RailPAC
Rail Passenger Association
of California and Nevada

P.O. Box 22344
San Francisco CA 94122

www.railpac.org

U.S. Environmental Protection Agency
EPA Docket Center, OAR, Docket EPA–HQ–OAR–2023– 0574,
Mail Code 28221T, 1200
Pennsylvania Avenue NW
Washington, DC 20460

Email: a-and-r-docket@epa.gov

April 4, 2024

Subject: RailPAC comment letter to EPA on California In-Use Locomotive Regulation, Docket ID No. EPA–HQ–OAR–2023–0574

The Rail Passenger Association of California and Nevada (RailPAC) is a 501c3, all-volunteer group of railroad professionals and advocates that has campaigned for improved mobility since 1978. RailPAC has long advocated for increased rail transportation as an environmental solution, and for rail electrification.

RailPAC recommends that EPA deny the California Air Resources Board (CARB)'s authority to implement its proposed regulations in lieu of EPA's locomotive regulations. This may seem counterintuitive, but we feel if EPA approves the CARB's regulations it is by default approving CARB's hydrogen rail strategy, instead of proven rail electrification technology. The problem with the hydrogen strategy is that it is technologically risky and likely not economically viable which means a continuation of diesel locomotives well past 2050.

Clearly diesel locomotive pollution around California railyards and busy mainlines in populated areas can be quite severe, with direct public health impacts. And while the State of California should be able to protect its own citizens from the harmful effects of locomotive emissions, the path that CARB has chosen will not succeed in reducing diesel locomotive pollution. The preferred long-term option for 'zero-emissions' rail propulsion at CARB and Caltrans, and among some freight railroads, is hydrogen. CARB's hydrogen-focused initiative will not fulfill the zero-emission goal. RailPAC has been very critical of this, as described in more detail in RailPAC's comments on the Draft 2023 California State Rail Plan[1], and the attached white paper titled "RailPAC Analysis of California Air Resources Board (CARB) Reports and Policies on Rail Transportation".

California needs a clear statewide plan for electrifying rail using proven, reliable technology. CARB, Caltrans and the railroads have not been supportive of conventional rail electrification using overhead 'catenary' wire, or overhead contact system (OCS). If they had embraced this proven zero-emissions rail propulsion technology, used for all types of rail operations around the world, the current dispute between the parties could have been avoided. Overhead catenary systems are the global gold standard and the only technology able to meet the long-term requirements of high-volume mainline freight and passenger systems. Both the BNSF Railway and the Union Pacific Railroad have both publicly stated that CARB's rules requiring zero-emissions locomotives by 2035 are an undue burden because practical heavy-duty electric freight locomotives "do not yet exist". Incredibly, CARB itself has long perpetuated this same false assumption, as detailed in the attached RailPAC white paper.

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[1] https://www.railpac.org/2023/05/11/railpac-submits-comment-letter-on-draft-2023-california-state-rail-plan/

All-electric freight locomotives (using overhead catenary wire), with far greater power capabilities than any in UP and BNSF's present diesel fleet, have in fact been successfully used for decades around the world. The European Union has electrified over half of its total railroad network including long-distance lines with OCS. Most of the world's largest countries have electrified their primary railway routes. China, Russia, India, and South Africa have extensive electrified rail networks powering the majority of their rail traffic.

The world's most powerful locomotives are all-electric, pulling 40,000-ton iron ore trains (about twice the weight of any US freight train) in South Africa and Australia. A 50 kV AC overhead wire would be the most economic and practical way to power very heavy electric freight trains, such as a 15,000-to-20,000-ton freight train up Cajon Pass that uses up to 30 MW of continuous power for over an hour. Modern 50 kV electrification for heavy freight rail was first used in this country in 1973, and linehaul electric freight rail trains were running at least 60 years before that. The Black Mesa & Lake Powell coal railroad, on the Navajo Nation in Arizona, was shut down in 2019[2]. The similar 33-mile Deseret Power Railway, between Utah and Colorado, is still in operation with four 50 kV GE E60s[3]. Also on the Navajo Nation in New Mexico is the 13-mile electric Navajo Mine Railroad, still in operation using four 25 kV GE E60 locomotives[4].

US Class I railroads have long operated freight under electrified wire, even if the locomotives themselves are diesel (the last Conrail electric train ran in 1981). Freight trains regularly run on the Northeast Corridor and several of its branches, including double-stacked container trains in Pennsylvania. Between Los Angeles and Fullerton (22 miles), BNSF Railway has agreed to California High Speed Rail Authority (CHSRA) installing OCS over tracks on the busy Southern Transcon mainline it owned by the Class I railroad, with the overhead catenary wires high enough for double-stacked container freight trains to run under them. Union Pacific is already operating freight trains on the Caltrain corridor under the energized 25 kV catenary wires.

