Zero-Carbon Trains

By John Benson

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1. Introduction

In my writings I tend to classify electric vehicles and other vehicles that match the above title by their location in our transportation networks. That is:

- Road Vehicles
- Tracked Vehicles
- Aircraft
- Maritime Vehicles (a.k.a. ships and boats)

Mostly I write about the first category, with occasional posts on the others. World-wide most tracked vehicles are already electrified. If a government agency is going to the trouble of laying a track system, it is not that much more expensive to put in an electric supply, and equip the locomotives and/or train-cars to tap into that supply. Also, once this is done the operating cost is generally much lower than fossil-fueled trains. A side benefit is that all emissions are much lower: especially important in urban areas. Having worked for two European Corporations for most of my career (Landis & Gyr and Siemens), I have spent much time on trains so equipped, and noted that they are also much quieter that the US's dominant diesel-electric technology.

The reason that diesel-electric (a generator driven by a diesel-engine driving electric traction motors) is dominant in the US (etc.) is that we have very long distances between metro-areas in many regions, and having just passive tracks in these stretches reduces the cost of installing and maintaining these tracks by a huge amount. Also, these sections are mostly used for freight, not passengers.

However, the days of the diesel-electric locomotives are quickly coming to an end.

2. California

As is has in anything having do with air-pollution (especially of the greenhouse gas (GHG) type), my home state is a first mover here.

The California Air Resources Board (CARB) fired a shot across the freight rail industry's bow to accelerate the drive to lower locomotive emissions to zero by 2035. In response, the Association of American Railroads (AAR) has filed suit against CARB. Regardless of the outcome, there is now heightened awareness of locomotive emissions. The issue isn't going away. Instead, the economic impact to implement tighter emission regulations will be in the billions for as far as the eye can see. [1]

Author's comment: Ha-ha. The California Government has more lawyers (and expert consultants) that just about anyone, and almost always wins. Apparently, the above suit is an attempted delaying factor.

[1] Robert H. Cantwell, Railway Age, "Clean Track Ahead," Sep 6, 2023, https://www.railwayage.com/mechanical/locomotives/clean-track-ahead/

On April 27, 2023, CARB issued an "In-Use" Locomotive Regulation laying out a roadmap toward zero emission locomotives in California by 2035. Highlights of the regulation:

- *Establishment of a "spending account" that collects fees (taxes) commencing in 2024 on locomotives that operate in California. This will be calculated as a function of their operating use and emission levels. The funds will eventually be used to purchase new low/zero emission locomotives.*
- *Limit idle time to 30 minutes.*
- *Prohibit the use of locomotives over the age of 23 years by 2030. This is a very critical feature of the CARB regulation with far reaching impact.*
- *Mandating Zero Emission (ZE) locomotives to operate exclusively by 2035.*

The potential impact of this regulation is likely to be very costly to the freight rail industry and may impede its ability to move freight in certain areas. Arguing that ZE locomotive technology is very much in its infancy, combined with the lack of infrastructure needed to support ZE locomotives, the industry is unlikely to meet this stringent regulation by 2035.

