Overview – VeRail Tier 4+ Dual Fuel Locomotive / Near-Zero Emissions Natural Gas Locomotive / Zero Emissions Track Miles (ZETM) Natural Gas Hybrid Locomotive

The revolutionary VeRail VR-series locomotives are the first locomotives designed specifically to meet California's "Tier 4+" and near-zero emissions levels. The ARB Tier 4+ targets call for a 70% reduction of NOx and PM below current EPA Tier 4 locomotive standards. The VeRail VR-series dual fuel locomotives are projected to provide over 90% reduction of NOx and PM, and a 22.7% reduction of GHG. VeRail VR-series straight natural gas locomotives are projected to meet near-zero emissions requirements for locomotives.

The VeRail VR-series of locomotives have been specifically designed to support the aggressive California initiatives and allow railroads to start utilizing Tier 4+ and near-zero emissions locomotives as quickly as possible. The VeRail VR-series locomotive is also designed to be an upgradeable locomotive that will serve as a bridge to full zero-emissions locomotives in the near future.

VeRail will soon be demonstrating a VR21C4-df 2,100 horsepower locomotive on the Pacific Harbor Line in the Ports of Los Angeles and Long Beach (POLA/POLB). The manufacture of the demonstration VR21C4-df locomotive will begin in late-summer 2016 and the actual on-rail demonstration will take place at POLA/POLB beginning in the fall of 2017. The proposed project is two years in length with the first year (2016-2017) including EPA certification of the VeRail 600 horsepower near-zero emissions locomotive engines. The second year will be actual railroad operation of the locomotive. The locomotive will be monitored and evaluated from emissions and operational perspectives to determine their long-term viability as an eventual replacement for conventional diesel locomotives.

Thus at the end of this demonstration a fully tested and certified near-zero emissions locomotive as well as a fully tested and certified California Tier 4+ locomotive will be available for railroads and rail operators throughout the South Coast Air Basin and the State of California. The project is being funded through private investment and grants from POLA/POLB, SCAQMD, and SoCalGas.

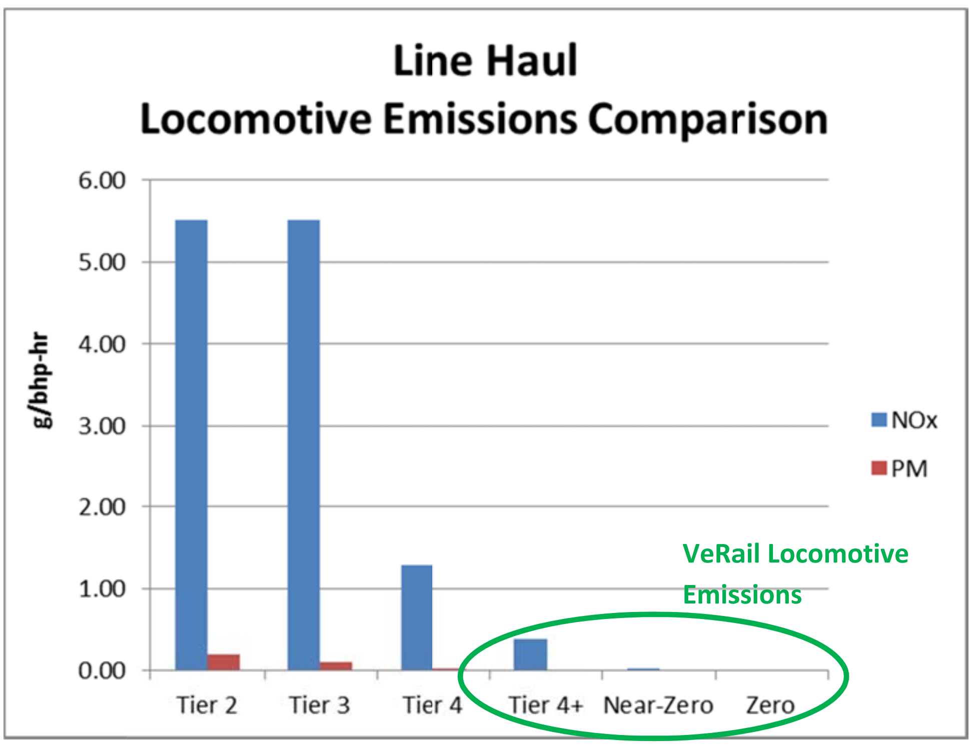

Figure 1: EPA Emissions Standards and California Targets
VeRail dual fuel locomotives are designed to meet ARB Tier 4+
VeRail CNG locomotives are designed to meet near-zero with Zero Emissions Track Miles capability

VeRail Demonstration Locomotive Technology

VeRail locomotives will virtually eliminate all emissions associated with compression-ignition (i.e. diesel) engine powered locomotives. The use of near-zero emissions natural gas locomotive engines in VeRail's locomotives will eliminate DPM without the need for cumbersome, expensive, and hard to maintain diesel particulate filters (DPFs). NOx emissions virtually eliminated by use of a three-way catalytic converter, rather than complicated and expensive Selective Catalytic Reduction (SCR) technologies required by diesel engines. By utilizing near-zero emissions technology, VeRail locomotives will immediately permit railroads to not only meet the EPA Tier 4 locomotive emissions standards, which took effect January 2015, but will allow them to meet ARB's Tier 4+ goal and beyond, including near-zero emissions.

The VeRail VR21C4-df locomotives proposed for this demonstration are fitted with two 1,200 horsepower VeRail near-zero emissions Natural Gas Power Modules (nzNGPM's) producing up to 2,400 continuous horsepower. Using these two nzNGPM's to produce 2,100 usable locomotive horsepower, the locomotive designated as a VR21C4-nz is projected to produce no more than 0.02 g/bhp-hr of NOx and no diesel particulate matter (DPM).