Both California High Speed Rail Authority and Brightline West 25 kV OCS systems are soon to begin construction. Caltrain electrified service begins this fall (51 miles vs. 9 miles route for the SBCTA Arrow hydrogen unit), meanwhile construction will begin this year on about 350 miles of OCS between California HSR and Brightline West. Either testing (CHSR) or actual service (Brightline) will begin in 2028 – 350 miles of OCS for HSR vs. 119 miles of hydrogen for Valley Rail.

Tests of hydrogen and battery-electric yard switcher locomotives are currenting planned in California. However, also needed is test installation of OCS on a freight line (such as the Alameda Corridor and Cajon Pass) and tests of battery electric with pantograph, first as part of a diesel and battery electric consist and then later battery-OCS power consists.

The often-argued main drawback of electrification is the upfront capital cost of overhead wire and supporting electrical infrastructure but once installed this is long lived. In the case of the recent Caltrain Modernization Program between San Francisco and San Jose, the rail electrification infrastructure cost

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[2] https://www.trains.com/trn/news-reviews/news-wire/26-final-effort-to-save-black-mesa-lake-powell-fails/
https://en.wikipedia.org/wiki/Black_Mesa_and_Lake_Powell_Railroad
https://navajotimes.com/biz/ngs-coal-train-operators-will-miss-best-job-in-the-world/

[3] https://www.thedieselshop.us/DesPower.HTML
https://en.wikipedia.org/wiki/Deseret_Power_Railway

[4] https://en.wikipedia.org/wiki/Navajo_Mine_Railroad

was about $20 million/route mile, much higher than the world average and easily the most expensive rail electrification project (per mile) in history. However, one of the main reasons for this is the relatively limited experience in the US with electric mainline rail construction and technology. This cost can conceivably be lower for a well-planned and managed and implemented project. Also important to cost control is an industrial supply chain and ecosystem of experienced, competing contractors, manufacturers, and vendors who know how to provide rail electrification economically. In Germany for example, the wage scales, material costs, and environmental regulations are similar to those in California, yet the cost of overhead wire catenary and supporting infrastructure is much less: as low as $2 million/route mile. India has electrified 45% of its railway network in just the past five years, with- all the mainlines in the (not small) country electrified by the end of 2024[5]. India is showing how rail electrification can be successfully implemented at a reasonable cost and relatively quickly when there is an organized program of "mass production", with positive economics of scale and skills development in contractors, suppliers, vendors, manufacturers, etc.

'Discontinuous electrification' can be undertaken as a strategy to transition from diesel and battery units can be undertaken as a transition strategy going from diesel and battery power consists with small amounts of catenary to all battery units with more catenary to all electric with 100% catenary. A derisking financing strategy combined with a 'discontinuous electrification' program would make zero-emissions passenger and freight rail operations practical and economical through staged implementation.

The argument that overhead catenary wire is too expensive to install and maintain is not borne out by the evidence of rail operations around the world. It must be emphasized that the many countries who have electrified their rail networks did so primarily because it proved to be more economical than comparable diesel power on heavily used lines, while also improving performance. With their better acceleration relying on overhead wire electric propulsion, more trains per hour use a particular stretch of track. This is especially true for stretches with mountain grades or frequent station stops. *Historically, rail electrification schemes were not built for the sake of being zero-emissions, but because it was simply a better lower cost way to run a railroad*. However, smoke-free operation was always a welcome quality; and in more recent times that has become a significant consideration.

The experience of rail electrification around the world has shown that not only is the capital cost justified with high enough frequency of trains, but that the lower operating and maintenance costs of electric locomotives will result in lower costs over the long run. The high upfront capital costs for rail electrification need to be viewed in the context of the several-decade lifespan of the infrastructure investment, the cumulative avoided cost of diesel fuel, locomotive maintenance and the pollution impacts of diesel locomotives over the same period.

The amortization period of the catenary infrastructure is typically up to 30 years. However, the structures and equipment can last much longer. There are examples of electric rail infrastructure and rolling stock (locomotives, multiple-unit trains, and streetcars) still operating more than 100 years after they were built. A proper economic analysis of a rail infrastructure capital project looks at a lot of different numbers to determine benefit/cost ratio and return on investment: time value of money, interest rates, inflation, locomotive unit cost, operation and maintenance costs, how often components have to be replaced, rail traffic projections, etc. The electrification of the BNSF mainline between Fullerton and San Bernardino, and the Metrolink San Bernardino Line for example, and other freight/passenger shared tracks in California, are all opportunities for public-private partnerships. These could leverage CHSRA's planned electrification investments in the region.