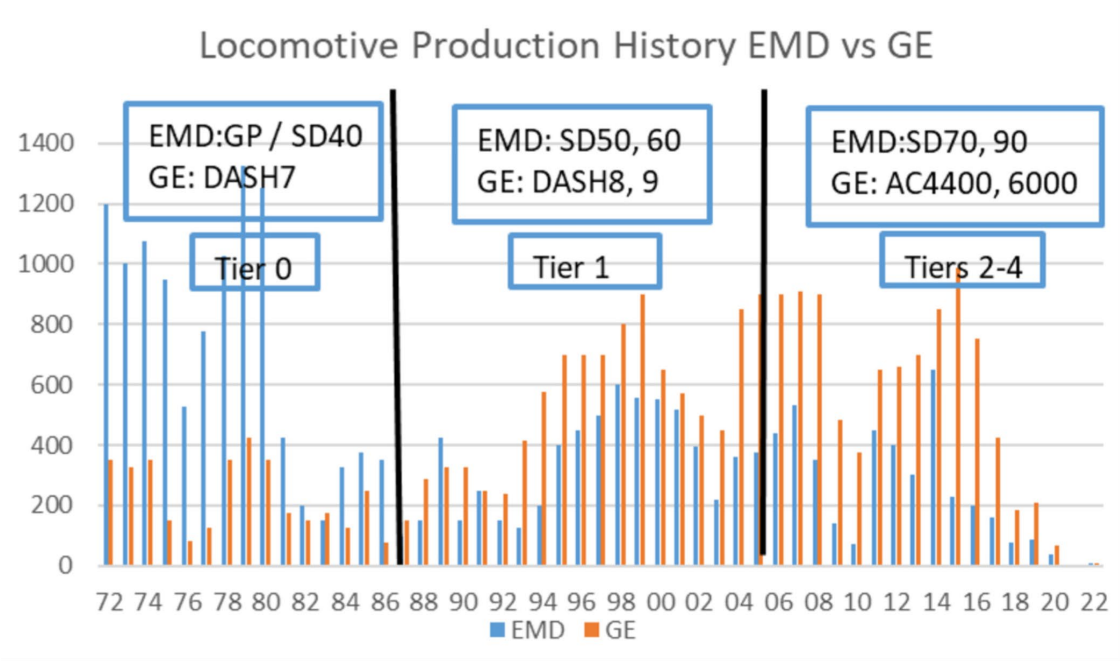
CARB gets its authority to regulate locomotive emissions from a unique Memorandum of Understanding (MOU) it signed many years ago with the Southern Pacific (now Union Pacific), then headquartered in San Francisco. For now, CARB is acting alone in its drive to impose stricter locomotive emission standards, but should it capture the support of EPA or other states, watch out. The EPA and CARB have ganged up on the trucking industry for years.

2.1. Diesel Emissions

Diesel engines fight a dual mandate: reducing carbon emissions in the struggle to reduce greenhouse gases, and reducing localized pollution (smoke and smog) through the reduction of NOx and PM (Particulate Matter). NOx and PM have been the focus of diesel emission development for the past 50 years, resulting in the development of a tiered approach to reduction. Since 1973, locomotive NOx limits have declined from 9.9 g/bhp-hour (Tier 0) in 1973 to 5.5 g/bhp-hour (Tier 3) in 2012. Tier 4 imposed a very stringent 1.3 limit. To hit this tremendous reduction requires extensive engine modification, particularly to the air intake, exhaust, cooling, and fuel delivery systems. Achieving these levels is expensive in terms of both capex and operating expense, which is one of the main reasons for the slow adoption of Tier 4 locomotives since 2015. NOx and PM dropped by almost 50% between Tiers 0 and Tier 2. Between Tier 0 and Tier 4, NOx and PM have been reduced nine-fold! Tier 0 and Tier 1 locomotives, which were produced until 2004, are indeed much dirtier than newer units.

2.2. New Locomotive Demand

Since the enactment of Tier 4 in 2015, only about 1,200 units have been built, with more than 1,000 of these Wabtec units. Developing Tier 4 locomotives has been a long, expensive journey with little payback to date. In fact, Caterpillar, parent company of Progress Rail/EMD, took a $935 million write-down at the end of fiscal year 2022 on its rail business in large part due to the slow adoption of Tier 4 locomotives. With CARB regulations, or a derivative thereof, this may change quickly.



Since Tier 2 took effect, GE (Wabtec) production has surpassed EMD.

2.3. 23-Year-Old Locomotives

The 23-year-old mandate by 2030 as outlined by CARB coincides with the imposition of Tier 2 requirements in 2005. In other words, no locomotive will be able to operate in California without complying with Tier 2 beyond 2030, but ultimately banned by 2035 if the regulation holds. Since 2005, there have been more than 15,000 locomotives delivered meeting Tier 2, the majority GE/Wabtec.