In addition to the two nzNGPM's, the locomotives will be equipped with two 600 horsepower Tier 4 diesel locomotive generator sets. These generator sets utilize EPA Tier 4 locomotive certified Cummins QSX15 engines. The addition of the two Tier 4 diesel generator sets allows the same VeRail VR21C4-nz locomotive to be demonstrated as a dual fuel (natural gas and diesel) locomotive. In this VR21C4-df configuration the locomotive uses just one of its two VeRail nzNGPM's, producing 1,200 horsepower of near-zero emissions power. The other 900 horsepower needed to achieve the full rated 2,100 horsepower of the locomotive comes from the twin 600 HP diesel generator sets.

Since a 2,100 horsepower locomotive only operates for about 2.5% of the time above 1,200 horsepower (per the standard US EPA switcher locomotive duty cycle), and since well over 57% of the horsepower during this 2.5% of the locomotive duty cycle still comes from the VeRail nzNGPM's, the overall natural gas substitution rate of the VeRail locomotive running in a dual fuel (natural gas and diesel) mode is projected to still be a very low 0.09 g/bhp-hr of NOx, well below the 0.39 g/bhp-hr NOx target for California Tier 4+. DPM is projected to be eliminated since the nzNGPM produces no DPM and the Cummins Tier 4 locomotive diesel engines utilize a DOC/DPF system to remove DPM from the exhaust stream.

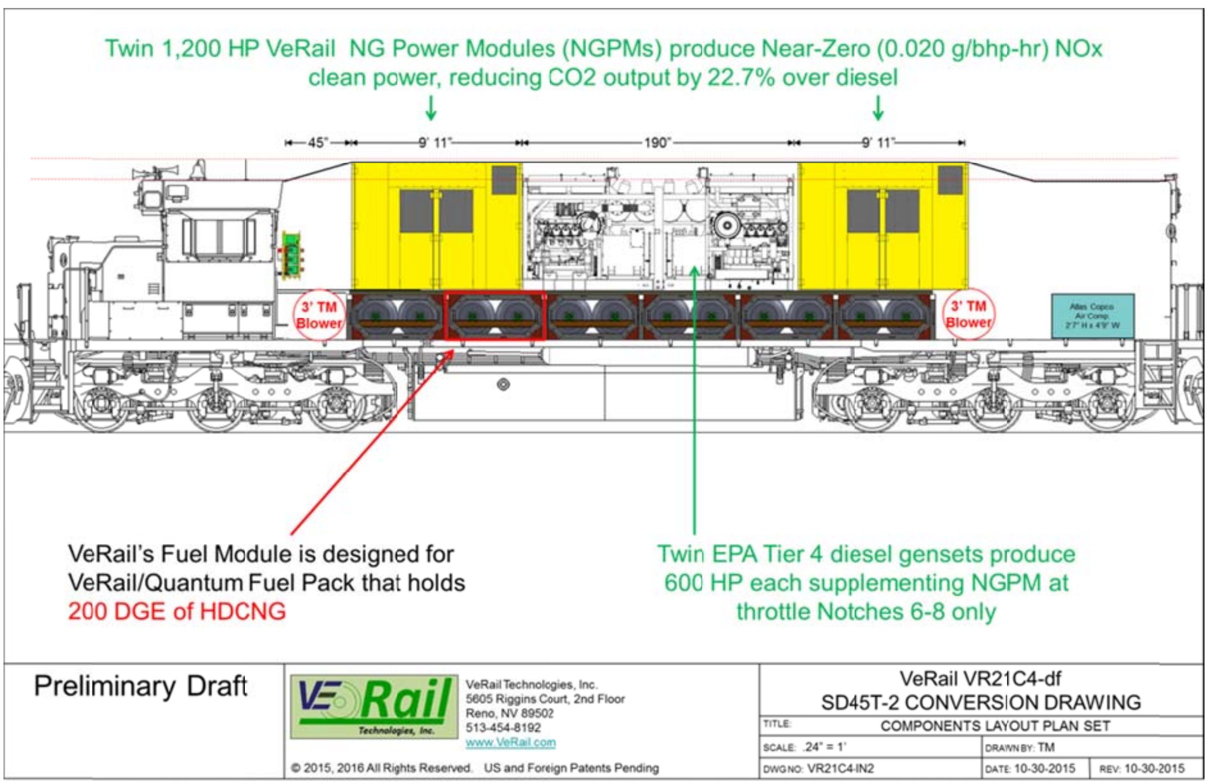

Figure 2: VeRail VR21C4-df Locomotive

Descriptive components layout and finished 2,100hp VR21C4-df locomotives

The VR21C4 locomotive has the two 1,200 horsepower nzNGPMs (shown in yellow in Figure 2) that are mounted above the frame. The two Tier 4 diesel generator sets (gensets) are shown in white between the two nzNGPM's. The 1,200 diesel gallon equivalent (DGE) of CNG storage tanks are shown beneath the generator sets in dark gray. Locating the CNG storage on the locomotive eliminates issues with the lack of a CNG tender specification by the FRA and having them above the frame nearly eliminates the potential for vehicle impacts at crossings damaging the CNG tanks. The ancillary equipment such as air systems and cooling is located in the rearmost compartment.
Running in straight natural gas mode, the VeRail VR21C4-df locomotive is projected to emit only 0.02 g/bhp-hr of NOx and no DPM. At these emissions levels VeRail locomotives would be considered a near-zero emissions locomotive. The NOx level is 98.5% below Tier 4 locomotive requirements and significantly exceeds ARB's Tier 4+ locomotive goal of 70% reduction of NOx and PM beyond the current EPA Tier 4 requirements. Even when backup/peak power EPA Tier 4 locomotive generator sets are utilized in the VR21C4-df (dual fuel natural gas and diesel) configuration to augment the VeRail nzNGPM's, the VeRail locomotive is projected to reduce NOx to over 90% below Tier 4 locomotive levels, and virtually eliminate DPM.