[5] https://www.energymonitor.ai/tech/electrification/how-india-made-45-of-its-railway-network-electric-in-just-five-years/

To address the initial construction cost issue, CARB. Caltrans, USDOT, USDOE and the freight railroads should be challenged to develop a financing package to dramatically derisk the impact of installing OCS systems on the freight railroads' financial position while construction is underway. They should also be challenged to undertake initiatives to reduce the cost of OCS installation including legislation. Partnerships between private railroad corporations, public agencies, electric utilities and financial institutions would spread the financial risks and costs over multiple parties.

A good finance model will get a 'rolling program' rail electrification program going. That's the only way we will see costs fall to the level of international OCS projects. Countries around the world who have electrified railways in recent years at fraction of the cost of the handful of relatively recent U.S. projects.

Unfortunately, CARB and Caltrans staff seem to be also operating under the same false assumption as the freight railroads: that heavy electric freight rail is not yet commercially viable, despite its history in this country and current practice around the world. Somehow the Golden State's present-day network of light rail lines, and now the Caltrain and new OCS installation and Central Valley HSR and Brightline West OCS rail electrification projects in the works, often are forgotten in discussions on "zero emissions rail" in California. By not embracing proven rail electrification technologies, CARB is undermining its own case.

Battery-electric power will find applications beyond current pilot deployments of yard switcher locomotives, including locomotives and trainsets with both batteries and pantographs. Locomotives, multiple-unit trains and streetcars using both overhead wire, and battery power on sections of track without wire, have been introduced over the past decade around the world.

Hydrogen and battery(only) powered locomotives and multiple units have their best applications in lightweight and short distance zero-emissions applications (railyard switching, branch lines). For heavy freight or genuinely high frequency or fast passenger rail going mush distance, the overhead wire is essential.

California public rail agencies have begun using "renewable" diesel fuels from recycled vegetable oil and fats are better than fossil fuels. Combined with a Tier 4 or rebuild, biofuel is cleaner than petroleum-diesel powered locomotive in terms of certain criteria emissions (though not significantly reducing greenhouse gas emissions) – more so if combined with mode shift. CARB lists renewable fuel as a transition fuel, so it passes muster as a solution to gain time before final rules are developed. The time could be spent in constructing overhead catenary. And biofuel in the near-term in no way justifies delay of planning mainline electrification. It really is a short-term 'stop-gap' measure before electrification is phased in across the rail network.

Finally, there needs to be a expanded focus on financially assisting the short-lines and industrial locomotives with the transition to zero-emissions. Generally, these are the oldest and dirtiest locomotives. Small short-line railroads also have little money to invest in expensive new equipment. There should be a limited exception for historic preservation and tourist railroads.

Notably, CARB ignores the significant impact of mode shift (from highway to rail) on both criteria and GHG emissions. In their insistence on hydrogen as a "zero emissions" rail propulsion technology, CARB and Caltrans seem to view the current level of railroad transportation in California (both passenger and freight) as static and never increasing; or even worse, decreasing because trains are seen as a pollution problem to be regulated and restricted.

CARB has asserted recently, in several recent planning and policy documents, the critical importance of reducing vehicle miles travelled (VMT) in California. However, CARB has never really recognized the need to accomplish this in part by *increasing* the overall number of regional/intercity passenger and freight trains in California. Substantial VMT reduction cannot possibly be achieved without greatly shifting much passenger and freight transport now on roads to rails.

CARB, EPA and other regulatory agencies should emphasize the key pollution and grid benefits of mode shift. Like the auto companies, the railroads should get credits for initiatives to shift traffic from truck to rail, especially local intrastate California traffic like container shuttles to inland ports.

CARB is currently actively against modal shift and unfortunately so are many communities. The agency's rules effectively punish a passenger operator for running more service with diesels, no matter how many cars said service would take off the road.

CARB has repeatedly emphasized that they only care about tailpipe emissions at the vehicle, and not where the electricity or hydrogen comes from (or how much energy, water or emissions is used to produce it). CARB has also never publicly acknowledged the energy efficiency difference of rail vs. road travel. Why do they not mention how much more electricity it would take to move the same tons of cargo via electric rail vs electric truck? They of course assume that electric trucks would be 100% powered by renewable energy, yet the 2016 CARB locomotive report tried to denigrate electric freight rail by implying new coal-fired plants would have to be built to power it. "Zero-emissions trucks" all have an embedded GHG emissions footprint for their manufacture and mining of materials. The lifecycle GHG emissions of "zero-emissions" trucks will thus will not be zero.

