Comments on Proposed CARB In-Use Locomotive Regulations Rule

Summary

The proposed in-use locomotive emissions rule is a long-overdue measure to limit pollutant emissions from locomotives in-use in California. It represents a practical path that will finally lower the excess and unnecessary toxic emissions that fence-line communities around train stations, railyards, and rail corridors have been subject to for decades. These high emissions are not inherent in diesel engine technology, as is shown by CARB's success in regulating emissions from heavy-duty diesel trucks. Diesel engines with proven aftertreatment systems have been able to operate with low emissions since the early 2000's, and CARB rules will have new on-highway trucks operating at near-zero toxic emissions after 2027. Instead, excessive locomotive emissions are the result of the long operating lives of locomotives combined with decades of weak regulatory oversight of a large and powerful industry. Due to lax federal requirements and loopholes, the majority of freight locomotives would still be operating with 1990's truck technology through 2032 without this regulation.

Although CARB's present proposal is a significant step forward, its effectiveness could be further increased and compliance costs could be decreased through changes in the proposed regulation. The present EPA certification procedure and locomotive classifications are being used to "game" the emission regulations, especially for passenger locomotives. As a result, the real in-use emissions from new Tier 4 passenger locomotives are much higher than the nominal emission standards. In the same way, locomotives destined for switching service (e.g. at Pacific Harbor Lines) are being granted incentives for Tier 4 service under the EPA "line-haul" cycle when their in-use emissions as switch locomotives will be much higher. To minimize the effect of these gaming strategies, CARB should base its emissions targets and emission fees on the time spent and MWH generated in each throttle notch, together with the emissions data for that throttle notch published in the EPA emissions data file. For locomotive engines equipped with temperature-sensitive aftertreatment such as SCR systems and diesel oxidation catalysts, the calculations should also incorporate the change in effectiveness as the catalyst cools during prolonged idle periods.

Because of their long operating lives, locomotives are especially suitable for being retrofit with aftertreatment technology. Retrofit systems to reduce NOx by 90% and PM by 50% have been developed, with costs a fraction of that of a new locomotive. However, the CARB focus on new locomotives has kept them from commercial viability. CARB should modify the proposed rule to take advantage of these quick and cost-effective emission control options by allowing emission fee accounts to be spent on retrofits, even if these don't achieve the full Tier 4 emission levels.

Recognizing the difficulty of meeting range requirements with pure battery propulsion systems, CARB now allows plug-in hybrid light-duty highway vehicles to qualify as ZEVs. CARB should make the same accommodation for plug-in hybrid locomotives. Equipped with on-board range-extender engines with DPF and SCR meeting Tier IV final non-road emissions, plug-in hybrid locomotives could supplant most

local freight and commuter passenger locomotives while operating on grid-derived battery power the great majority of the time. Since the range extender would always operate at high load, the SCR and DPF systems would operate at peak efficiency almost all the time.

We plan to evolve this document into a Sourcebook of locomotive emissions information that will be publicly available for many groups of people who want to advocate for better public policy around locomotive emissions.

CARB can improve this rulemaking to both actually accelerate practical low-emissions locomotives and improve its oversight and incentivizing of the locomotives it does have some influence over. CARB could build on its leadership in the automobile and truck emissions programs to become the worldwide leader in practical low-emissions locomotive programs.

Proposed Changes to the In-Use Rule

Summary

1. End the focus on only the EPA federal Tier 4 emission standard with two discrete emissions levels for NOx and PM. Start enforcing a combined (NOx + 13.3*PM) emissions approach. This will allow incentives to be granted to very beneficial and now common technologies that reduce NOx emissions more than PM.
2. Allow the railroads to spend this money on emissions retrofits based on combined emissions for older locomotives to more quickly reduce in-use NOx emissions from a much larger percentage of the locomotive fleet.
3. Allow Zero Emissions credits to be accrued by hybrid locomotives, not just zero emissions locomotives that are not yet available in the market with acceptable range.
4. For applications where in-use emissions are known to be higher than the certified emissions levels, build in a process to charge the emissions fees based on in-use emissions. Passenger locomotives are a prime example and should use a passenger locomotive duty cycle. Line haul locomotives that are used in switcher service are another example.
    a. The preference should be to use actual in-use emissions. Incentivize changes in operational practices that reduce emissions even if the locomotives are certified the same.

Cleanest Available Locomotive Definition Update

Below is how the draft regulation defined the “Cleanest Available Locomotive”

(9) "Cleanest Available Locomotive" means a locomotive for which the Primary Engine has engine emissions equal to or less than;

(A) 1.3 grams per brake horsepower-hour (g/bhp-hr) oxides of nitrogen (NOx) and 0.03 g/bhp-hr particulate matter (PM) prior to the year 2030;

(B) 0.15 g/bhp-hr NOx, 0.006 g/bhp-hr PM, and GHG emissions 15 percent less than Tier 4 for years 2030 to 2035;

(C) 0.000 g/bhp-hr NOx, 0.000 g/bhp-hr PM and 0.000 g/bhp-hr GHG emissions for years 2035+.

We recommend the following revisions to allow for combined emissions in the same way that the Carl Moyer program uses cost-effectiveness calculations for incentive funding.

Revise (A) and (B)

1.3 grams per brake horsepower-hour (g/bhp-hr) oxides of nitrogen (NOx) and 0.03 g/bhp-hr particulate matter (PM) or {NOx + 13.3*PM} less than 1.70 g/bhp-hr prior to the year 2030;

0.15 g/bhp-hr NOx, 0.006 g/bhp-hr PM, or {NOx + 13.3*PM} less than 0.223 g/bhp-hr and GHG emissions 15 percent less than Tier 4 for years 2030 to 2035;

Spending Account Revisions

We propose and believe the railroads will insist that the spending account be revised to allow the generation of credits from battery hybrid diesel locomotives and also for the railroads to spend account funds to implement after-treatment emissions retrofits on existing older locomotives.

Revise 2478.4 (b) (1) (B)

Funds held in the Spending Account shall only be used for the purchase, lease, or rental of the Cleanest Available Locomotive, ~~or~~ to repower to the Cleanest Available Locomotive, or to install an emissions retrofit system that achieves in-use NOx levels below 2.5 g/bhp-hr.

> (or an incrementally lowering Retrofit NOx target, it could start at 2.5 g/hphr and incrementally lower each year, add this incrementally dropping NOx value as a third column to the *Particulate Matter and Annual Factors by Year* Table in the new rule)

Revise 2478.4 (c) (1) (E)

Usage means total MWhs from conventional locomotives or the fossil fuel-based MWhrs for battery hybrid locomotives for the previous calendar year of Locomotive operations in California or the .

Revise 2478.4 (c) (2)

Until December 31, 2034, for each Zero Emission or Battery Hybrid Locomotive in the Locomotive Operator's Fleet, the Zero Emission Credit shall be determined according to the following formula and Table 1:

Revise 2478.4 (c) (2) (C)

Usage means total MWhs for the previous calendar year Zero Emission Locomotive operations in California or Zero Emissions share of MWhrs of battery hybrid locomotive operations in California.

The need to adjust emissions fees with better estimates of in-use emissions

The fees should be directly related to **in-use** emissions. It is 2021: every recently rebuilt locomotive that operates under Federal Railroad Administration approval has an event recorder that records throttle position and time. Most railroads have their data automatically uploaded by a cellular modem service with Witronix or a similar cloud-based operating data service. These companies routinely generate throttle setting and time reports for their customers. All post-1973 rebuilt locomotives have publicly available EPA certification data listing brake specific emissions values by throttle notch. It would be a simple accounting exercise to combine event recorder data with EPA throttle notch data to calculate actual in-use emissions.

A compromise for freight locomotives could be to use the basic EPA Tier status for locomotives whose recorded idle time is at or below the value of the EPA line haul duty cycle (38%). If a locomotive event recorder duty cycle data indicates idle activity in excess of 38%, that locomotive has to use switcher locomotive emissions levels, or its emissions will need special calculations that account for in-use emissions (this is a simple calculation using the EPA certification spreadsheet and event recorder details)

This accounting for in-use emissions calculations now could work in the railroads' favor as a locomotive that could only be certified to Tier 2+ could actually have lower in-use NOx and PM emissions than a Tier 4 locomotive with some simple anti-idling equipment, very mild hybridization and a rather simple SCR retrofit. In this way the recording of idle time and calculation of in-use emissions is a benefit to freight railroads for actually reducing their true emissions across more of their fleet instead of worrying about purchasing a smaller number of new 'Tier 4' locomotives.

Wabtec switcher locomotives being funded for purchase by the Pacific Harbor Line (PHL) at the Ports of LA and Long Beach and Tier 4 diesel passenger locomotives are two prime examples of the problem of grossly under-reported emissions when the 'EPA Certification' emissions are multiplied by the fuel consumption to determine actual in-use emissions. This corrupts both the state emissions inventories and the emissions incentives program used to purchase new locomotives. As detailed in a following section of this document, single engine Tier 4 passenger locomotive NOx emissions if accounted for correctly will be 2 to 4 times the EPA NOx standard depending on actual operating conditions.

Passenger locomotives are an even worse abuser of the EPA certification issues in 3 ways

- **They are certified without accounting for hotel power use**
- **They use the 'line-haul' duty cycle for determining a single weighted emission value (which is grossly unrepresentative of passenger locomotive operation)**
- **They are emissions tested with the 'hotel power' turned off. This allows the locomotive to operate only for emissions testing at a lower engine speed and power output, thus generating lower emissions that are not achievable when the locomotive is in passenger service (Call this a reverse VW Dieselgate!!)**

Attachments

Appendix 1: Locomotive Emissions Regulations, Testing and Duty Cycles

Appendix 2: Regulatory References

Appendix 1: Locomotive Emissions Regulations, Testing and Duty Cycles

Explaining why actual in-use locomotive emissions are so poorly accounted for in CARB's emissions inventories requires a basic understanding of locomotive testing procedures and additionally how duty cycles are used in the calculation of a single weighted emissions value for each of the four regulated criteria pollutants. These duty cycles were a compromise value that EPA came up with before the 1998 rulemaking that first regulated locomotive emissions. Modern changes in cloud recording of locomotive operating data, idle reduction systems and the maturity of diesel after-treatment make continued reliance on these duty cycles for all locomotives a detriment to public health and efficient expenditure of public incentive funding.