Since VeRail's locomotives in the 2,000hp to 4,000hp range are targeted for ports, railroad yards, local switching, and heavy transfer service, these locomotives are perfectly suited for use mainly in ozone nonattainment areas. Locomotives in this horsepower range are operated by Class I railroads as well as short line railroads and industrial facilities. There are over 500 of these aging (25-35 years old) and highly-polluting freight locomotives in intrastate use in California. Thus VeRail believes that this project is well suited in its scope of locomotives covered to make the greatest emissions reduction possible across California in the shortest amount of time.

In addition to railroad operating partners, VeRail has assembled a consortium of leading technology companies to make this near-zero emissions locomotive a reality. VeRail's supply partners include Quantum Technologies (www.qtww.com), a world leader in high pressure CNG and hydrogen fuel tanks; TMV Control Systems (tmvcontrol.com), a world recognized and locomotive proven developer of advanced locomotive and traction control systems; and American Traction Systems (www.americantraction.com), a well-established developer and provider of high power solid state electric propulsion controls and accessories for locomotives, including hybrid and straight-battery vehicles.

Greenhouse Gas Emissions Benefits for the South Coast Air Basin and State of California

Under California's current LCFS, CNG fuel (Pathway Identifier CNG002) has been assigned a Carbon Intensity Value (CIV) of 79.46 gCO2e/MJ. Diesel (ULSD - Pathway Identifier ULSD001) is assigned a CIV of 102.76 gCO2e/MJ. Based on these numbers CNG reduces GHG emissions by 22.7% over diesel. Landfill gas CNG (biomethane - Pathway Identifier CNG003), which also generically called Renewable Natural Gas (RNG), is assigned a CIV of only 19.21 gCO2e/MJ. Thus the use of renewable CNG (RCNG) can reduce GHG emissions by 81.3% according to the current LCFS. RCNG is available for the proposed VeRail locomotive project at POLA/POLB. Hence the GHG reduction potential for this project is substantial, at a low of 22.7% and a high of 81.3%.

VR-series locomotives would reduce annual CO2 emissions per locomotive by 101.5 tons per year using CNG, compared to a diesel locomotive consuming 40,000 gallons per year of diesel fuel, producing 448 tons of CO2. In addition, by using RCNG made from waste streams, the LCFS provides for an 81.3% reduction of CO2 emissions per locomotive which would be 364 tons of CO2 emissions per locomotive per year.

Upgradability to Zero Emissions Battery Hybridization

The VeRail locomotive is also designed to be able to utilize battery modules either in place of an existing nzNGPM or as an adjunct to the existing nzNGPM's. In most cases the rigorous duty cycles of locomotives in the South Coast Air Basin will require that batteries be used as an adjunct to an onboard fuel powered system such as the VeRail nzNGPM. VeRail's proposal partner, Quantum Technologies, has extensive experience in not only the design and development of high pressure CNG, but has also worked extensively with the design and development of battery powered vehicles, both straight battery and hybrid. Quantum is VeRail's partner for the further development of the zeBPM for locomotive application.

There is plenty of space on the VeRail locomotive for the VeRail zeBPM and because of the different size footprint of the battery modules themselves, the zeBPM can be installed as a replacement for a standard nzNGPM, in the auxiliary equipment space at the rear of the VeRail VR series locomotive, or even under the frame in the area currently taken up by a locomotive diesel fuel tank. Because a battery system does not contain an explosive liquid or gas, mounting the zeBPM under the locomotive frame does not have the crashworthiness ramifications of an underframe fuel storage system. Hence this large amount of space may be perfectly suited in many cases for a zeBPM.

The demonstrator locomotive going into the ports in 2017 already has 3,600 HP of onboard NG and diesel power configured as two 1,200 HP near-zero emissions NGPM's (2,400 HP total) and two 600 HP Tier 4 diesel gensets (1,200 HP total). The 1,200 HP diesel Power Modules can be replaced with a single 1,200 HP NGPM, turning the entire locomotive into a 3,600 HP near-zero emissions locomotive. With no diesel fuel needed, the area currently taken up by the diesel fuel tank can be replaced with a zeBPM battery module. The zeBPM can provide 800-1200 HP of zero emissions power and can be used alone on light trains or in low power throttle notches on any train. The zeBPM can also be used in conjunction with the near-zero emissions nzNGPM's to provide 4,400 HP for propulsion, thus equaling the horsepower rating of today's highest horsepower Tier 4 line haul locomotives, while producing near-zero or zero emissions.

Operational Advantages

Unlike a fuel tender concept there is no need to change anything on the existing line haul fleet. Under a battery tender concept each diesel locomotive in the train will need to be converted to be able to pull electric power from the battery tender. This will require the addition of high voltage, high current power cables between the "mother" locomotives and the battery tender. Changes will need to be made to the main electrical cabinet of the locomotives so that the electric power from the battery tender is connected to the main power bus of the mother locomotive. This will require changes to the main electrical cabinet of every locomotive that may be used with a battery tender. Considering the fact that over 10,000 *individual* line haul locomotives visited the South Coast Air Basin (TA-FL p. I-10), the conversion of these line haul locomotives will be a major undertaking costing hundreds of millions of dollars. Any train that does not have *all* its locomotives converted to serve as mother units for the battery tenders will be unable to take advantage of the zero emissions stored energy provided by battery tenders. Thus unless a line haul locomotive fleet for use with the battery tenders is dedicated to just the South Coast Air Basin, the battery tenders have limited use.

For example, if just one locomotive in a train's locomotive consist was unable to pull power from battery tenders, this would have an extremely adverse effect on air quality. Looking just at NOx: If a train had four conventional diesel locomotives on it, with three of those locomotives operating as zero emissions battery tender powered locomotives (0 g/bhp-hr NOx), and the fourth conventional diesel locomotive meeting EPA Tier 3 standards (5.5 g/bhp-hr), 25% of the train's horsepower hours (and therefore emissions) would be produced by the Tier 3 line haul locomotive. 25% of 5.5 g/bhp-hr is 1.375 g/bhp-hr. This means that the train's NOx emissions would not even meet the Tier 4 line haul NOx emissions standard of 1.3 g/bhp-hr. This is a major problem considering the fact that California is pushing for a minimum Tier 4+ emissions output reduction of 70% below Tier 4 (0.39 g/bhp-hr).