Particulates from tire and road wear are a significant source of particle pollution from trucks and a problem completely avoided by trains. CARB and Caltrans need to consider tire and road wear pollution in their environmental evaluation of trucks.

Sincerely,

Brian Yanity, Vice President-South

Rail Passenger Association of California and Nevada (RailPAC)

RailPAC Analysis of California Air Resources Board (CARB) Reports and Policies on Rail Transportation:

Why CARB has long been an obstacle to rail electrification and sustainable rail transportation in California

RailPAC
Rail Passenger Association of California and Nevada

April 2024

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California needs to follow the rest of the world with overhead wire rail electrification.

With California's electrical grid moving toward Zero Emissions, electrification with overhead catenary wire is the most effective way to accelerate the move to zero emissions operations of the state's mainline passenger and freight trains because its efficiency will require less grid expansion. This synergy is being proven around the world. It is unfortunate that unproven hydrogen technology seems to be the primary "zero emissions" rail technology option considered by the California Air Resources Board (CARB) and Caltrans for the state's intercity and regional trains. CARB's rationale for this is opaque at best.

In recent years CARB has repeatedly published incorrect factual claims and outright misinformation about electrification of railroads, particularly overhead wire electrification, and the real prospects for hydrogen propulsion. This myopia ignores successful applications of overhead catenary wire electrification, also referred to herein as overhead contact system (OCS), around the world and in the US. Rather than being an emerging technology, overhead catenary wire railroads are the modern descendants of over a century of operation in California and the US. Instead of expanding this proven technology, CARB and Caltrans have advocated a largely untested technology, hydrogen propulsion, despite the lack of even a minimal existing hydrogen fuel infrastructure (other than truck delivery) and other well-known drawbacks.

The laws of physics mean that hydrogen-powered trains will always have inferior energy efficiency because of hydrogen's low energy density compared to other fuels, and the need for conversions of energy to produce hydrogen, then be converted back into useful power. Hydrogen propulsion drive trains are inherently far more complex compared to conventional catenary electric trains, and by the limited power output of onboard fuel cells compared to an all-electric drivetrain fed by an external source. Hydrogen is also inherently limited by its low energy density compared to other fuels. Hydrogen trainsets are several times more expensive to acquire, operate and maintain than a standard electric (overhead catenary train. Other disadvantages stem from the inherent complexity of hydrogen supply chains, on-board storage systems, and drivetrains. More complicated systems onboard mean more potential points of failure and higher costs, as was shown recently in Germany. Future technological developments will not change these realities.

Environmental justice and safety issues are also presented by hydrogen tanks, pipelines, and storage facilities. Hydrogen is a flammable and potentially explosive gas that leaks easily. The risks of hydrogen leaks and explosions to crews, passengers, and trackside communities have yet to be fully evaluated.

Electric trains, powered by overhead wires or third rail, are the most energy efficient way of rapidly moving large numbers of people over land. A conventional OCS electric train does not have to store its fuel supply onboard and carry its weight. Instead, it takes its energy from an external source, as needed, where the energy goes straight to the traction motors. With fewer moving parts, electric trains have proved to be much more dependable than diesel- powered trains. Also, electric energy can be supplied from a variety of sources including renewables. Trains can also regenerate electric power during braking and feed electricity otherwise dissipated as heat back into the grid.

Electric, zero-emissions rail transportation is a proven technology over a century old, in widespread (and growing) use throughout the world. Despite being well established, electric rail also has been called a 'future proof' technology. Not only are electric trains quieter, emit no emissions, and have far greater overall energy efficiency, but they can also accelerate faster than diesel-powered trains and have lower operations and maintenance costs. Faster acceleration enables more capacity for a section of track and increased train frequency as a result of improved equipment utilization. Passenger rail lines relying exclusively on diesel-powered trains are limited in their speed, capacity, and capability. Heavy battery or hydrogen powered trains will face the same limitations.

Given that the largest contributors to greenhouse gas (GHG) emissions in this state are cars and trucks powered by fossil fuels, it is essential not only to increase use of electrical propulsion, but also to simultaneously shift substantial amounts of freight and passenger transport to rail. Rather than continuing as a source of pollution, railroads must play a large role in the solution.