3. EU & US Regulations

In 2025, the U.S. EPA Tier 5 standard and the European Euro7 standard should come into effect. Both standards limit the emission of harmful substances by trains and locomotives to very low values. In particular, in the Tier 5 standard, in comparison with Tier 4, the value of NOx (oxides of nitrogen) decreases from 1.3 g/dHp-hr to 0.2 g/dHp-hr, and the value of PM (particulate matter) from 0.03 to 0.00. Thus, the standard requires zero PM emissions and almost zero NOx emissions.[2]

Typically, long before standards change, locomotive factories design and manufacture prototype locomotives that meet the requirements of these standards. Already today, prototypes and many production locomotives have been manufactured that meet these requirements.

Depending on the primary energy source, three types of new rolling stock can be distinguished.

[2] Alex Luvishis, Ph.D, Railway Age, "Zero-Emission Locomotives on U.S. Railways?" Feb 12, 2021, https://www.railwayage.com/news/zero-emission-locomotives-on-u-s-railways/

3.1. Battery-Electric

The EMD Joule battery-electric switcher locomotive from Progress Rail with power of 2,400 kWh will operate on the network of the Port of Los Angeles. These locomotives should be delivered in 2021.The locomotive is expected to operate for up to 24 hours without recharging, depending on the initial charge and load conditions. The six-axle electric locomotive is equipped with a modern asynchronous traction drive and has a capacity of 3,200 hp.

Author's comment: Note the more recent article excerpt below. The electric switcher described above was delivered, albeit a bit behind schedule.

Pacific Harbor Line (PHL) rolled out a new zero-idle EMD® Joule battery-electric locomotive that will be tested as part of PHL's service to the ports of Los Angeles and Long Beach, California.[3]

Built by Progress Rail, the locomotive was unveiled as part of a ceremony honoring nine new PHL locomotive engineers that will help move millions of shipping containers at the ports. The unit recently arrived to begin a year of testing and continue PHL's efforts to advance zero-emission locomotive solutions, PHL officials said in a press release.

Back to reference 2.

In October 2018, Wabtec (then GE Transportation) announced a plan to build a main line battery-electric locomotive in conjunction with BNSF. This locomotive is built on the Evolution Series diesel locomotive platform at the company's plant in Erie, Pa. The body of the locomotive contains lithium-ion batteries with a total energy of 2,400 kWh, traction inverters similar to those used on diesel-electric locomotives with an AC drive, and a microprocessor control system. The locomotive, called the FLXdrive but designated as a BEL44C4D, is currently being tested as the middle unit in a three-unit consist, placed in between two Wabtec Tier 4 diesel-electrics. It is undergoing testing on freight trains between Barstow and Stockton, Calif., (approximately 370 miles) to accumulate train braking energy that will be used in traction mode. Fuel consumption by the diesel locomotives is expected to be reduced by 10-15%.

Author's comment: Again a more recent update:

Wabtec and Australian mining firm Roy Hill have unveiled world's first 100% battery-powered, heavy-haul locomotive for mainline service in ceremonies today (Oct. 31, 2023) at Wabtec's Erie manufacturing facility.[4]

The FLXdrive locomotive contains 72 lithium-ion modular battery packs with a total of 36,288 cells, giving the locomotive an energy capacity of 7 megawatt-hours. This is about three times the power of a 2.4-megawatt-hour FLXdrive prototype that operated 13,000 miles on BNSF Railway in California with zero failures in 2021…

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[3] Progressive Railroading, "PHL to test new electric locomotive at California ports," May 5, 2023, https://www.progressiverailroading.com/mechanical/news/PHL-to-test-new-electric-locomotive-at-California-ports--69186

[4] Carl Swanson, Trains, "Wabtec unveils first production FLXdrive battery heavy-haul locomotive," Oct 31, 2023, https://www.trains.com/trn/news-reviews/news-wire/wabtec-unveils-first-production-flxdrive-battery-heavy-haul-locomotive/

The FLXdrive unit will undergo extensive testing in Erie over the next six to eight months before being shipped 10,500 miles to Australia to enter revenue service on the Roy Hill railway, a 214-mile privately owned iron ore railroad in Western Australia's remote Pilbara region. Roy Hill owner Hancock Prospecting opened its line in 2015 and ships more than 63 million tons of iron ore annually to steel makers in Japan, South Korea, India, Malaysia, China, and Vietnam.