During emissions testing, a locomotive is tested against an electrical load bank at 11 power settings: low idle, idle, dynamic brake, and throttle notches 1 through 8. Throttle notch 1 is approximately 5% of rated power and power levels go up to 100% at Notch 8, these are labeled in the left column of the table below. Emissions are measured at each of 11 locomotive operating modes. Then the emissions at each power setting are multiplied by the weighting in one of the two duty cycle columns. Brake-specific emissions are calculated by dividing the weighted sum of hourly emissions in each mode by the weighted sum of the power output in each mode, as provided in 40 CFR 1033.

EPA Locomotive Duty Cycles

Throttle Notch	% Rated Power	EPA Linehaul	EPA Switch
Low Idle	0	19.0	29.9
Idle	0	19.0	29.9
Dyn Brk	0	12.5	0.0
1	4.5%	6.5	12.4
2	11.5%	6.5	12.3
3	23.5%	5.2	5.8
4	35.0%	4.4	3.6
5	48.5%	3.8	3.6
6	64.0%	3.9	1.5
7	85.0%	3.0	0.2
8	100.0%	16.2	0.8

For freight locomotives in the late 1990's the use of only two duty cycles was reasonable. The 'linehaul' duty cycle was for long distance locomotives that travel long distances operating at higher power and the 'switch' duty cycle was for switching locomotives that stay at one railyard and sort railcars.

The average amount of time a locomotive operates at high power and low power are opposite for the two duty cycles in the table. The linehaul spends a lot of time at full power (16.2%) and the switchers do not (0.8%). Switchers spend most of their time at idle and low load (85%) and thus have very low average exhaust temperatures. Later in the document this table will be expanded with a proposed third duty cycle type for intercity and commuter locomotives for California service.

The 'line haul' duty cycle is being misapplied to locomotives in switcher service

The Pacific Harbor Line (PHL) railroad helped demonstrate one of the cleanest diesel-fueled single engine switcher locomotives to be tested in North America, the EMD24B. Analysis of its certification results combined with common engineering knowledge from the diesel engine industry indicates that this locomotive will operate at particulate emissions 96% below and NOx emissions 31% below the Tier 4 locomotive standard. The upcoming order of 6 Wabtec higher emissions, low horsepower line haul locomotives is a blatant step back in emissions reductions and if it is supported by taxpayer incentive funding should be put on hold and analyzed for its impact on the surrounding communities. The attempt to use line haul locomotives in a switcher locomotive application is an egregious abuse of already lax EPA regulation of this industry and illustrates glaring problems in the way the state has used decades of incentive funding for technology demonstration.

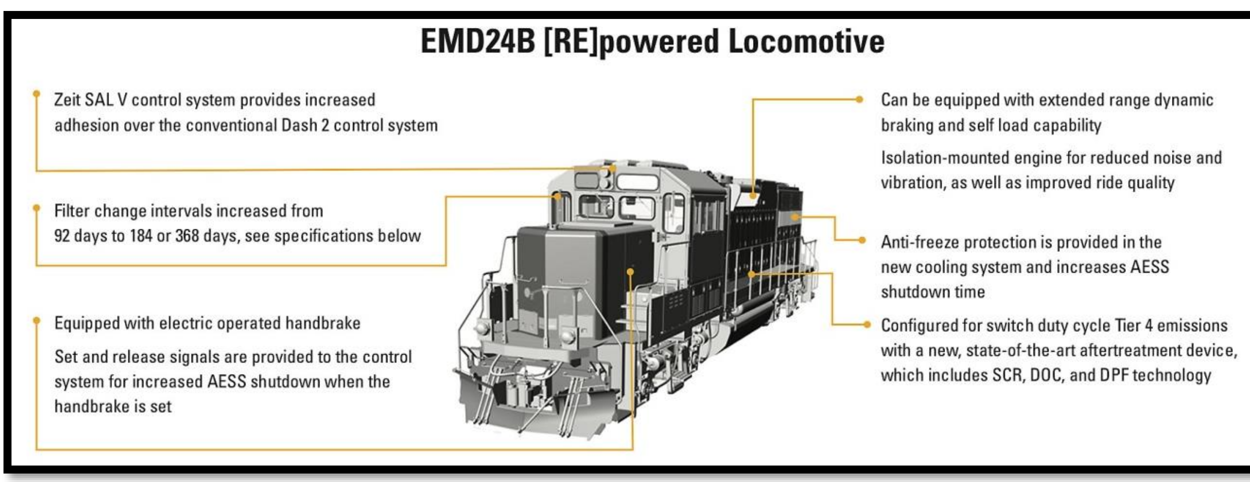
Carl Moyer reference case **#2020-36** (link) indicates that ARB and South Coast Air Quality Management District (SCAQMD) are using Carl Moyer funding to subsidize the Pacific Harbor Lines (PHL) purchase six new and/or repowered Tier 4 switcher locomotives using GE engines instead of purchasing six EMD24B locomotives (described in this article) that PHL

In the case by case determination at the above link, the project includes the following description

> This project directly benefits or is located within a disadvantaged community, it makes use of the cleanest available technology, and is consistent with project types supported by the community.

In the following pages we will dispute this claim in the CARB determination and point out how egregious a backwards step these 'line-haul' locomotives in switching service are when it comes to toxic air emissions that the fence line communities around the ports are subject to.

It is important to know that the Tier 4 EMD24B locomotives are equipped with three different emissions reduction after-treatment systems. A diesel particulate filter (DPF) which would lower actual PM emissions to 30 times lower than the Tier 4 PM standard. A selective catalytic reduction (SCR) system that reduces NOx emissions 30% below the standard. A diesel oxidizing catalyst (DOC) used to reduce hydrocarbon and CO emissions.



This CARB verification letter for the EMD24 locomotive system issued on May 19, 2019 indicated that the EMD 24B locomotive achieved 3000 hours of in-service use with PHL and then passed an additional emissions test at the Southwest Research Institute test facility in order to achieve CARB verification. The

CARB letter also confirms these locomotives are equipped with the required after-treatment that industrial and truck engines use to get PM emissions below 1/30 of the Tier 4 standard and NOx emissions 1/2 to 1/6 of the Tier 4 locomotive standard.

The alternate WABTEC switcher locomotives that PHL is now trying to purchase will be equipped with recently marketed inline 6 cylinder engines based on the WABTEC V12 Tier 4 freight locomotive engines that WABTEC developed for long distance line-haul freight locomotives. Instead of using the 3 after treatment systems that the EMD24 switcher locomotive is equipped with (DOC, SCR, DPF), the ET22 only uses exhaust gas recirculation (EGR) and in the freight locomotives that WABTEC has certified, these systems just barely meet the Tier 4 locomotive PM and NOx standards. This is the CARB verification letter for the ET23 engine system listed in the Carl Moyer case by case determination.

EPA certification data for all locomotives in the US is publicly available at this link, relevant data for these locomotives is extracted in the table below and illustrates that this purchase is a significant step backwards in emissions that will negatively impact the community for decades.

								Certification Level in g/bhp-hr			
Model Year	Engine Family	Manufacturer Name	Beginning MY	Ending MY	Models Covered	Displacement	Displacement Units	NOx Line Haul	NOx Switch	PM Line Haul	PM Switch
2021	MGETK0958T4K	(GE)Wabtec Transportation Systems, LL	2015	2020	ET22	958	Cubic inches	1.2		0.02	
2021	MPGRK58.6D14	(EMD)Progress Rail Services	1954	2020	EMD24B, EMD24C	4.88	Liters		0.9		0.00

The red row is the certification data for the WABTEC ET22 which is the inline 6 cylinder version of the V12 freight locomotive engine, the ET44 that is rated at 4400HP. In WABTEC locomotive nomenclature the two digits typically indicate the locomotive HP so this locomotive would be expected to generate 2200HP

The green row is for the EMD24B and EMD24C locomotives.

This table lists the weighted average emissions submitted by the manufacturers when certifying their locomotive systems to the EPA standard, which is 1.3 grams of NOx and 0.03 grams of particulate matter (PM). The WABTEC engine just barely meets the NOx standard at 1.2 grams whereas the EMD locomotive is 42% below the WABTEC NOx levels at 0.9 grams.

For PM emissions levels, the WABTEC comes in at 0.02 grams/hphr which is 33% below the PM standard, but the EMD24 locomotive comes in at 0.00 grams/hphr. It is common knowledge in the emissions industry and acknowledged by ARB that engines using a diesel particulate filter put out PM emissions at or below 0.001 grams/hphr. Taking this into account the EMD engine will operate with 95% less PM emissions than the WABTEC locomotive based on these duty cycle average emissions in the certification table.

There is a sleight of hand being played in this emissions table, it should be noted that the WABTEC average emissions values are under column labels NOx Line haul and PM Line Haul, whereas the EMD emissions values are under columns labels NOx Switch and PM Switch. What this means is that the WABTEC locomotives is being certified as a line haul freight locomotive intended to haul long trains over long distances with high average duty cycles. The EMD locomotive is being certified as a switcher locomotive that is intended to operate mainly in railyard service sorting rail cars in the rail yard and building up longer sets of railcars into train sets that linehaul locomotives later move across the state or the country. Pacific Harbor Lines is a switching rail service whose locomotives rarely leave the port facility. Their website clearly indicates that switching railcars for the ports is their primary business.

PHL - Pacific Harbor Line

Pacific Harbor Line, Inc. provides rail transportation, maintenance and dispatching services to the Ports of Long Beach and Los Angeles, which together form the largest container port in the United States. In addition to switching over 40,000 units of carload freight annually, PHL provides rail switching services for nine on-dock intermodal terminals and provides dispatching services for about 140 intermodal or unit trains per day. PHL connects with BNSF and UP.