The "sparks effect" is the phenomenon, documented around the world, of marked increase in passenger ridership following electrification due to:

- Increased train speed and frequency because of better acceleration
- Passenger comfort (quieter, smoother ride, no smoke)
- Increased reliability (fewer train breakdowns)
- Lower equipment, operations and maintenance costs, enabling investment in more frequent service

In the US, overhead wire rail was implemented more than a century ago. Several light rail systems using OCS are in operation in California, and OCS is the primary propulsion in Amtrak's Northeast Corridor. Fortunately, Caltrain, the California High Speed Rail (CHSR) project, and Brightline West have all adopted overhead wire electrification, because of its manifest advantages.

In the rest of the world, with its comparatively large reliance on railroads for both passenger and freight, there is no contest. The European Union has electrified over half of its total railroad network including long-distance lines with OCS. Most of the world's largest countries have electrified their primary railway routes. China, Russia, India, and South Africa have extensive electrified rail networks powering the majority of their rail traffic. The International Energy Agency strongly endorses rail electrification worldwide as a strategy to reduce both GHG emissions and fossil fuel consumption[1].

Overhead rail electrification has a successful history In California and the US

The US pioneered long-distance, heavy-duty OCS electric railroading with the Milwaukee Road (pictured below) and other major electric rail projects over a century ago. Regional electric rail systems helped develop California metropolitan areas in the first half of the twentieth century. Pacific Electric freight trains in Southern California operated until the 1950s (see below), and the Sacramento Northern Railway ran electric freight locomotives between Oakland, Sacramento, and Chico until 1965[2]. Somehow these historical examples, and the Golden State's present-day network of light rail lines, and now in the works the Caltrain new OCS installation and Central Valley HSR and Brightline West OCS rail electrification projects, often are forgotten in discussions on "zero emissions rail."

[1] https://www.iea.org/fuels-and-technologies/rail
[2] http://www.wrm.org/about/railroad-history/sacramento-northern-railway

The Milwaukee Road was running electric long-distance freight and passenger trains on 663 miles of electrified track through the Cascades and Rocky Mountains, from 1914 to 1974.

Most of the world's largest countries have electrified their primary railway routes. China, Russia, India, and South Africa have extensive OCS electrified rail networks powering the majority of their rail traffic, including on long-distance lines. The European Union as a whole has electrified over half of its total railroad network miles. The International Energy Agency strongly endorses rail electrification worldwide as a strategy to reduce both GHG emissions and fossil fuel consumption[3].

Over a dozen countries effectively already have all their mainlines electrified. Switzerland has been essentially 100% electric since 1967. Others are spending the equivalent of tens of billions of dollars each year on expanding overhead wire rail electrification. A wide variety of rail operations around the world, from South Africa (which operates all-electric 40,000-ton iron ore trains, twice as heavy than any U.S. freight trains), to India, China, Europe, Japan, Korea, etc., have shown that OCS on main lines is overall less expensive than maintaining and operating an all-diesel fleet for an equivalent level of heavy service on main lines. This has

[3] https://www.iea.org/fuels-and-technologies/rail

been proven reliable in all types of terrain and weather conditions. An OCS electric locomotive also can have much greater power per unit than diesel, so fewer locomotives are needed on a multi-locomotive train to do the same job. In fact, all of the world's most powerful locomotives are electrics using OCS. The 'fuel cost' is much less; and since OCS electric locomotives have so many fewer moving parts, they are far less costly to maintain. There are costs to maintain a catenary overhead contact system, but it is more expensive to maintain diesel locomotives than electrics. This shows in most cases that the overall maintenance cost of an all-electric, frequently-used railroad line, including overhead wire maintenance, is significantly less than using diesel power. Also, since electric trains require less maintenance, they spend less time in depots, resulting in higher equipment availability and even a slightly smaller fleet size. Given the complexity of hydrogen locomotives, an expectation for higher maintenance costs should be factored into the cost analysis.

Electric freight trains were once a common sight in California:
Local freight train pulled by electric locomotives in South Los Angeles, 1953, operated by the Pacific Electric Railway, which was then owned by the Southern Pacific Railroad.
(Photo: Pacific Electric Railway Historical Society)

The total length of mainline railway electrified in the US is about 1,500 miles. In the Northeast US, the Northeast Corridor is electrified for 457 miles between Washington, D.C. and Boston, as is the Keystone Corridor between Philadelphia and Harrisburg, parts of the SEPTA system around Philadelphia, New Jersey Transit, Metro North, and the Long Island Railroad. The Chicago area is served by two regional electric rail lines (the Metra Electric and the South Shore Line). More recently, Denver RTD has constructed a 25-kV electric regional rail system over 54 miles in length. Some of these overhead line systems were installed many decades ago, which demonstrates the longevity of this sort of equipment. The 39-mile, 50 kV Deseret Power Railway in Colorado and Utah carries coal from a mine to a power plant and is isolated from the national rail network.