So even if enough battery tenders were available for every train in the South Coast Air Basin, if each three- or four-locomotive train is not equipped with 100% battery tender compatible "mother" locomotives, the emissions per train would be adversely affected to the point of it not even equaling the emissions reduction of simply using a set of Tier 4 diesel locomotives.

Since only four VeRail locomotives would be needed vs. 12 battery tenders, the overall length added to the train is kept to a minimum. Four VR21C4's on EMD SD40-2 frames (at about 68' long per locomotive), would be just under 275'. This is roughly equivalent to a single 5-unit intermodal well car set. 12 fuel tenders of just 50' each would be 600 feet in length. So to support battery tenders would require double the length needed for VeRail locomotives (see Figure 3) and add approximately 10% to the train length. This could be a major problem for length-limited sidings located along the route.

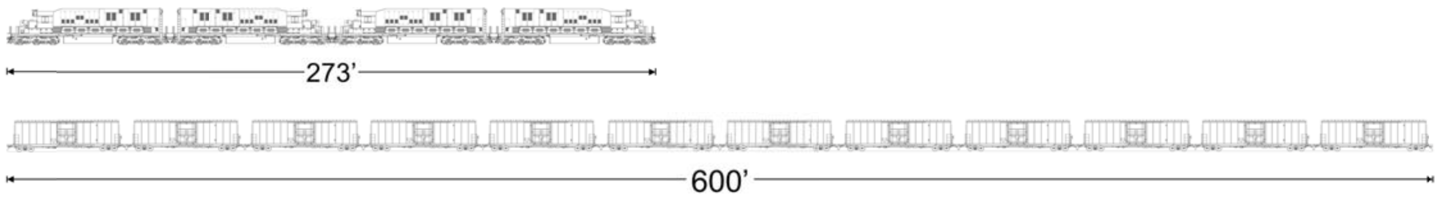

Figure 3: Length comparison of four VeRail locomotives to twelve 50’ battery tenders

Four VeRail locomotives weigh about 400,000 pounds (200 tons) each, or 800 tons total. 12 battery tenders weighing about 280,000 pounds each (140 tons) equal 1,680 tons, over double the weight of the VeRail locomotive set. Additional tonnage moved on each train requires additional energy. Considering the grades coming out of the Ports of Los Angeles and Long Beach (sea level) to the just the Inland Empire region of the South Coast Air Basin (~1,050 feet above sea level), substantial additional power would be expended by each train just to pull the battery tenders.

For example: On the Alameda Corridor between Mile Post 10 (just east of Compton) to West Redondo Junction (the end of the Alameda Corridor), trains must climb over 150 feet. This is an average 0.28% grade. Between Nadeau (Mile Post 4) and 25th Street (Mile Post 0.3) trains must climb a 0.5% grade. The speed limit on the Alameda Corridor is 40 MPH. At 40 MPH on a 0.5% grade, 1,680 tons (the weight of 12 140-ton battery tenders) would require an additional 2,260 horsepower to move the train. If the train already had four 4,400 horsepower locomotives (17,600 horsepower total), this additional 2,260 horsepower represents 12.8% of the available locomotive horsepower being needed just to pull the battery tenders. If a train only had three locomotives, the existing three locomotives may not have sufficient horsepower to pull the additional battery tenders added to the locomotive consist.

If near-zero emissions natural gas locomotives with Zero Emission Track Miles capability (such as VeRail VR44C3-Hcng locomotives) were used, the additional train tonnage is reduced to only 800 tons (the weight of the locomotives themselves). The VeRail locomotives would require less than 1,050 horsepower to move the weight that the locomotives themselves add to the train. Since each VeRail VR44C3-Hcng locomotive would produce at least 4,400 horsepower (17,600 horsepower total), the additional 1,047 horsepower needed on the steepest part of the Alameda Corridor would represent only 5.9% of the horsepower available. This is within the normal operating margin for horsepower on a given train.

Additionally, since the battery tenders do not have control cabs, and because they must supply their power directly to each mother locomotive, the locomotive consist of each train must be disassembled and then reassembled with battery tenders for use in the South Coast Air Basin (see TA-DL p. VI-3). This is a time consuming process, far more complex than simply adding a set of three or four VeRail locomotives to the front of an existing diesel-powered train train when operating in the South Coast Air Basin, and then pulling the set of VeRail locomotives off of the train just before it exits the Basin.

So while zero emission battery locomotives could make perfect sense for certain switching operations, near-zero emission natural gas powered line haul locomotives with hybrid battery storage (to support Zero Emissions Track Miles) are expected to be operationally superior to the use of battery tenders.

Cost Analysis – South Coast Air Basin

ARB staff estimates that, on any given day, about 455 UP and BNSF interstate line haul locomotives are operating in the South Coast Air Basin. If each locomotive requires three battery tenders to operate, a total of about 1,365 battery tenders would be needed. Moreover, ARB staff estimates that at least a one-third margin in additional battery tenders (i.e., about 455) would be needed in a battery tender pool to account for battery tenders that will be undergoing regular maintenance, or be unavailable due to damage, battery depletion, or any other miscellaneous operational needs. As a result, ARB staff estimates that, for full freight interstate rail operations in and around the South Coast Air Basin, UP and BNSF would need a total of up to 1,820 battery tenders. (TA-DL p. VI-13)

Using these same estimates, 455 VeRail locomotives would be needed to supply the train horsepower of the existing 455 line haul locomotives operating in the South Coast Air Basin. This is a 1-to-1 ratio since each VeRail locomotive would supply the same horsepower as one line haul locomotive. Assuming the same one-third margin of additional VeRail locomotives needed in a locomotive pool to account for locomotives that will be undergoing regular maintenance, or be unavailable due to damage, or any other miscellaneous operational needs, 150 pool locomotives will be needed. This totals approximately 605 total VeRail locomotives.