The distinction between linehaul locomotives and switcher locomotives when they are certified is important, as it determines which duty cycle-weighted average emissions will be experienced in-use.

The table below is extracted from the second worksheet in public EPA certification data spreadsheet from the link above. Instead of duty cycle weighted average values, this table has the values determined for each throttle setting. This data is combined with the duty cycle data (either line haul or switcher) to calculate a single duty cycle weighted value, for example the Tier 4 standard requires that NOx emissions be below 1.3 grams/ (hp-hr)

			NOx Notch Test Results in g/bhp-hr											PM Notch Test Results in g/bhp-hr										
Model Year	Engine Family	Manufacturer Code	NOx Dynamic Brake	NOx Low Idle	NOx Normal Idle	NOx Notch 1	NOx Notch 2	NOx Notch 3	NOx Notch 4	NOx Notch 5	NOx Notch 6	NOx Notch 7	NOx Notch 8	PM Dynamic Brake	PM Low Idle	PM Normal Idle	PM Notch 1	PM Notch 2	PM Notch 3	PM Notch 4	PM Notch 5	PM Notch 6	PM Notch 7	PM Notch 8
2021	MGETK0958T4K	GE	6.4	5.2	3.1	1.0	2.0	1.5	1.2	1.0	1.0	1.0	1.1	0.13	0.06	0.05	0.07	0.03	0.02	0.01	0.01	0.00	0.01	0.02
2021	MPGRK58.6D14	EMD			21.6	1.4	0.3	0.2	0.3	0.4	0.5	0.8	0.9			0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Observing the data for the WABTEC locomotive illustrates that the NOx levels for dynamic brake, low idle and normal idle are much higher than the EPA standard of 1.3, which means if the duty cycle weighted NOx emissions for the WABTEC locomotive were calculated with the more appropriate switcher duty cycle instead of the line haul duty cycle, it most likely would not meet the 1.3 gram/hphr Tier 4 standard for NOx. A look at the PM emissions levels by throttle notch position is even more skewed to idle and low load. If the duty cycle weighted average PM emissions were calculated with the switcher duty cycle they could end up over 0.04 grams/hphr which would make the EMD24 locomotives 98% lower in PM emissions.

To accurately calculate the weighted average emissions values for the ET22/ET23 locomotive under the more appropriate switcher duty cycle, WABTEC would have to provide these themselves or these values could be calculated by a third party if additional certification data was requested and made available by CARB or EPA under a public records request.

The issues of line-haul locomotives being used in switching service is another example of why the in-use locomotive rule needs provisions for accounting for actual emissions.

When an air agency claims that it is funding the 'cleanest' locomotive available, it should not be a locomotive that just barely meets the Tier 4 emissions standard (possibly with an inappropriate duty cycle), but it should credit locomotives whose emissions are well below the standard. These locomotives typically would use diesel aftertreatment which is a technology with over a decade of experience and iteration in millions of on-road trucks.

Tier 4 Passenger Locomotives Exaggerate Emissions Reductions

Currently there are 4 flaws in the current EPA emissions certification regulations and practices that lead to passenger locomotives emitting much higher emissions that they are certified for.

- **There is a broad loophole in the EPA locomotive certification procedures that allows the locomotives to be tested without hotel power system being active. This means the locomotives are tested in an operating configuration inconsistent with active passenger train service.**
- **A duty cycle is being used that represents only 15% of the fleet. The EPA regulation mandates that the OEM propose a representative one if added design features are inconsistent with a standard duty cycle.**
- **The power used by the hotel power system is not counted in the weighted average emissions, drastically undercounting the total locomotive emissions.**
- **When the hotel system is active on a single-engine locomotive, it overrides the Automatic Engine Start-Stop system, which in typical locomotives is required to turn off the locomotive main engine after 30 minutes of idle time. This appears to be a violation of the Clean Air Act.**

These 4 flaws in the emissions certification testing result in a new diesel passenger locomotive that is certified as Tier 4, but generates real operating emissions (ROE) of NOx that are 2 to 4 times the standard. Unlike long-distance passenger locomotives, locomotives that operate in commuter and intercity rail service start and stop frequently and also sit for extended times generating only hotel power for the passenger cars. These services operate over 85% of the passenger locomotive fleet in the US. They should be granted a passenger locomotive duty cycle that is tailored to Commuter/Intercity locomotive operations including the accounting of an appropriate amount of hotel power. **The continued purchase of these Tier 4 passenger locomotives with 20-year prepaid scheduled maintenance parts packages will lock passenger agencies into Tier 2+ NOx emissions for the next 20 years at a time that the ongoing battery and power electronics evolutions are already making these locomotives obsolete.**

This started as a compromise regulation in 2008 when diesel emissions systems were new, but now that there is a demonstrated passenger locomotive retrofit that can produce ROE emissions of NOx at less than ½ the Tier 4 standard, it is time to challenge the air agencies to properly test for ROE and incentivize actual lower passenger locomotive emissions as the nation looks to invest in fixing its infrastructure. In addition to the wasted public funding on new tier 4 passenger locomotives, the risk to the health and wellbeing of both passengers and local residents is significant and as a result there should be an effort to:

- **Perform studies that calculate real operating emissions for these locomotives.**
- **Adjust the incentive funding programs to promote locomotives with lower ROE.**
- **Mandate that incentive-funded locomotives record locomotive performance parameters that keep track of this performance.**
- **Propose that EPA and/or CARB develop an intercity/commuter passenger locomotive duty cycle and/or enforce the EPA regulation that mandates the OEMs to provide an appropriate alternate.**

Background

Current Tier 4 emissions standards for locomotives have resulted in lower emissions on newly manufactured units as compared to older Tier 0, 1, 2, or 3 units but the 'New Technology' passenger locomotives with high-speed engines should not be considered 'low emissions' by modern standards. The Tier 4 locomotive standard allows a brand-new locomotive to emit 6.5 times as much NOx, and three time as much particulate matter (PM) per horsepower as a heavy-duty diesel truck manufactured in 2010. Further, near-zero emissions natural gas engines are currently commercially available in trucks with NOx levels reduced another 75% over 2010 truck standards. This 'Low NOx' truck emissions standard will be mandated in California starting in 2024.

In addition to the emissions gap between the standards for on-road trucks in 2024 and locomotives, the effect of ROE will multiply the NOx emissions reduction gap by at least a factor of 2, making the passenger locomotive-to-truck NOx ratio greater than 52 to 1. The diesel PM ratio is also excessive as Diesel Particulate Filter-equipped trucks have operated at ROE of particulates that is 20 times lower than Tier 4 locomotives since 2007.

In 2017 CARB released a report from UCR C-CERT and InfoWedge titled "Collection of Activity Data from On-Road Heavy-Duty Diesel Vehicles." This report looked at 19 different types of on-road heavy duty trucks and pointed out that in many real world truck applications the trucks emitted significantly more NOx emissions in various air basins than were accounted for by their mileage and EPA certification emissions levels. Therefore, the accounting of these emissions in the air basin emissions inventories included in State Implementation Plans (SIP) needed to be revised. Passenger locomotives are now due a similar level of scrutiny as over $1 billion of public funds is being allocated for new passenger locomotives that do not operate as cleanly as advertised. Transparency on this issue and adjustment of incentives could lead to cleaner technologies.

SCR Performance related to Exhaust Temperature

The technical challenge of defining and measuring real operating emissions compared to certification test cycles can be summarized easily. Selective Catalytic Reduction conversion efficiency of NOx is directly related to the exhaust temperature; higher average temperatures convert higher percentages of NOx, up to a peak of 95%. This conversion efficiency drops to 40% at an exhaust temperature of 200°C. Below 200°C, the system has to be turned off because it is no longer hot enough to properly vaporize and decompose the Diesel Exhaust Fluid (DEF). This relationship is shown in Figure 1. When the DEF injection system is turned off, the locomotive could be emitting 15 times or more NOx emissions than the EPA standard.

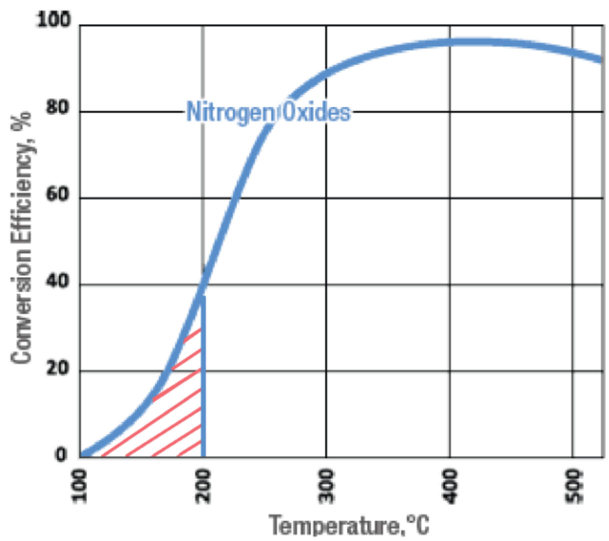


Figure 1 - NOx Table from ARB Emissions Report

The default EPA emissions testing duty cycles used for both on-road trucks and locomotives are established with the intent to closely approximate the majority of use of the equipment that is being regulated. Any time the real-world operating duty cycle deviates from the standard testing cycle, it will cause the ROE from the vehicle to deviate from the regulated values. Further, the EPA regulations for emissions testing of locomotives are clear: a manufacturer shall propose an alternate duty cycle when it is apparent that their equipment is special and one of the two default duty cycles is inappropriate.

In on-road trucks, lower average duty cycles are experienced in diesel trucks that are operated locally in urban areas or perform vocational activities like cement mixers and garbage trucks. In the rail industry, the locomotives were given two default duty cycles to certify to, one for freight locomotives that spend a majority of time at high load pulling trains long distances, and a switcher locomotive duty cycle, where the locomotives idle for a significant amount of time and very rarely are used at full load. The line haul duty cycle could be considered an acceptable compromise for long-distance passenger locomotives but these only make up a small percentage of the passenger locomotive fleet. More than 85% of the passenger locomotives in the US operate in intercity and commuter rail service where they stop and sit frequently. Unlike line haul locomotives, passenger locomotives idle for long periods of time operating at low power levels providing hotel power to the passenger coaches. Unlike switcher locomotives, when they are moving, they are typically at full load accelerating the train to the next stop. Because of these major differences, neither duty cycle is appropriate to quantify the average emissions of a passenger locomotive.