Railroad electrification around the world (both passenger and freight combined, as of 2022)[4]

Country	Miles Electrified (approx.)	Percentage Electrified
Ethiopia/Djibouti	470	100%
Armenia	435	100%
Switzerland	3,200	99%
Laos	256	98%
Belgium	1,900	85%
India	34,300	83%
Georgia	800	82%
Italy	8,200	79%
South Korea	2,300	78%
Sweden	7,600	76%
Netherlands	1,400	76%
Japan	12,500	75%
Taiwan	800	73%
Bulgaria	1,800	71%
Portugal	1,100	71%
Austria	2,400	69%
North Korea	2,400	68%
Norway	1,600	68%
Spain	6,900	68%
China	62,000	67%
Poland	7,500	65%
Azerbaijan	790	60%
Bosnia and Herzegovina	350	56%
Germany	14,000	55%
Finland	2,000	55%
France	9,700	54%
Russia	27,200	51%
Morocco	630	49%
South Africa	5,900	47%
Ukraine	5,800	47%
Slovakia	1,000	44%
Turkey	3,400	43%
Uzbekistan	1,600	39%
United Kingdom	3,800	38%
Israel	155	18%
Iran	1,400	17%
United States	**1,500**	**< 1 %**

[4] References on rail electrification statistics by country:
https://www.cia.gov/library/publications/the-world-factbook/fields/2121.html
http://uic.org/IMG/pdf/synopsis_2015_print_5_.pdf
http://statbel.fgov.be/fr/statistiques/chiffres/circulation_et_transport/transport/ferroviaire/
https://core.indianrailways.gov.in/
https://www.sciencedirect.com/science/article/abs/pii/S0360544221006125
https://www.infraestruturasdeportugal.pt/pt-pt/infraestruturas/rede-ferroviaria
https://en.wikipedia.org/wiki/List_of_countries_by_rail_transport_network_size

"When they did get to run, the EMD freight electric locomotives showed the designs were more than viable": 6,000 hp GM6C on Conrail, Feb. 11, 1979, at Middletown, Pennsylvania
(photo: Stephen J. Salamon , David P. Oroszi collection),
from "Testing EMD electric freight locomotives",by Preston Cook, May 31, 2022, Trains.com:
https://www.trains.com/ctr/railroads/locomotives/testing-emd-electric-freight-locomotives/

Arizona's Black Mesa & Lake Powell Railroad electric General Electric (Wabtec) E60 50 kV 6,000 hp locomotives, which ran from 1973 to 2019

The often-argued main drawback of electrification is the upfront capital cost of overhead wire and supporting electrical infrastructure, but once installed this is long-lived. There are examples of electric rail infrastructure and rolling stock (locomotives, multiple-unit trains, and streetcars) still operating more than 100 years after they were built. As part of the recent Caltrain Modernization ('CalMod') Program between San Francisco and San Jose, the electrification infrastructure cost was about $20 million/route mile, much higher than the world average and easily the most expensive rail electrification project (per mile) in history. However, one of the reasons for this is the relatively limited experience in the US with electric mainline rail construction and technology. This cost can conceivably be lower for a well-planned and managed and implemented project. Also important to cost control is an industrial supply chain and ecosystem of experienced, competing contractors, manufacturers, and vendors who know how to provide rail electrification economically. In

Germany for example, the wage scales, material costs, and environmental regulations are similar to those in California, yet the cost of overhead wire catenary and supporting infrastructure is much less: as low as $2 million/route mile. Thus the high Caltrain electrification costs should not be used as the universal benchmark for all other California rail electrification projects moving forward. India has electrified 45% of its railway network in just the past five years, with- all the mainlines in the (not small) country electrified by the end of 2024[5]. India is showing how rail electrification can be successfully implemented at a reasonable cost and relatively quickly when there is an organized program of "mass production", with positive economics of scale and skills development in contractors/suppliers/vendors/manufacturers, etc.

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CARB has long been dismissive of proven rail electrification and the environmental benefits of rail transportation

The state of California needs to develop and implement policies that will electrify the California rail network. The emphasis should be on conventional overhead wire electrification for mainline railroads. Hydrogen and battery-powered locomotives and trains have a very limited range, and are much more expensive to purchase, operate, and maintain, compared to conventional all-electric locomotives using OCS.