1,820 battery tenders x $5M each = $9,100,000,000

605 VeRail Line Haul Locomotives x $3M each = $1,815,000,000 (cost savings = $7.285B)

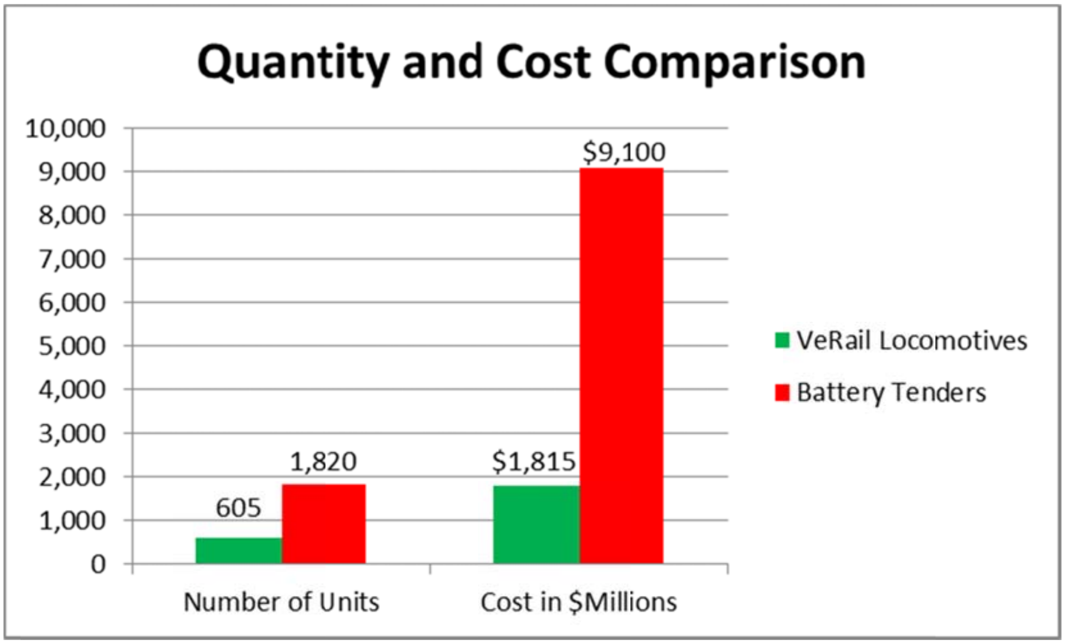

Figure 4: Unit quantity and cost comparison for South Coast Air Basin

Emissions Analysis

The VeRail VR24C3-Hcng locomotive is targeted to produce no more than 0.02 g/bhp-hr of NOx. This would qualify the locomotive to California's near-zero emissions standard *for on-road trucks*. ARB has not yet set a near-zero emissions target for locomotives, but if it follows ARB's 90% NOx reduction standard for trucks (from 0.2 g/bhp-hr NOx for Tier 4 Final to 0.02 g/bhp-hr for near-zero emissions) then locomotives would need to emit no more than 0.13 g/bhp-hr of NOx to meet a near-zero emissions target. The VeRail near-zero emissions natural gas locomotive is designed to reduce NOx almost 85% beyond what is anticipated to be California's near-zero emission locomotive standard. Considering rail's 4:1 efficiency over trucks, a comparable ton-mile emissions factor on a VeRail locomotive is targeted to be a weighted 0.005 g/bhp-hr per ton mile.

Based on the 0.02 g/bhp-hr NOx, a VeRail locomotive on a train running from the operating from the Ports of Los Angeles / Long Beach to Barstow, California (about 180 miles) would expend about 7.5 MWh of energy (see TA-DL p. VI-12). This calculates to approximately 10,058 hp-hrs. Based on a NOx level of 0.02 g/bhp-hr a VeRail locomotive would produce just a little over 200 grams of NOx to complete the trip from the Ports to Barstow. For comparison purposes, a Tier 3 line haul locomotive emitting 5.5 g/bhp-hr of NOx and running at full power (throttle Notch 8) would produce this same 200 grams of NOx in about 30 seconds. A Tier 4 line haul locomotive emitting 1.3 g/bhp-hr of NOx and running at full power (throttle Notch 8) would produce 200 grams of NOx in about 127 seconds.

With the addition of a small 680 kWh, 800 peak HP battery pack, a VeRail VR44C3-Hcng hybrid locomotive could produce as little as 0.015 g/bhp-hr of NOx and provide zero emission track miles, especially for empty container trains heading to the Ports of Los Angeles and Long Beach. If this lower number were used, a VeRail locomotive would produce only a little over 150 grams of NOx to complete the trip from the Ports to Barstow. This is the equivalent of a current Tier 3 line haul locomotive running in Notch 8 for 22 seconds, or a Tier 4 line haul locomotive running in Notch 8 for 95 seconds.

When looked at from this standpoint, the reduction of NOx alone for trains running in the South Coast Air Basin is staggering.

Incremental Investment Cost vs. Emissions Reduction – Technology Value Proposition and Cost Analysis

In order to get a true picture of the cost of emissions reduction, it is necessary to compare incremental equipment costs to actual emissions reduction. The key is to find a technology that not only reduces emissions but does so in the most economical manner. This is especially true if public funds such as grants or subsidies are being used to offset the overall cost of the new emissions reducing technology. Using the graph found in Figure 5, the best technology would have the lowest NOx output at the lowest cost. Since line haul trains running in the South Coast Air Basin (and other areas of California) will require multiple locomotives, the overall cost of equipment per train, as well as overall emissions reduction per train, must be considered and analyzed.