The EPA mandates that if the OEM installs special equipment that changes the duty cycle significantly from the switcher or the line haul, it is the OEM's responsibility to come up with an alternative duty cycle. This should apply in the case of single-engine passenger locomotives because the OEM has installed special equipment that generates Head End Power from the propulsion engine. It deactivates the EPA-mandated Automatic Engine Start-Stop system, causing the locomotive to remain active 24 hours per day idling for up to 80% of the time. The EPA should be pressed to enforce its own alternative duty cycle requirement on the passenger locomotive fleet.

'New Technology' Passenger Locomotives are unlike Two-Engine Legacy Units

For power system redundancy and higher fuel efficiency, the majority of legacy diesel passenger locomotives used a large medium-speed engine for propulsion power and then had a second smaller high-speed engine that generated hotel power to provide heating, cooling and lights in the passenger cars. This type of two engine locomotive is illustrated in Figure 2. What makes a 'new technology' passenger locomotive different is that it has replaced those two engines with one large high-speed engine. When passenger locomotives had two engines, it was a more acceptable compromise to certify the larger main propulsion engine to the duty cycle of a freight locomotive and the HEP engine was tested and certified as an off-road generator. Now that one engine serves both functions, the current EPA locomotive duty cycles are even worse representatives of the ROE for a majority of diesel passenger locomotives in North America. This should be investigated and changes proposed as to how these locomotives are certified. Public agencies need accurate information to be able to compare these locomotives and grant emissions-reduction incentive funding for their purchase.

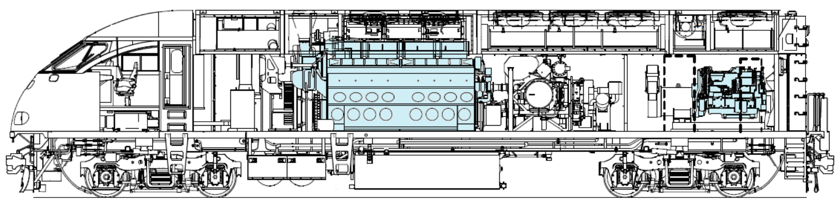


Figure 2 - Legacy Passenger Locomotive with Two Engines

Locomotive Duty Cycles				
Throttle Notch	% Rated Power	EPA Linehaul	EPA Switch	Commuter /Intercity
Low Idle	0	19.0	29.9	0.0
Idle	0	19.0	29.9	70.0
Dyn Brk	0	12.5	0.0	6.9
1	4.5%	6.5	12.4	2.9
2	11.5%	6.5	12.3	2.3
3	23.5%	5.2	5.8	1.6
4	35.0%	4.4	3.6	1.0
5	48.5%	3.8	3.6	1.2
6	64.0%	3.9	1.5	1.5
7	85.0%	3.0	0.2	2.6
8	100.0%	16.2	0.8	10.0

Figure 3 - Duty Cycles and Power Per Notch

Sample Duty Cycles and NOX Emissions

Figure 3 is a table of 3 different duty cycles and a sample power ratio for each power setting. Column 1 is the 11 different power settings at which the locomotive can operate. Column 2 is the EPA recommended power table (table 3 of 40 CFR Part 1033.530) indicating percentage of rated power for each throttle notch starting with 4.5% at Notch 1 to 100% at Notch 8. These are representative power settings and represent reasonable starting values for analyzing multiple different locomotives. More accurate results for different locomotives should be calculated in the future with percentages derived from measured power data from those specific locomotives. Columns 3, 4 and 5 are weighted duty cycle portions for each power setting. Column 3 is for the EPA line haul application and column 4 is for the EPA switcher application. Column 5 is a sample duty cycle generated by the author to represent commuter and intercity passenger locomotives.

A commuter/passenger locomotive typically spends 4 to 8 hours a day moving around passengers and the rest of the time is stationary at idle, only operating the hotel power system to keep the passenger coaches at the appropriate temperature in colder and hotter climates. This 24 hour cycle leads to high idle time percentages great than the 59.8% switcher duty cycle. Because the Commuter/Intercity passenger locomotive's primary purpose in motion is to accelerate and stop frequently for each station, the notch 8 column for full throttle is over 10 times that of a switcher, but approximately half of the line haul. The conflict of the passenger locomotive duty cycle with the two existing cycles at both high load and idle make it apparent that neither the Line haul or the Switcher duty cycle is a good approximation of the passenger locomotive duty cycle for commuter/intercity service.

As commuter and intercity locomotives make up over 80% of the passenger locomotive fleet compared to long-distance passenger locomotives and spend a majority of their time in urban areas where criteria emissions are a challenge, it is the Commuter/Intercity passenger locomotives that the duty cycle for passenger locomotives should be based on. Generating this new duty cycle should be as easy as requiring passenger agencies getting public emissions-reduction incentive funding to start turning over the event recorder data files they already acquire and in some cases are legally obligated to maintain under their funding contracts with the funding air agencies.

Quantifying Real Operating Emissions

Figure 4 is a chart of the NOx emissions of the two currently available tier 4 certified passenger locomotives in service in the US. These charts are generated from public EPA data files. The vertical axis is the NOx emissions in grams per horsepower hour (g/hphr) and the horizontal axis is the different power settings of the locomotive, including low idle, idle, and dynamic brake followed by eight notches of power. The dashed orange line is set to the EPA Tier 4 NOx standard of 1.3 g/hphr and the dashed grey line illustrates the Tier 0+ NOx

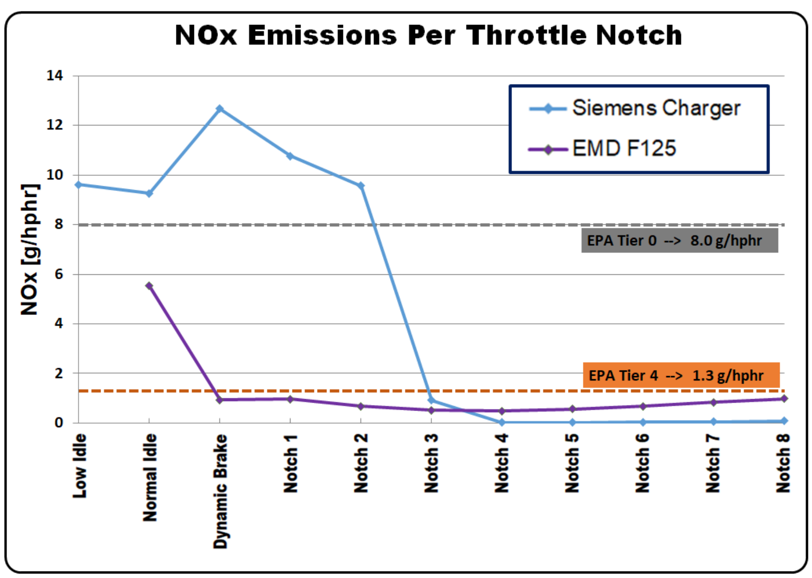


Figure 4 - NOx Emissions vs Power Setting

standard of 8.0 g/hphr. The blue line represents the Cummins QSK95 engine used in the Siemens Charger locomotive and the purple line is for the Caterpillar C175-20 engine used in the EMD Rail F125 locomotive. These data points are publicly available in a spreadsheet on the EPA website.

The Cummins line is what would be expected from Figure 1, the NOx data points from dynamic brake through Notch 2 are at very low loads where the exhaust temperatures would remain below 200°C and the DEF injection system would be turned off. At Notch 3 the engine load is high enough that the DEF system can be turned on, but not high enough for maximum NOx conversion. This agrees with Figure 1 where after turning on the DEF when the exhaust temperature is 200°C, the conversion efficiency is only 40% compared to 95% at temperatures between 350°C and 475°C. What is interesting is Cummins measuring NOx emissions of 0.03 and 0.02 from Notch 4 through Notch 7 which is over 80% below the EPA truck standard and 96% below the Tier 4 Locomotive standard.

	Duty Cycles					Siemens Charger w Cummins QSK95				
Throttle Notch	EPA Line Haul	EPA Switch	Commuter /Intercity	Tractive Power	Aux Power	Power [HP]	NOx [g/hphr]	EPA LH Weighted NOx [g/hr]	EPA SW Weighted NOx [g/hr]	Commuter Weighted NOx [g/hr]
Low Idle	19.0%	29.9%	0.0%	0	75	75	9.62	137.1	215.7	0.0
Idle	19.0%	29.9%	70.0%	0	75	75	9.27	132.1	207.9	486.7
DB	12.5%	0.0%	6.9%	0	35	35	12.68	55.5	0.0	30.6
Notch 1	6.5%	12.4%	2.9%	287	85	372	10.77	260.7	497.4	116.3
Notch 2	6.5%	12.3%	2.3%	511	95	606	9.57	376.9	713.2	133.4
Notch 3	5.2%	5.8%	1.6%	1,007	100	1,107	0.92	52.9	59.1	16.3
Notch 4	4.4%	3.6%	1.0%	1,489	110	1,599	0.02	1.4	1.2	0.3
Notch 5	3.8%	3.6%	1.2%	1,956	115	2,071	0.02	1.6	1.5	0.5
Notch 6 Rep	3.9%	1.5%	1.5%	2,383	120	2,503	0.03	2.9	1.1	1.1
Notch 7	3.0%	0.2%	2.6%	3,574	125	3,699	0.06	6.7	0.4	5.8
Notch 8	16.2%	0.8%	10.0%	4,070	130	4,200	0.09	61.2	3.0	37.8
wgt HP	1192.1	440.4	691.9			16,342		1,089.0	1,700.5	828.8
HEP [hp]	**0**					**NOx [g/hphr]**		**0.91**	**3.86**	**1.20**

Figure 5 – Corrected Weighted NOx Values for 0HP Hotel Power Loads

The EMD data indicates that the only time the C175-20 engine exceeds the EPA standard is at idle. Due to the similarity of the engines, the difference between these curves could be that the Caterpillar engine in the EMD unit was certified at lower RPM settings with the hotel power turned off, whereas the Cummins engine RPM was programmed to operate at a high enough RPM to always generate hotel power. This loophole in the EPA locomotive certification testing regulation will be discussed in detail in a later section.