3.2. Hydrogen Fuel Cells and Hybrids

Wabtec says the above is a conceptual image of a hydrogen-powered locomotive and fuel tender.[5]

As the railroad industry searches for ways to reduce and ultimately eliminate its greenhouse gas emissions, Wabtec sees hydrogen as the locomotive fuel of the future, whether it's burned in internal combustion engines or used to power fuel cells.

Author's comment: In the last sentence in the above paragraph, there is a third choice, external combustion (combustion turbines) fueled by hydrogen. Much work has been done on this technology for electric utility applications by Wabtec's former owner (GE) and my former employer (Siemens).

"We think this is going to be an impactful technology. We're not seeing this as a fringe thing. This is going to be the thing that replaces diesels in the future," says Philip Moslener, Wabtec's corporate vice president for advanced technologies.

Hydrogen produces no greenhouse gas emissions when burned as a fuel. "It is not economically viable today," Moslener says, noting that hydrogen currently costs significantly more than diesel fuel.

But hydrogen production is expected to rise, which should bring the cost down to rival diesel fuel as early as 2030. In the U.S., the Bipartisan Infrastructure Law includes $7 billion in funding to develop six to 10 hydrogen production and storage hubs, while there are similar efforts under way in Canada. Energy companies, meanwhile, are making investments in hydrogen production facilities.

[5] Bill Stephens, Trains, "Wabtec: Hydrogen is the locomotive fuel of the future," Aug 30, 2023, https://www.trains.com/trn/news-reviews/news-wire/wabtec-hydrogen-is-the-locomotive-fuel-of-the-future/

So Wabtec aims to match its hydrogen locomotive research and development efforts to the planned pace of hydrogen production in North America. Wabtec hopes to field its first hydrogen prototype in 2027.

Hydrogen-powered fuel cells, combined with batteries to store electricity, would be a zero-emissions solution to replace the diesel-electric locomotive, Moslener says.

But fuel cells don't yet have the power density required for a line-haul locomotive. A road locomotive would need 3,300 kilowatts of power – or 10 times what's available from fuel cells that can fit on a locomotive today, Moslener says.

The development of ever more powerful fuel cells is expected to continue, however, much like the way batteries have gained more storage capacity and extended the range of electric vehicles in recent years…

If a fuel cell locomotive consist ultimately needs more battery capacity, railroads could always add one of Wabtec's FLXdrive battery-electric locomotives to the train, he says.

Due to their lower horsepower requirements, fuel cell switching locomotives may become viable sooner than road locomotives.

Road locomotives and switchers will require different energy-management systems because of the different demands of each type of service. Fuel cells prefer producing a consistent amount of power, Moslener says, so switchers would need to draw electricity from batteries rather than tap the fuel cell. Conversely, road locomotives often operate with relatively steady power demands and could tap a combination of the fuel cells and batteries to power their traction motors.

3.3. Retrofitting Locomotives to Burn Hydrogen

The other path is burning hydrogen in internal combustion engines. "We also see that as a viable solution, especially one where it's a transition technology," Moslener says. "The nice thing about internal combustion engines is it's engines. We know engines. Customers are comfortable with engines. They know how to maintain them. They know how to operate them."

Another plus: Wabtec's Evolution series locomotives can run on hydrogen with little modification. "That's the nice thing about our EVO family of engines is that they have the capability, the genetics, to be able to be modified to hydrogen," Moslener says.

The biggest technical hurdle is how to bring hydrogen fuel to the combustion chamber. Like liquified natural gas, hydrogen needs a spark to ignite. The Wabtec LNG-powered locomotives in use on Florida East Coast Railway rely on port injection with diesel fuel used as a pilot. That technology needs to be adapted for hydrogen use, Moslener says.

Hydrogen makes metal brittle over time, which can lead to mechanical failure. To solve this problem, Wabtec is working with the U.S. Department of Energy's Oak Ridge and Argonne national laboratories. In a project funded by a Department of Energy grant, Argonne is doing computer simulation work, while Oak Ridge is testing a single-cylinder, hydrogen-fueled engine that uses port injection.