light weight truck for 125 mph.

Compared to a freight locomotive, a high-speed passenger locomotive also has a different operational profile and must provide redundant power for HEP in all modes of service, also at standstill. Additionally, frequent starts and stops must be accounted for. These requirements are well met with the multi-engine propulsion concept. As with the above German locomotive, the advantages of multi-engine propulsion compared to conventional diesel locomotives can be summarized as follows:

- Significantly lower overall locomotive weight compared to traditional single engine solutions. With high speed engines the weight saving is approx. 2 tons (based on the 4-axle TRAXX DE ME locomotive) for the Stage IIIB exhaust emission standard. The weight saving is of course considerably higher when comparing to a single low or medium speed diesel engine.
- Faster acceleration of the engines and thus of the complete train.
- Proven industrial heavy-duty diesel engines which already today fulfill the exhaust emission standard of Tier4. The diesel engine assemblies are modular and can, e.g. at future revisions, be replaced with new generation engines meeting future emission standards.
- Higher mission reliability with engine redundancy.
- Lower fuel and lube oil consumption with significant reduction of CO₂ emissions compared to single engine concepts.
- The engines of different suppliers can be used without major modifications of the locomotive. Hence, second sourcing for the diesel engine is possible.
- Substantially reduced maintenance and overhaul costs and increased spare parts availability over the product lifetime.

As all diesel engines feed into the same locomotive traction converter, the full tractive effort and HEP is always available, even if one or more engines are shut off. Engine start is by the alternator, eliminating the need of conventional starters and reducing stresses on batteries. The power conversion is similar to the ALP-45DP locomotive. Also here, a monocoque carbody and fabricated trucks are prerequisites for lowering the overall weight and increasing the locomotive performance.

Outlook

Looking forward to the next decades of commuter and passenger rail services in North America, the railroads and the industry are challenged to enhance such future services and make them a long-term commercial success [4]. Based on the North American rail infrastructure, both electric and diesel-electric locomotives are needed. The dual-powered locomotive bridges the gap between electrified and non-electrified networks. The new technologies applied can contribute to productivity gains of the railroads so as to reach and maintain a competitive edge over alternative modes of transportation. Today, technologies for lightweight carbodies and trucks are available and proven in USA, and can also fulfill new standards, e.g. crash requirements. Propulsion for traction is constantly being further developed, allowing new combinations of diesel, electric and battery power sources as is seen by the new ALP-45DP and TRAXX AC3 developments. Taking these technologies forward, also new diesel-electric passenger locomotives are now feasible with

multi-engine designs, which fulfill Tier4 and have the potential of substantial fuel savings and exhaust emission reductions.

Looking forward to future US freight diesel locomotives, the above technologies would be much less targeted to reduce axle loads, but could be used rather to add a module for electric propulsion under catenary, e.g. in tunnels and in regions sensitive to diesel exhaust emissions and engine induced vibrations in track beds. Hence, it reflects the reverse situation in the US compared to Europe (see above case for the TRAXX AC3) where the American application is primarily with diesel propulsion with small sections of the network being potentially electric. In addition, the above technologies allow energy savings with power regeneration into batteries and ultracaps, which can be significant in stop-and-go traffic and shunting. Also, they allow to combine several diesel engines in a single freight locomotive with fuel saving features as described above with the German TRAXX DE ME. Such savings can be considerable with medium distance light freight trains hauled by a single locomotive, e.g. in light intermodal applications.

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