	Duty Cycles					Siemens Charger w Cummins QSK95				
Throttle Notch	EPA Line Haul	EPA Switch	Commuter /Intercity	Tractive Power	Aux Power	Power [HP]	NOx [g/hphr]	EPA LH Weighted NOx [g/hr]	EPA SW Weighted NOx [g/hr]	Commuter Weighted NOx [g/hr]
Low Idle	19.0%	29.9%	0.0%	0	75	375	9.62	685.4	1,078.6	0.0
Idle	19.0%	29.9%	70.0%	0	75	375	9.27	660.5	1,039.4	2,433.4
DB	12.5%	0.0%	6.9%	0	35	335	12.68	531.0	0.0	293.1
Notch 1	6.5%	12.4%	2.9%	287	85	672	10.77	470.7	898.0	210.0
Notch 2	6.5%	12.3%	2.3%	511	95	906	9.57	563.5	1,066.3	199.4
Notch 3	5.2%	5.8%	1.6%	1,007	100	1,407	0.92	67.3	75.1	20.7
Notch 4	4.4%	3.6%	1.0%	1,489	110	1,899	0.02	1.7	1.4	0.4
Notch 5	3.8%	3.6%	1.2%	1,956	115	2,371	0.02	1.8	1.7	0.6
Notch 6 Rep	3.9%	1.5%	1.5%	2,383	120	2,803	0.03	3.3	1.3	1.3
Notch 7	3.0%	0.2%	2.6%	3,574	125	3,999	0.06	7.2	0.5	6.2
Notch 8	16.2%	0.8%	10.0%	4,070	130	4,500	0.09	65.6	3.2	40.5
wgt HP	1492.1	740.4	991.9			19,642		3,058.0	4,165.5	3,205.5
HEP [hp]	**300**					**NOx [g/hphr]**		**2.05**	**5.63**	**3.23**

Figure 6 - Corrected Weighted NOx Values for 300HP Hotel Power Load

The Cummins engine was certified to a NOx value of 1.0 g/hphr (g). Figure 5 is a table that uses EPA notch data and some assumptions to generate a new weighted NOx value that can accommodate 3 different duty cycles, the EPA Line Haul, the EPA Switcher and the author proposed Commuter/Intercity Passenger Locomotive. These are calculated in the order listed in the last 3 columns. The rated power proportions per notch from figure 3 were used to determine the values in column 5, working backwards from an advertised rated-tractive power of 4200 HP, from which was subtracted an estimated 130 HP auxiliary load in Column 6. Auxiliary loads were estimated down to low idle with a reduced auxiliary load entered for dynamic braking as the Siemens Charger is advertised to re-inject its dynamic braking energy back into the DC bus. With the low power aux loads set from 75 to 95 HP, the weighted NOx value calculates to 0.91 (yellow highlight) which is close enough to the EPA certified value to accept the existing table assumptions as close. In this case under the switcher locomotive cycle the locomotive would certify at 3.86 grams of NOx which is not surprising considering the very high NOx values at idle through Notch 2 in Figure 4. What is interesting is that the NOx value under the Commuter duty cycle rises to 1.20 which is still below the 1.3 value of the standard. All of this testing was done without accounting for the fact that this single engine locomotive will spend a lot of time idling, but also putting out between 200 and 800 HP of hotel power for the passenger cars depending on how long the train is and the outdoor ambient temperatures.

HEP [hp]	EPA LH Weighted NOx [g/hphr]	Ratio of ROE vs EPA	Commuter Weighted NOx [g/hphr]	Ratio of ROE vs EPA
0	0.91	0.7	1.20	0.9
100	1.37	1.1	2.05	1.6
200	1.73	1.3	2.71	2.1
300	2.05	1.6	3.23	2.5
400	2.33	1.8	3.66	2.8
500	2.58	2.0	4.02	3.1

Figure 7 - Corrected NOx vs Hotel Loading

Figure 6 is the same table with 300HP of HEP load added to the locomotive; 300HP is being proposed as a good starting point for a generic passenger locomotive duty cycle for single engine locomotives. In this case the EPA line haul duty cycle results in NOx emissions 1.6 times higher than what the locomotive was certified to. When the commuter duty cycle is applied, the NOx value shoots up to 3.23, which is 2.5 times the EPA standard.

Figure 7 is a table calculating the NOx values for both the EPA line haul and commuter duty cycles for HEP loads from 0 to 500 in 100HP increments. It is clear in the table that at any HEP load of 100HP or above, the locomotive's real operating emissions exceeds the standard even using the less appropriate line-haul duty cycle. When using the commuter duty cycle, at 100hp the locomotive is already at 1.6 times the EPA standard. At 500HP the ROE ratio is 3.1. With increasingly higher HEP loads, the engine will be operating at higher loads and higher exhaust temperatures and these calculated ROE values will be less and less accurate.

From the different NOx trend lines in Figure 4 and discussions with mechanical personnel familiar with the Progress Rail F125 locomotives at Metrolink, it appears that Caterpillar utilized the engine speed change loophole in the EPA locomotive emissions regulation in order to achieve NOx emissions levels below 1.3 grams/(hp-hr)

If the Caterpillar engine in the Progress Rail locomotive was emissions tested in its normal operating condition with the hotel power system on, its engine RPM would likely be higher and its emissions data in figure 4 for idle through throttle notch 2 would look similar to the Cummins trend line as both engines have a similar SCR system that would have to be deactivated at lower exhaust temperatures to prevent clogging of the catalyst elements with crystalized UREA from the diesel exhaust fluid (DEF). To account for this change in engine RPM, in Figures 8 and 9 the idle through notch 2 NOx values for the EMD locomotive were increased to 10 assuming this engine would have similar emissions as the smaller Cummins engine if tested with the hotel power system active.

	Duty Cycles					EMD F125 with Caterpillar C175-20				
Throttle Notch	EPA Line Haul	EPA Switch	Commuter /Intercity	Tractive Power	Aux Power	Power [HP]	NOx [g/hphr]	EPA LH Weighted NOx [g/hr]	EPA SW Weighted NOx [g/hr]	Commuter Weighted NOx [g/hr]
Low Idle	19.0%	29.9%	30.0%	0	75	75	10.00	142.5	224.3	225.0
Idle	19.0%	29.9%	41.8%	0	75	75	10.00	142.5	224.3	313.5
DB	12.5%	0.0%	6.1%	0	35	35	10.00	43.8	0.0	21.4
Notch 1	6.5%	12.4%	2.9%	180	85	265	10.00	172.3	328.6	76.9
Notch 2	6.5%	12.3%	1.6%	460	95	555	10.00	360.8	682.7	88.8
Notch 3	5.2%	5.8%	1.3%	940	100	1,040	0.51	27.6	30.8	6.9
Notch 4	4.4%	3.6%	3.8%	1,400	110	1,510	0.49	32.6	26.6	28.1
Notch 5	3.8%	3.6%	0.4%	1,940	115	2,055	0.57	44.5	42.2	4.7
Notch 6 Rep	3.9%	1.5%	1.3%	2,560	120	2,680	0.68	71.1	27.3	23.7
Notch 7	3.0%	0.2%	2.6%	3,400	125	3,525	0.83	87.8	5.9	76.1
Notch 8	16.2%	0.8%	8.3%	4,000	130	4,130	0.98	655.7	32.4	335.9
wgt HP	1164.1	414.9	621.0			15,945		1,780.9	1,624.9	1,200.9
HEP [hp]	**0**					**NOx [g/hphr]**		**1.53**	**3.92**	**1.93**

Figure 8 - Corrected Weighted NOx Values for 0HP Hotel Power Load

In figure 4 it is clear that the Caterpillar NOx emissions were 2 to 4 times higher than the Cummins engine from notches 3 thru 8. When this data is input into Figure 8 with 0 HP of hotel power load, it is estimated that the weighted NOx value for inappropriate line haul duty cycle is already over the 1.3 gram NOx standard, at 1.53 grams. When the approximated Commuter duty cycle is used the weighed NOx value jumps to 1.93 gram which is already 48% above the EPA standard without any load on the hotel power system.

Figure 9 is the same table, but with 300HP of hotel load, and now the weighted NOx emissions are 4.03 grams / (hp-hr) which is 2.1 times the EPA Tier 4 NOx standard.

	Duty Cycles					EMD F125 with Caterpillar C175-20				
Throttle Notch	EPA Line Haul	EPA Switch	Commuter /Intercity	Tractive Power	Aux Power	Power [HP]	NOx [g/hphr]	EPA LH Weighted NOx [g/hr]	EPA SW Weighted NOx [g/hr]	Commuter Weighted NOx [g/hr]
Low Idle	19.0%	29.9%	30.0%	0	75	375	10.00	712.5	1,121.3	1,125.0
Idle	19.0%	29.9%	41.8%	0	75	375	10.00	712.5	1,121.3	1,567.5
DB	12.5%	0.0%	6.1%	0	35	335	10.00	418.8	0.0	204.4
Notch 1	6.5%	12.4%	2.9%	180	85	565	10.00	367.3	700.6	163.9
Notch 2	6.5%	12.3%	1.6%	460	95	855	10.00	555.8	1,051.7	136.8
Notch 3	5.2%	5.8%	1.3%	940	100	1,340	0.51	35.5	39.6	8.9
Notch 4	4.4%	3.6%	3.8%	1,400	110	1,810	0.49	39.0	31.9	33.7
Notch 5	3.8%	3.6%	0.4%	1,940	115	2,355	0.57	51.0	48.3	5.4
Notch 6 Rep	3.9%	1.5%	1.3%	2,560	120	2,980	0.68	79.0	30.4	26.3
Notch 7	3.0%	0.2%	2.6%	3,400	125	3,825	0.83	95.2	6.3	82.5
Notch 8	16.2%	0.8%	8.3%	4,000	130	4,430	0.98	703.3	34.7	360.3
wgt HP	1464.1	714.9	921.3			19,245		3,769.9	4,186.1	3,714.7
HEP [hp]	**300**					**NOx [g/hphr]**		**2.57**	**5.86**	**4.03**

Figure 9 - Corrected Weighted NOx Values for 300HP Hotel Power Load

Figure 10 is a table illustrating the ratio of the calculated ROE of NOx compared to the EPA NOx standard for hotel power settings from 0 to 500 HP for both the line haul and commuter duty cycle. At best using the inappropriate line haul duty cycle at no hotel power load, the best results are still 20% above the standard. With 500HP of hotel load under the commuter duty cycle the REO NOx emissions are estimated at 4.81 gram/ (hp-hr) of NOx which is almost 4 times the standard and slightly better than the Tier 2+ NOx standard of 5.5 grams.