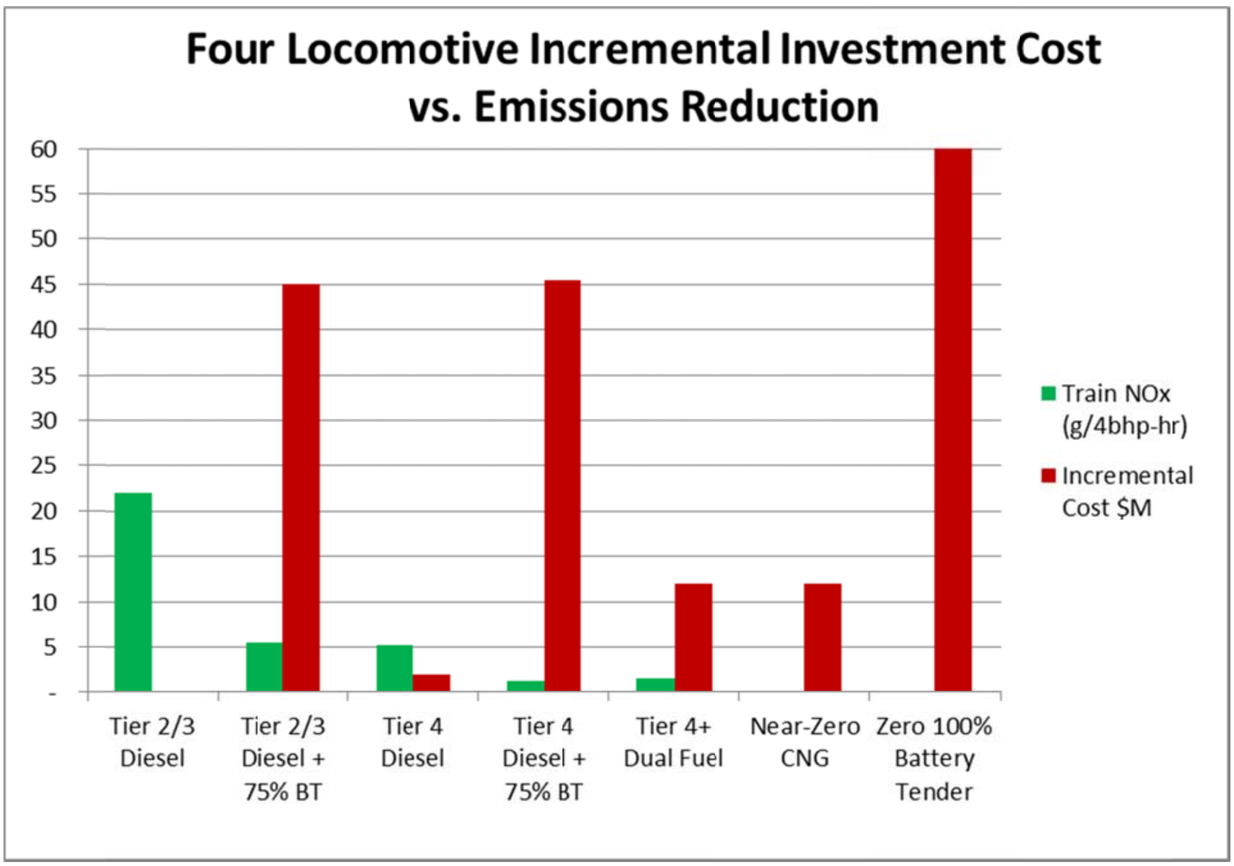

Figure 5: Investment vs. Emissions Reduction – Train with four locomotives

The graph in Figure 5 shows a comparison of six new technologies as applied to a train powered by four locomotives. The new technology data is compared to a baseline (the first set of bars) of existing Tier 2 and Tier 3 locomotives, which make up the bulk of the line haul locomotives operating in California today The graph assumes four locomotives of the same emissions level on a single train, so the NOx output is the total produced by the four locomotives, expressed as g/4bhp-hrs.

The second set of bars (Tier 2/3 Diesel + 75% BT) assumes that three of the four locomotives (75%) on the train are operating with a Battery Tender (BT). This illustrates the issue raised earlier that if all the locomotives on a given train are not capable of operating with a battery tender, then the benefits of the tender are greatly reduced. Notice that the NOx output reduction of a battery tender powered train if just one locomotive on the train was incapable of connecting with a battery tender is no better than the overall NOx output of a train powered by four conventional Tier 4 diesel locomotives with no battery tenders (the third set of bars entitled Tier 4 Diesel). But when the differential cost to add the battery tenders ($45M) is compared with the differential cost for Tier 4 diesel locomotives compared to Tier 2 or 3 locomotives ($2M) it is clear that the emissions reduction cost for a train that is not completely equipped with battery tenders is hardly justifiable compared to simply using four currently available Tier 4 diesel locomotives.

If the battery tender powered train had four Tier 4 locomotives, and one of them could not operate with the battery tenders (fourth set of bars entitled Tier 4 Diesel + 75% BT), the NOx output for the train would be substantially lowered, basically reducing overall Tier 4 NOx emissions by 75% and effectively creating a train with Tier 4+ emissions. But note from the fifth set of bars (Tier 4+ Dual Fuel) that the same NOx emissions reduction could be achieved by simply using a set of four Tier 4+ dual fuel locomotives costing only 25% of the price of the battery tender set. Another way of looking at this is that for the same investment, four trains could move to the Tier 4+ emissions reductions vs. just one train with Tier 4 locomotives and 75% battery tenders. Again, this shows how critical it will be for battery tender equipped trains to make sure that every locomotive on the train can operate with battery tenders, otherwise the emissions reduction is seriously compromised.

The sixth bar (Near-Zero CNG), however, shows that for the same price as the dual fuel Tier 4+ locomotives, a set of 100% natural gas powered near-zero emissions locomotives could virtually eliminate NOx emissions. Compared to a set of four Tier 4 diesel locomotives with three of the locomotives connected to battery tenders, the overall train NOx is reduced by almost 94%. Remarkably the cost to do so is actually 75% less than the cost to equip just three of the four Tier 4 diesel locomotives on the train with battery tenders.