For years, CARB, other California public agencies, and the freight railroads have denied the existence of practical rail electrification for passenger and freight as practiced widely around the world. Both Caltrans and CARB's longstanding obstinance and obscurantism regarding rail electrification has caused lasting environmental damage to the state, and real harm to communities near rail yards and tracks. Given the widely documented public health impacts of diesel pollution from locomotives, it has probably cost Californians' lives. However, a broader issue than the question of zero-emissions rail is that CARB has always viewed rail transportation as a pollution problem, rather than inherently a solution. CARB also has refused to acknowledge that a mode shift, from trucks and cars to trains, even if diesel powered, greatly reduces GHG emissions. Caltrans and CARB have always made it clear that they want hydrogen power to be used instead of overhead wire electrification, and not as a complement to it. Fortunately, Caltrain, CHSRA, and Brightline West are ignoring this and proceeding with 25 kV electrification. The focus should be the technology that is seeing the most miles of advancement, Overhead Catenary Systems. Caltrain electrified service begins this fall (47 miles vs. 9 miles hydrogen unit for Arrow), meanwhile construction will begin this year on about 350 miles of OCS between California HSR and Brightline West. Either testing (CHSR) or actual service (Brightline) will begin in 2028 – 350 miles of OCS for HSR vs. 119 miles of hydrogen for Valley Rail.

[5] https://www.energymonitor.ai/tech/electrification/how-india-made-45-of-its-railway-network-electric-in-just-five-years/

In their insistence on hydrogen as a “zero emissions” rail propulsion technology, CARB and Caltrans seem to view the current level of railroad transportation in California (both passenger and freight) as static and never increasing; or even worse, decreasing because trains are seen as a pollution problem to be regulated and restricted.

CARB has asserted recently the critical importance of reducing vehicle miles travelled (VMT) in California. However, CARB has never really recognized the need to accomplish this in part by *increasing* the overall number of regional/intercity passenger and freight trains in California. Substantial VMT reduction cannot possibly be achieved without greatly shifting much passenger and freight transport now on roads to rails.

Ideologically, this represents a "we can just green the status quo" thinking. But the status quo has more problems than vehicle tailpipe emissions--land use and affordability--that are actually worsened by limiting rail transportation. Proponents of hydrogen rail at least in part justify it based on idea that the current "aesthetic" status quo can continue (ie., have no "ugly" wires over railroad tracks), and also that severe restrictions on rail capability and capacity are advisable.

California public agency “zero-emissions” rail technology studies are skewed very heavily in favor of short hydrogen multiple units. Such units would not have sufficient long-term throughput and range needed for a passenger line with mountain grades like the Metrolink Antelope Valley Line, especially considering that other planning documents call for 8-car sets and massive capacity increases at stations. At the same time, increased frequency has proven to induce higher ridership on California intercity/regional rail and rail transit system. With California intercity+regional rail presently a low-throughput system--by global standards--it's also appealing to a type of suburban mindset ("environmental means low rise and fewer people"), which some old-guard environmentalists retain. Increased throughput (and by extension high ridership yields, lowered fares from lower operating costs/higher ridership, and creation of equity/opportunity through increased frequency and decreased cost barriers) has been the primary reason for favoring overhead electrification to other systems. To an extent, hydrogen fails to provide the same throughput even that diesel power has at present in California, which itself isn't all that good.

California needs to expand electrification of the rail network, with conventional overhead wire electrification as its backbone, combined with catenary-battery hybrids for relatively short unelectrified sections and branch lines. Rail and environmental advocates have long been CARB and Caltrans, in written and oral public comments, that there needs to be a comprehensive 'bullet proof' statewide plan for phasing in rail electrification, using **proven** technology. If these public servants had not been so dismissive of rail electrification and rail transportation generally, as well as those advocating for it, perhaps they wouldn't be in as difficult a position as they find themselves now, with the freight railroads suing them.

CARB is incorrect in treating heavy duty zero-emissions rail propulsion as an “emerging technology”

Unfortunately, CARB seems to deny that practical, economical heavy electric freight rail technology is in widespread use throughout the world. As stated on the CARB fact sheet “Incentive Funding for New Technology”[6], “Based on development timelines for new technology, CARB staff estimate that ZE passenger and switch locomotives would be commercially available by 2030, and ZE line haul locomotives by 2035.” Why are CARB staff assuming that we must wait until 2035 for zero-emissions line haul freight locomotives? Between the years 2014 through 2016 Amtrak electric locomotives were constructed by Siemens in the Sacramento area

[6] https://ww2.arb.ca.gov/resources/fact-sheets/carb-fact-sheet-locomotives

(shown below), only about 13 miles from CARB's headquarters. Siemens, Alstrom (Hornell, NY) and Stadler (Salt Lake City) all have powerful electric locomotives in their global portfolios. Electric locomotives are available right now from a range of major locomotive builders worldwide.