HEP [hp]	EPA LH Weighted NOx [g/hphr]	Ratio of ROE vs EPA	Commuter Weighted NOx [g/hphr]	Ratio of ROE vs EPA
0	1.53	1.2	1.93	1.5
100	1.93	1.5	2.83	2.2
200	2.28	1.8	3.50	2.7
300	2.57	2.0	4.03	3.1
400	2.83	2.2	4.46	3.4
500	3.06	2.4	4.81	3.7

Figure 10 - Corrected NOx vs Hotel Loading

The tables in figures 5,6,8,9 were generated with good engineering judgement and approximations for auxiliary power loads to indicate the trend of excess ROE of NOx when utilizing an approximate commuter passenger locomotive duty cycle and various hotel power loads. To more accurately calculate the actual ROE would require actual emissions testing of the locomotive with various hotel power loads, derivation of an average duty cycle from the California passenger fleet, and participation of the locomotive OEM to get the appropriate auxiliary loads used in the calculations. These estimated ROE values are intended to encourage CARB, EPA and other air agencies to initiate the data acquisition and testing process to derive better ROE values for these locomotives. These ROE values are especially important in California with the ongoing calculations of air basin NOx and PM inventories and more cost effective public incentive funding for lower emissions passenger locomotives. With the estimated ROE of NOx for both the Siemens and EMD locomotives typically operating at 2 to 3 times the EPA standard for NOx, it is important to quantify these ROE emissions before California invests in anymore new diesel passenger locomotives.

Conclusions and Recommendations

This preliminary data set and calculations indicate that the existing system for certifying diesel locomotives used in intercity and commuter passenger service is significantly undercounting the ROE. Quantifying the scale of this problem, implementing an appropriate testing duty cycle, and basing emissions reduction incentive funding on ROE is neither complicated nor expensive. Underestimating ROE results in suboptimal results from emissions incentive funding. It misdirects research away from better solutions and locks in mediocre emissions reductions for several decades.

Better data will require:

1. An effort to measure ROE
    a. Static locomotive emissions testing with the hotel system turned on
    b. 3rd party in-use emissions measurements on sample trains
    c. Updating or enforcing funding contracts to mandate the reporting of passenger train operational data
    d. Firmware updates to locomotive control systems to record the additional engine parameters needed to track in-use emissions values

2. A revised test method that accounts for an average hotel power value added to the power settings in the duty cycle table
3. A revised duty cycle that accounts for the time these locomotives sit idle generating hotel power

To determine the scale of this problem, all of these locomotives can be statically loaded and tested during maintenance activity. A simple portable emissions system could be used to monitor NOx and exhaust gas temperature to give a better understanding of the interaction between extended dwell times and ROE while generating a low load. Notch 1 and 2 self-loading with the HEP system active would be good initial test points for 300 and 500HP of hotel power.

Modern locomotives are equipped with event recorders that can upload operating data. They also have electronic fuel injection microcontrollers that can indicate fuel flow and power being generated plus two NOx sensors that record both NOx and Oxygen proportions in the exhaust. With slight firmware changes by the OEMs, these data can be made available and the ROE estimated, totalized and reported to the funding agencies that are providing the emissions incentives.

Locomotive Idling Issues

The proposed in-use locomotive rule has language that is finally giving CARB the authority to start enforcing the locomotive idling limitations that have been incorporated into the federal EPA locomotive emissions regulation since it was passed in 2008. One thing CARB can do sooner than the implementation rules proposed for freight locomotives is investigate the excessive idle times of new Tier 4 passenger locomotives purchased under public incentive funding. The section below explains how the NOx emissions generated when these new Tier 4 passenger locomotives are idling is not only higher than that of the Tier 2 HEP engines typically installed in California passenger locomotives, it also appears to violate the Clean Air Act.

The Tier 4 Passenger locomotive idling issue

Picture a passenger train sitting for an hour or so at its layover passenger station in your neighborhood. The locomotive is at idle and has an onboard electrical system that can provide up to 600kW of hotel power to power the heat or air conditioning needs of the passenger cars. At this particular time, the weather is such that the hotel power system is operating at 150kW which is ¼ of its capacity.

Because of loopholes in the emissions certification program specific to these Tier 4 passenger locomotives, that locomotive is generating 50 times the NOx emissions of a diesel truck at 150kW. So one passenger locomotive sitting at idle for more than 10 minutes generating ¼ of its hotel power rating is the equivalent of 50 fully loaded tractor trailer trucks driving around your neighborhood in a loop at 65 mph for 10 minutes.

In addition to midday layovers at central passenger stations, passenger locomotives at several passenger stations around California typically idle all night from when they are dropped off after service until they leave in the morning.

Ironically the high idle emissions loophole in the EPA locomotive emissions standard (40 CFR 1033) did not have a corresponding idle control loophole for the new single engine Tier 4 passenger locomotive.

Therefore, anytime a passenger locomotive is idling for more than 30 minutes without an operator in the locomotive cab, the locomotive appears to be in clear violation 40 CFR 1033.5(d) which is a violation of the clean air act with predetermined penalties either for the manufacturer or the user.

Background of passenger locomotive Hotel Power systems

Legacy passenger locomotives typically had two engines, a larger 'main' engine for propulsion and a second smaller engine for generating hotel power. Hotel power is used to provide heat and air-conditioning for the passenger cars, this second isolated power system is the additional equipment unique to passenger locomotives and not common on freight locomotives. 40 CRF 1033.5(d) is the EPA regulation for emissions testing and certifying of locomotives. Under 40 CFR 1033 the smaller engine that only generates hotel power is excluded from being regulated as a locomotive engine and was regulated under 40 CFR 1039, which is the EPA regulation for emissions certifying industrial diesel engines for off-road application (not highway trucks).

> (d) The provisions of this part do not apply for any auxiliary engine that only provides hotel power. In general, these engines are subject to the provisions of 40 CFR part 1039. However, depending on the engine cycle, model year and power rating, the engines may be subject to other regulatory parts instead.

Because the engine generating hotel power was regulated by 40 CFR 1039, it was not subject to the automatic engine start/stop provisions of the locomotive regulation 40 CFR 1033. To the consternation of many neighborhood groups and air agencies, the passenger agencies had a habit of allowing these hotel power engines to operate around the clock providing power for heating and cooling empty passenger cars. These were constant speed generator engines that were significant noise makers even when operating a low loads. For this reason many air agencies have funded the installation of wayside power boxes that passenger locomotives could be plugged into so that the hotel power generators could be turned off with beneficial reductions in fuel consumption, exhaust emissions and noise. It has been observed that getting the passenger agencies to consistently use these wayside power systems has been a challenge after they are installed.

The latest generation of new passenger locomotives built to the Tier 4 standard have moved away from the big and small engine approach and now only have one main engine that provides power for both propulsion and hotel power. Because of this architectural change in the new Tier 4 passenger locomotives, both the Siemens Charger and the EMD F125 passenger locomotives appear to be in violation of 40 CFR Part 1033.115 in that they are required to shut the 'main' locomotive engine off after 30 minutes of idling except under one of the following conditions.

(g) *Idle controls.* All new locomotives must be equipped with automatic engine stop/start as described in this paragraph (g). All new locomotives must be designed to allow the engine(s) to be restarted at least six times per day without causing engine damage that would affect the expected interval between remanufacturing. Note that it is a violation of 40 CFR 1068.101(b)(1) to circumvent the provisions of this paragraph (g).

(1) Except as allowed by paragraph (g)(2) of this section, the stop/start systems must shut off the main locomotive engine(s) after 30 minutes of idling (or less).

(2) Stop/start systems may restart or continue idling for the following reasons:

(i) To prevent engine damage such as to prevent the engine coolant from freezing.

(ii) To maintain air pressure for brakes or starter system, or to recharge the locomotive battery.

(iii) To perform necessary maintenance.

(iv) To otherwise comply with federal regulations.

(3) You may ask to use alternate stop/start systems that will achieve equivalent idle control.

(4) See §1033.201 for provisions that allow you to obtain a separate certificate for idle controls.

(5) It is not considered circumvention to allow a locomotive to idle to heat or cool the cab, provided such heating or cooling is necessary.

The spirit of 1033.155(g)(5) was likely intended to keep an operating engineer in the locomotive cab comfortable, hence the qualifier 'provided such heating and cooling is necessary'. It is a stretch to assume this allows the locomotive manufacturer to program its locomotives allow the system to idle for more than 30 minutes if the hotel power system is enabled. If passenger cars are occupied and the hotel system needs to be operating for passenger comfort, there should be an operator in the locomotive cab allowing the automatic engine start/stop system to be manually overridden by the operator per 1033.155(g)(5).

1033.115(g) specifically links this idle shutdown feature to 40 CFR 1068.101(b)(1) which indicates fines of $44,539 to the manufacturer for each piece of equipment in violation of this rule. Further the passenger agencies could be fined $4,454 for improperly overriding the manufacturer's automatic start/stop system and idling locomotives past 30 minutes.