The rightmost (seventh) set of bars entitled Zero 100% Battery Tenders shows the cost to equip a train having four locomotives with four sets of battery tenders. While there is clearly no NOx emissions, the cost is five times that of the near-zero emissions CNG locomotives. Looked at another way, compare the emissions reduction costs for battery tenders to the baseline Tier 2/3 diesel locomotives. To remove 100% of the NOx would cost $60 million. To remove 99.6% of the NOx (Near-Zero CNG) would cost merely $12 million, an 80% savings over the battery tenders.

A final way to look at this is to consider the amount of NOx that could be reduced for the amount of money spent. For $60 million one train could be equipped with Tier 2, 3, or 4 locomotives with battery tenders producing zero g/4bhp-hr of NOx. NOx emissions for the train would be reduced by 22 g/4bhp-hr. If the same $60 million were spent to purchase near-zero emissions CNG locomotives, five trains could be powered by the locomotives purchased. Each near-zero emissions train would produce a mere 0.08 g/4bhp-hr which equates to a 21.2 g/4bhp-hr NOx reduction. Multiplied by five trains, the same $60 million investment would eliminate almost 105 g/4bhp-hr of NOx compared to 22 g/4bhp-hr for the single train zero emissions battery tenders. Based on the numbers the question must be asked whether full zero emissions technology is really the answer to reduce freight locomotive emissions in the shortest possible time and at the best cost to the public.

Time to Implementation

The first VeRail VR-Series natural gas locomotive will be delivered to the Ports of Los Angeles and Long Beach for testing on the Pacific Harbor Line (PHL) in the fall of 2017. The VeRail locomotive design for the PHL demonstration is well-suited for line-haul freight duty as well. In fact, the VeRail VR21C4-df locomotive as currently configured can be software converted to a 3,600 HP Tier 4+ line haul configuration. The VR21C4-df locomotive already has 3,600 horsepower available which is provided by the two 1,200 horsepower nzNGPM's (2,400 horsepower total) plus two 600 horsepower Tier 4 diesel gensets (1,200 horsepower total) for an aggregate 3,600 horsepower. The six EMD traction motors used in the VR21C4-df are capable of handling 600 horsepower each and the traction controllers are designed to handle the voltage and current requirements for these high horsepower traction motors.

For comparison purposes to the proposed 2,100 horsepower VR21C4-df locomotive software re-configured as a 3,600 horsepower VR36C4-df line-haul locomotive, EMD manufactured the following comparable horsepower line-haul locomotives, many of which were and even still are used in the South Coast Air Basin:

EMD SD40-2 3,000 HP line-haul locomotive
EMD SD45T-2 3,600 HP line-haul locomotive
EMD SD50 3,600 HP line-haul locomotive
EMD SD60 3,800 HP line-haul locomotive
EMD SD70 4,000 HP line-haul locomotive

As can be seen from the above list, the VR36C4-df configuration of the VR21C4-df locomotive for the Ports demonstration will meet or exceed the horsepower rating of three of the above line-haul locomotives, would provide 95% of the horsepower rating of the SD60 locomotive, and 90% of the horsepower rating of the SD70 locomotive. With the addition of an 800 HP battery pack, as mentioned earlier, the total available horsepower would be 4,400, equal to that of a current GE ES44AC Tier 3 line haul locomotive, or a GE ET44AC Tier 4 line haul locomotive.

Additionally, the VeRail VR-series locomotive design can utilize AC traction motors as well as the current DC traction motors. (DC traction motors will be utilized on the VR21C4-df locomotive for the Ports demonstration and were used on the five EMD line-haul models locomotives listed above.) AC traction motors are better suited to line-haul service than DC traction motors and have become the de-facto standard for line-haul locomotives for the last 5-10 years. In a presentation to ARB, VeRail outlined its design for a VR44C4-Hcng AC traction near-zero emissions locomotive built on a 4,000 horsepower EMD SD70MAC frame. These locomotives were designed specifically as an option for moving freight from the ports out of the South Coast Air Basin.

Since the Ports demonstration of a VeRail near-zero emissions locomotive is scheduled to start in the fall of 2017, substantial locomotive emissions reduction could be seen in the South Coast Air Basin far before the implementation of either battery tenders or fuel cell locomotives. To illustrate how this accelerated emissions reduction can take place: Table X3, Pathways to Potentially Develop and Demonstrate Zero-Emission Track-Mile and Zero-Emission Freight Locomotives found on page X-9 of the Draft Technical Document – Freight Locomotives estimates costs and timelines to move toward near zero-emissions and zero-emission locomotives. Under this scenario presented, the battery tender or SOFC-GT fuel cell locomotives would not complete their research and design phase until 2018 for the battery tenders, and 2020 for the fuel cell locomotive. By the end of 2018 the VeRail locomotive in the Ports is expected to have completed about 3,000 hours of demonstration testing, moving it toward California emissions verification for production unit funding and full scale roll-out starting in 2019. The build of a test prototype phase for a battery tender would just be starting to take place in 2019-2020. For a SOFC-GT fuel cell locomotive Table X3 estimates that build and test of a prototype unit would not take place until 2021-2022. By this time the VeRail near-zero emissions locomotives, which can provide zero-emission track miles through the addition of a hybrid battery system, can be in production for 3-4 years. If only 150 VeRail line haul locomotives were built per year from 2019 to 2022, there would be enough VeRail locomotives to support the entire 455 South Coast Air Basin line haul locomotive fleet identified by ARB (TA-DL p. VI-13). All of this could take place before a SOFC-GT fuel cell locomotive even begins small scale demonstration.