(b) The following prohibitions apply to everyone with respect to the engines and equipment to which this part applies:

(1) *Tampering*. You may not remove or render inoperative any device or element of design installed on or in engines/equipment in compliance with the regulations prior to its sale and delivery to the ultimate purchaser. You also may not knowingly remove or render inoperative any such device or element of design after such sale and delivery to the ultimate purchaser. This includes, for example, operating an engine without a supply of appropriate quality urea if the emission control system relies on urea to reduce NO_X emissions or the use of incorrect fuel or engine oil that renders the emission control system inoperative. Section 1068.120 describes how this applies to rebuilding engines. See the standard-setting part, which may include additional provisions regarding actions prohibited by this requirement. For a manufacturer or dealer, we may assess a civil penalty up to $44,539 for each engine or piece of equipment in violation. For anyone else, we may assess a civil penalty up to $4,454 for each engine or piece of equipment in violation. This prohibition does not apply in any of the following situations:

Public Funding of 'Low Emissions' Passenger Locomotives

California public funding has purchased 37 of the Siemens Charger locomotives for 3 different passenger rail agencies and 40 Progress Rail F125 locomotives with costs varying between 7 and 12 million per locomotive. In many cases the higher costs for the Siemens Chargers include a 25 year parts support agreements. At average cost of $7 million, estimated total public capital expenditure on Tier 4 passenger locomotives is approximately $540 million. With this much public funding spent on such durable equipment that generates significant criteria and greenhouse gas emissions, the public agencies have done a poor job of tracking in-use emissions and how much fuel is consumed by each locomotive and in each locomotive how much fuel is consumed for propulsion vs hotel power.

Carl Moyer - Real, enforceable, quantifiable and surplus emission reductions

The legislative language is written out below illustrating that Carl Moyer funding is to be spent on emissions reductions that are '**real**' and '**quantifiable'**. It should be asked of CARB how it meets this legislative requirement if it has never tested a Tier 4 passenger locomotive with the hotel power system turned on and further how it can calculate in-use emissions if it is not tracking and averaging the actual duty cycle of the locomotives. A later section of this sourcebook would explain how easy it would be for CARB to collect this data and how the customers that have used public funding to purchase the equipment are contractually obligated to supply the data.

> HSC § 44287.1
> (a) The state board shall, at its first opportunity, revise the grant criteria and guidelines adopted pursuant to Section 44287 to incorporate projects in which an applicant turns in nonroad internal combustion technology and equipment that the applicant owns and that still has some useful life, coupled with the purchase of new nonroad zero-emission technology and equipment that is in a similar category or that can perform the same work.

(b) When it evaluates the benefits of a project described in subdivision (a), the state board shall count both of the following emission reduction streams, provided that they are real, enforceable, quantifiable, and surplus emission reductions:
(1) The displacement of the emissions from the older nonroad internal combustion technology and equipment for its remaining life with the new nonroad zero-emission technology and equipment.
(2) After the time period specified in paragraph (1), the displacement of emissions from new nonroad internal combustion technology and equipment meeting the emission standards in place at time of purchase, with the new nonroad zero-emission technology and equipment over its remaining life.
(c) A project described in subdivision (a) shall meet the cost-effectiveness criteria in Section 44283 and all other criteria of the program, including the requirement that the emission reductions be real, enforceable, quantifiable, and surplus.
(d) The incremental cost of a project described in subdivision (a) may include, at the discretion of the applicant, some or all of the reasonable salvage value of the nonroad internal combustion technology and equipment turned in, as determined by the state board. However, an applicant that elects to include these costs shall be required to meet the cost-effectiveness criteria in Section 44283.

Locomotive Operating Data and Locomotive Event Recorders

All modern passenger locomotives automatically upload locomotive event recorder and on-board camera data to a 3rd party cloud service, for air agencies to acquire this data they only have to enforce the below contractual obligations. This is not a burden on the passenger agencies as the 3rd party data aggregator can provide the reports directly to the air agency at the request of the passenger rail agency.

At the end of this attachment is a single month of sample data for a single passenger locomotive. These reports can also be provided for rolling 12 months and the entire fleet in one report from the 3rd party aggregator.

BAAQMD contract 20MOY175 language for Siemens Charger

D. Grantee shall install an Electronic Monitoring Unit (EMU) on each piece of Project Equipment at the time of purchase or installation and shall maintain and operate the EMU on the Project Equipment throughout the Project Equipment Operational Period. The EMU must be capable of providing complete digital information regarding total Project Equipment activity both within the Air District and within California. The data from the EMU shall be submitted to the Air District along with the Grantee's Annual Monitoring Report.

SCAQMD Contract   13441/134411 - First 20 F125's for Metrolink

CARB and SCAQMD rights for monitoring to insure emissions benefits are real and quantifiable

15. MONITORING AND ENFORCEMENT – CONTRACTOR agrees to operate the Equipment according to the terms of this Contract, including the CMP Guidelines, and to cooperate with SCAQMD and CARB in implementation, monitoring, enforcement, and other efforts to assure the emission benefits are real, quantifiable, surplus, and enforceable. CONTRACTOR also understands and agrees that in addition to SCAQMD, CARB, as an intended third-party beneficiary of this Contract, also has the right to enforce the terms of this Contract to ensure emission reductions are generated. SCAQMD and CARB will seek

Contractor is obligated to make operational information available

3.3 CONTRACTOR agrees to make operational information for the locomotive available, upon reasonable notice, to SCAQMD or CARB staff during the life of the locomotive. This information may include annual hours operated, location data from the Positive Train Control (PTC) system, and amount of fuel consumed.

Locomotive Duty Cycles

During emissions testing, a locomotive is tested against a load bank at 11 power settings: low idle, idle, dynamic brake, and throttle notches 1 through 8. Throttle notch 1 is approximately 5% of rated power and power levels go up to 100% at Notch 8, these are labeled in the left column of the table below. Emissions are measured at each of 11 locomotive operating modes. Then the emissions at each power setting are multiplied by the weighting in one of the two columns. Brake-specific emissions were calculated by dividing the weighted sum of hourly emissions in each mode by the weighted sum of the power output in each mode, as provided in 40 CFR 1033.

	Percent weighting		
Test Mode	EPA Line-haul	EPA Switch	Metrolink Commuter
Low Idle	19.0%	29.9%	61.8%
Hi Idle	19.0%	29.9%	10.0%
Dynamic Brake	12.5%	0.0%	6.1%
Notch 1	6.5%	12.4%	2.9%
Notch 2	6.5%	12.3%	1.6%
Notch 3	5.2%	5.8%	1.3%
Notch 4	4.4%	3.6%	3.8%
Notch 5	3.8%	3.6%	0.4%
Notch 6	3.9%	1.5%	1.3%
Notch 7	3.0%	0.2%	2.6%
Notch 8	16.2%	0.8%	8.3%

Neither the EPA line-haul nor switch cycle much resembles passenger locomotive operation. A more representative duty cycle has been developed from analysis of monitoring data on a Metrolink commuter locomotive involved in an emissions reduction study around 2010. This table compares this cycle based on actual passenger locomotive operations to the EPA-specified cycles. The commuter cycle includes even more idle time than the switch cycle, as locomotives are often left idling with the HEP engine running even when the train is not in service, in order to supply power to the passenger cars. Most of this idle time is for relatively long periods, so that the condition is mostly low idle. Passenger locomotives spend more time in high-load operation than do switchers, although not as much as the EPA line-haul cycle.

Locomotive Event Recorder Reports

Below is a sample event recorder report for 30 days of passenger locomotive operation in 2020

Throttle	Duration	Energy	Avg Power	Distance Traveled	
Stop	0.0 hr	0 hph	0 hp	0.0 mi	
Idle Moving	34.6 hr	2,046 hph	59 hp	1,549.4 mi	
Idle Stationary	68.7 hr	782 hph	11 hp	0.1 mi	
Idle Stationary > 30 Minutes	111.3 hr	1,266 hph	11 hp	0.0 mi	68.5%
Throttle 1	9.5 hr	1,544 hph	163 hp	360.9 mi	3.0%
Throttle 2	11.2 hr	2,569 hph	229 hp	430.8 mi	3.6%
Throttle 3	8.8 hr	4,174 hph	474 hp	361.2 mi	2.8%
Throttle 4	7.8 hr	5,860 hph	749 hp	347.5 mi	2.5%
Throttle 5	6.4 hr	7,425 hph	1,156 hp	269.7 mi	2.1%
Throttle 6	5.0 hr	7,260 hph	1,453 hp	224.1 mi	1.6%
Throttle 7	2.1 hr	3,833 hph	1,800 hp	102.5 mi	0.7%
Throttle 8	33.4 hr	79,348 hph	2,377 hp	1,809.1 mi	10.7%
Dynamic	14.2 hr	708 hph	50 hp	655.2 mi	4.6%
Engine Shutdown	113.4 hr	279 hph	2 hp	1.9 mi	100.0%
Other	1.0 hr	0 hph	0 hp	0.0 mi	
Engine Not Loading	0.0 hr	0 hph	0 hp	0.0 mi	
Total	427.5 hr	117,093 hph	274 hp	6,112.4 mi	313.0 hr

The highlighted column to the right in the data illustrates the calculation of duty cycle for this locomotive from the event recorder data. This data correlates well with the 2010 Metrolink data in the previous table.

When the air agencies start to track the locomotive operating data for the locomotives under the contracts that were used to fund the locomotive purchases, the process does not have to be a burden on the passenger rail agencies. The data can be provided directly to the air agencies by the third parties who are already paid to store the information and generate these reports by their passenger rail agencies customers.

Appendix 2: Regulatory References

Code of Federal Regulations applicable to locomotive testing

This section documents the EPA emissions certification loopholes specifically set up for single engine passenger locomotives which allow the significant increase of in-use emissions over the certification emissions levels. The first loophole allows the weighted average emissions to be calculated without consideration of the effects of hotel power generation, and the second loophole allows the emissions testing of the locomotive at engines speeds it would not actually operate at when in actual passenger service. This is done in the case of the Metrolink F125 locomotives which means there that the locomotives emissions while the locomotive setup for passenger service have not been tested and documented. It is believed that the NOx emissions of the Siemens Chargers locomotives are 2 to 4 times the EPA standard when the locomotives operate in intercity commuter service and are not plugged into wayside power when laying over. Even if the actual duty cycle was known for the F125 locomotives at Metrolink, there is no accurate way to estimate their in-use emissions because the emissions data has not been measured for that locomotive at the correct engine speeds due to the second loophole below.

§ 1033.501 General provisions.

(i) For passenger locomotives that can generate hotel power from the main propulsion engine, the locomotive must comply with the emission standards when in non-hotel setting. For hotel mode, the locomotive is subject to the notch cap provisions of § 1033.101 and the defeat device prohibition of § 1033.115.

The paragraph above is the foundation of multiple loopholes for modern passenger locomotives that only have one diesel engine when conventional legacy passenger locomotives had two engines. Opposite of the VW emissions scandal where the manufacturer cheated with a defeat device by testing the vehicle with one set of engine parameters and operating during service with different parameters. In this case the EPA is specifically telling the manufacturer that it can turn off a system for certification testing that will never be turned off when the locomotive is in active passenger service. This is the EPA handing the OEM a defeat device they can use.

§ 1033.101 Exhaust emission standards.

(3) Exhaust emissions that exceed the notch standards specified in paragraph (e)(2) of this section are allowed only if one of the following is true:

(i) The same emission controls are applied during the test conditions causing the noncompliance as were applied during certification test conditions (and to the same degree).

(ii) The exceedance result from a design feature that was described (including its effect on emissions) in the approved application for certification, and is:

(A) Necessary for safety;

(B) Addresses infrequent regeneration of an aftertreatment device; or

(C) Otherwise allowed by this part.

§1033.101 (3) (ii) (C) above are the notch cap provisions (in English, maximum emissions allowed) that the first regulation said couldn't be violated. As highlighted, they can be violated if ***otherwise allowed in the part***, which refers back to the first regulation paragraph where you can turn off the hotel power, and the AECD defeat device exception below where the engine speed is allowed to change when the hotel power is turned off.

§ 1033.115 Other requirements.

(f) *Defeat devices.* You may not equip your locomotives with a defeat device. A defeat device is an auxiliary emission control device (AECD) that reduces the effectiveness of emission controls under conditions that the locomotive may reasonably be expected to encounter during normal operation and use.

(1) This does not apply to AECDs you identify in your application for certification if any of the following is true:

(i) The conditions of concern were substantially included in the applicable duty cycle test procedures described in subpart F of this part.

(ii) You show your design is necessary to prevent locomotive damage or accidents.

(iii) The reduced effectiveness applies only to starting the locomotive.

(iv) The locomotive emissions when the AECD is functioning are at or below the notch caps of § 1033.101.

(2) This does not apply to AECDs related to hotel mode that conform to the specifications of this paragraph (f)(2). This provision is intended for AECDs that have the primary function of operating the engine at a different speed than would be done to generate the same propulsive power when not operating in hotel mode. Identify and describe these AECDs in your application for certification. We may allow the AECDs to modify engine calibrations where we determine that such modifications are environmentally beneficial or needed for proper engine function. You must obtain preliminary approval under § 1033.210 before incorporating such modifications. Otherwise, you must apply the same injection timing and intake air cooling strategies in hotel mode and non-hotel mode.

§1033.115 (f)(2) above is the loophole allowing the locomotive to increase engine speed when hotel power is turned on causing exhaust temperatures to drop and hence the emissions after-treatment to stop injecting diesel exhaust fluid (DEF or UREA) to prevent clogging of the substrates due to crystalizing UREA.

DPF 0.001 g/hphr ROE reference from CARB

When it comes to particulate emissions, heavy duty engines in on-road service since 2007 have shed the what was a well deserved 'dirty diesel' reputation as since the conversion to ultra low surfur diesel fuel and the implementation of diesel particulate filters, trucks emit an amount of particulates that is a challenge to actually measure. Gone are the days of diesel trucks belching black smoke, when some one runs their finger inside the exhaust tip of a modern diesel engine, their finger is now covered in rust and not soot. If you were run your finger in the exhaust tip of a modern gasoline powered car, you would get soot on your finger.

In simpler terms, this means that heavy duty diesel engines equipped with a DPF typically emit particulates at 1/10 the 2010 on-road truck emissions standard. This is an important fact for this sourcebook because when a locomotive barely meets the 0.03 gram/(hp-hr) emissions standard, that is approximately 30 times the amount of particulates that a modern on-road truck generates for the same amount of power and time.

This 0.001 g/(hp-hr) value is referenced in the Heavy-Duty Engine and Vehicle Omnibus Regulation and Associated Amendments Resolution, CARB, Aug 2020

> Page 6, WHEREAS, most currently certified engines are compliant with the existing PM emission standard of 0.01 g/bhp-hr PM , and in fact exhibit certification levels that are at or close to 0.001 g/bhp-hr;
>
> Page 7, WHEREAS, CARB's proposed 2024 and subsequent model year NOx and PM emission standards would be more stringent than the existing federal 2024 model year NOx and PM emission standards. Consequently, the current ABT accounting mechanism would no longer accurately account for credits generated under California's on-road heavy-duty engine emissions program;

CARB Omnibus Low-NOx Rule

NGV America Article on CARB Low-NOx Engine Rule

> September 1, 2020
>
> Last Friday, the California Air Resources Board (CARB) approved the Omnibus Low-NOx Rule, requiring new engines and trucks to meet more demanding NOx standards – 75% lower in 2024 and 90% lower in 2027. The rules also lower the standard for particulate matter by 50 percent and include new tougher in-use testing protocols, extended deterioration requirements, and extended warranty provisions, among other things. CARB also approved changes to the optional low-NOx certification program under which most natural gas engines are currently certified. The new rules will require optional low-NOx engines and trucks to be certified to a level of no more

than 0.02 g/bhp-hr in 2024 and 0.01 in 2027. PM levels would have to be no more than 0.005 g/bhp-hr to be considered an optional low-NOx engine.

Congressional Report on EPA non-performance leasing to Truck industry Consent Decree

Link to the report - ***Asleep at the Wheel , The Environmental Protection Agency's Failure to Enforce Pollution Standards For Heavy-Duty Diesel Trucks***

Locomotive Tier 4 compared to modern truck emissions

The Tier 4 locomotive standard allows a brand-new locomotive to emit 6.5 times as much NOx per horsepower as a heavy duty diesel truck manufactured in 2010. Diesel particulate filters that all on-road heavy duty trucks have been equipped with since 2007 reduce PM emissions by 95% over the Tier 4 PM standard. Further, near zero emissions natural gas engines are currently commercially available in trucks with NOx levels reduced another 75%, and this 'Low NOx' truck emissions standard will be mandated in California starting in 2024. It is likely that in 2024 only 20% of the North American passenger rail industry and less than 5% of the freight rail industry will have achieved Tier 4 standards that will be generating 26 times the NOx emissions and 20 times the PM per equivalent power. For single engine passenger locomotives that NOx ratio increases to 52 due to the EPA certification loopholes of:

1. In appropriate duty cycle for calculating weighted emissions levels
2. Not accounting for hotel power which can account for up to 40% of fuel consumed
3. The EPA allowed defeat device of allowing single engine passenger locomotives to be emissions tested with the hotel power turned off at a lower engine RPM

'NEW' Locomotive Definition Issue

Bonus information for people who get to the end of the sourcebook.

Many people outside the rail industry are mystified at how and why the rail industry can operate 1980's diesel technology forever. Conventional wisdom indicates that this challenge would be difficult to fix in the federal legislation.

With a review of the Clean Air Act and other federal regulations ,it appears that a simple definition fix of the word 'New' in the EPA locomotive standard CFR 40 part 1033.901 could close the perpetual rebuild loophole. This fix is rather simple and we hope that CARB makes an effort to push EPA to fix this when it works on a future Tier 5 rulemaking.

Based on the Clean Air Act

States can adopt stricter standards of mobile source emissions except for a few specific exceptions which are covered at this link here https://www.law.cornell.edu/uscode/text/42/7543

See (e)(1)(B)

(e) Nonroad engines or vehicles

(1) Prohibition on certain State standards

No State or any political subdivision thereof shall adopt or attempt to enforce any standard or other requirement relating to the control of emissions from either of the following new nonroad engines or nonroad vehicles subject to regulation under this chapter—

(A) New engines which are used in construction equipment or vehicles or used in farm equipment or vehicles and which are smaller than 175 horsepower.

(B) New locomotives or new engines used in locomotives.

The states are explicitly not allowed to regulate 'New' locomotive emissions under the Clean Air Act.

This now explains why the definition of 'new' was so goofy in the CFR 40 part 1033.901 definitions:

> (1) A locomotive or engine is new if its equitable or legal title has never been transferred to an ultimate purchaser. Where the equitable or legal title to a locomotive or engine is not transferred prior to its being placed into service, the locomotive or engine ceases to be new when it is placed into service. A locomotive or engine also becomes new if it is remanufactured or refurbished (as defined in this section). A remanufactured locomotive or engine ceases to be new when placed back into service. With respect to imported locomotives or locomotive engines, the term "new locomotive" or "new locomotive engine" also means a locomotive or locomotive engine that is not covered by a certificate of conformity under this part or 40 CFR part 92 at the time of importation, and that was manufactured or remanufactured after the effective date of the emission standards in 40 CFR part 92 which would have been applicable to such locomotive or engine had it been manufactured or remanufactured for importation into the United States. Note that replacing an engine in one locomotive with an unremanufactured used engine from a different locomotive does not make a locomotive new.

When CARB works with EPA on Tier 5 standard in next rulemaking there should be a fight to not consider a 'remanufactured' locomotive to be 'new'. This is not a constitutional issue and should clear out the rebuild loophole, and/or force EPA to add into the new rulemaking a BACT technology requirement for locomotives after their useful life.