Since the VeRail VR21C4-df locomotive demonstration on PHL is in a heavy duty switching environment, the VeRail demonstration beginning in 2017 will also show the applicability of these new near-zero and ZETMS locomotives to replace the existing 400-500 intrastate switcher locomotives with VeRail locomotives. If only 100 intrastate Class locomotives were converted to VeRail locomotives each year, the entire statewide fleet could be converted in 4-5 years.

So while the goals may seem aggressive, because of the state of the VeRail technology, it is plausible to be in full commercial production by 2019, vs. a projected 2027 for line haul battery tenders, or 2029 for SOFC-GT fuel cell locomotives.

It should be noted that for each year of delay in adopting near-zero or zero emissions locomotives, the current locomotives in California contribute significantly to the emissions inventory of the State and areas such as the South Coast Basin. Based on published studies of ports emissions inventory data, as well as studies of existing switcher locomotives, each year waiting to move from near-zero emissions to zero emissions is extremely costly in terms of annual emissions inventory.

Take, for example, a 2,000 horsepower switcher locomotive using 30,000 gallons of diesel fuel per year. Based on a conversion factor of 15.2 horsepower hours generated per gallon of fuel consumed, this locomotive would generate 456,000 hp-hrs per year. A Tier 3 switcher can emit up to 5.0 g/bhp-hr of NOx and meet the EPA Tier 3 standards. This means that a Tier 3 switcher using 30,000 gallons of diesel fuel per year would produce 2,280,000 grams of NOx per year. While zero emissions would appear to be the answer to this high NOx output, a near-zero emissions locomotive using 30,000 gallons of fuel but emitting only 0.02 g/bhp-hr of NOx (which is the target for the VeRail locomotive), will produce only 9,120 grams of NOx per year. That is a reduction of 2,270,880 grams of NOx per year for a near-zero emissions locomotive vs. a Tier 3 locomotive.

While the removal of the 9,120 grams of NOx may seem worthwhile, if it takes just one year more to develop and implement a zero emissions locomotive, we have put 2,270,880 unnecessary grams of NOx into the environment while waiting for the zero emissions technology. Since we are only removing an additional 9,120 grams of NOx each year with the zero emissions technology over the near-zero emissions VeRail technology, it will take another 249 years to make up for the extra 2,270,880 grams of NOx a Tier 3 switcher locomotive produces annually over a near-zero emissions VeRail locomotive while waiting for full zero emissions technology.

For this reason VeRail recommends that ARB seriously consider near-zero locomotive technology which is upgradable to provide zero-emissions track miles, and implement this technology as soon as possible.

It should also be pointed out that the cost of zero emissions fuel cell or battery tender locomotive technology over near zero emissions natural gas technology can be a major impediment to quick deployment of the cleaner locomotives sought by California. While the earlier cost analysis section (regarding battery tender costs vs. VeRail locomotive costs) shows a difference of over $7B ($1.8B for 605 near-zero emissions locomotives vs. $9.1 for 1,820 battery tenders) in implementation costs for South Coast Air Basin line haul trains alone, Table ES-6 Estimated Capital Costs of Advanced Locomotive Technologies found on page ES-14 of the Technology Assessment estimates the total cost for battery tenders for the South Coast Air Basin alone at $39B over 30 years. That averages out to $1.3B per year to implement zero emission technology vs. less than $100M per year to implement near-zero emissions technology with ZETM hybrid capability. This price differential could further push off implementation of the zero emission locomotive technology or totally push it outside the realm of economic reality. Considering the fact that every year of delay in moving from current Tier 3 locomotive emissions (5.5 g/bhp-hr of NOx for line-haul) to VeRail near-zero emissions (0.02 g/bhp-hr of NOx for line haul) contributes nearly 250 years of NOx emissions to the environment, and that a 4-5 year total locomotive replacement plan for line haul locomotives in the South Coast Air Basin and all 400-500 intrastate locomotives in California could be done for less than 8% of the cost of battery tenders for just the South Coast Air Basin alone, one has to question the economical practicality of battery tenders vs. near-zero natural gas locomotives. It will certainly be faster and easier to find money to pay for almost 1,000 locomotives at $3B that will benefit the entire State of California as opposed to $39B for 1,820 fuel tenders (or fuel cell locomotives) that would benefit just the South Coast Air Basin.

Finally, the operational challenges of battery tenders on locomotives needs to be taken into account, since the more complex the implementation of new locomotive technology becomes, the more likely it is that railroads will oppose the transition to the new technology. As noted earlier, to add and remove battery tenders to a locomotive consist on trains between the Ports and outside the South Coast Air Basin will be very time consuming and disruptive. The additional weight of up to 12 battery tenders per train will impose an energy cost penalty of over 10% to each train. The envisioned use of near-zero emissions locomotives with ZETM capability would be to simply add the near-zero emissions locomotives to the train ahead of the existing locomotive consist. Because of the limited grades within the South Coast Air Basin this should be a suitable arrangement to move trains to at least the Inland Empire. If trains need to move to farther points, such as Barstow, it could make sense to attach the near-zero locomotives to the train in a DPU configuration with three locomotives at the front of the train and one at the back, or two near-zero emissions locomotives at the front of the train and two at the back. Either way, it will be much easier to simply cut off these “helper” locomotive sets at a given point near or outside the boundary of the South Coast Air Basin versus having to disassemble a train’s locomotive consists in order to remove the battery tenders attached to each locomotive in the train.

So the use of near-zero emissions locomotives for moving a train just within the South Coast Air Basin would require no change to the existing train configuration, because arriving or departing trains will continue to have the existing diesel locomotives that will take trains from the borders of the South Coast Air Basin on through the transcon routes to points east.

Future Technology Expansion

The fuel cylinders have been designed to store either natural gas or hydrogen at 5,000 psi. The locomotive is thus ready to convert to fuel cells if and when the technology becomes economically cost effective. The existing CNG fuel cylinders can be used to store hydrogen and one or more of the 1,200 HP nzNGPM's can be replaced with a zero emissions fuel cell power module (zeFCPM).