Amtrak ACS-64 mainline electric locomotive manufactured at the Siemens plant in Florin California. This plant is about 13-miles from CARB's headquarters in downtown Sacramento.

Overhead wire rail electrification is a proven technology over a century old, used successfully by many heavy-duty freight rail operations around the world. Most of the major railways of the world outside of the Americas electrified their mainlines long ago. The world's most powerful locomotives are all-electric, pulling 40,000-ton iron ore trains (about twice the weight of any US freight train) in South Africa and Australia.

A 50 kV AC overhead wire would be the most economic and practical way to power the heaviest electric freight trains up steep grades, such as a 15,000-to-20,000-ton freight train up Cajon Pass that uses up to 30 MW of continuous power for over an hour. 50 kV electric iron-ore trains weighing over 40,000 tons have been in operation in South Africa for decades. The more standard 25 kV (the same voltage as Caltrain, CHSR, and Brightline West) can effectively power most heavy freight trains on routes with less grades. It is also possible for locomotives with 'dynamic' transformer taps to switch voltages en route. Some electric locomotives in operation today (including on the NE Corridor) can switch to different supply voltages, along different parts of the line, to allow flexibility in operation.

Modern 50 kV electrification for heavy freight rail was first used in this country in 1973, and linehaul electric freight rail trains were running at least 60 years before that. The Black Mesa & Lake Powell coal railroad, on the Najavo Nation in Arizona, was shut down in 2019[7]. Unfortunately, their GE 50 kV locomotives were scrapped. The similar 33-mile Deseret Power Railway, between Utah and Colorado, is still in operation with four 50 kV GE E60s[8]. Starting in the late 1990s, both of these Southwestern isolated electric coal railroads purchased some used GE electric locomotives from Mexico, which were converted to 50 kV. Also on the

[7] https://www.trains.com/trn/news-reviews/news-wire/26-final-effort-to-save-black-mesa-lake-powell-fails/
https://en.wikipedia.org/wiki/Black_Mesa_and_Lake_Powell_Railroad
https://navajotimes.com/biz/ngs-coal-train-operators-will-miss-best-job-in-the-world/

[8] https://www.thedieselshop.us/DesPower.HTML
https://en.wikipedia.org/wiki/Deseret_Power_Railway

Navajo Nation in New Mexico is the 13-mile electric Navajo Mine Railroad, still in operation using four 25 kV GE E60 locomotives[9].

535-mile Sishen–Saldanha OREX line, South Africa: 40,000 ore trains in continuous operation under 50 kV catenary since 1976 (Photo: Peter Ball)

One of the world's most powerful locomotives: China Railways HXD1 series 12,900 hp freight two unit locomotive set, which by itself under 25 kV overhead catenary wire pulls 20,000 ton trains
(Photo: https://commons.wikimedia.org/wiki/File:HXD10004.jpg)

While the cost of rail electrification varies by route, the benefit/cost ratio is generally quite positive on lines with heavy rail traffic. The upfront capital cost is also something that is possible to be paid back over a minimum period of 30 years or less, but the analysis must also factor in the much lower O&M costs of electric locomotives compared to diesel. For example, India has enough capital to complete electrification of all their mainlines by the end of next year[10]. India has been steadily electrifying thousands of route miles every year, something which US railroads claim is impossible and prohibitively expensive (though they provide no

[9] https://en.wikipedia.org/wiki/Navajo_Mine_Railroad

[10] https://wap.business-standard.com/article-amp/indian-railways/indian-railways-net-zero-goals-hinge-on-electrification-solar-storage-121110201480_1.html

economic analysis to back up that claim). In overhead electrification is the "gold standard" for performance, efficiency, and economical operation of frequent and heavy train service.

California public agencies' perpetual, irrational rejection of rail electrification, led by CARB, is often noted (off the record) by international rail experts, engineering consultants and manufacturers. An example appeared in a 2021 blog post piece by world-renowned rail and transit expert Alon Levy titled "California Gets Electrification Wrong"[11]. One of the commenters on Levy's post argued that Caltrans, CARB, and other public agencies in California need to challenge the Class I railroads on electrification:

> This is exactly why American passenger rail infrastructure is terrible: public servants see their job as "working within the existing constraints." This is why their lunches are absolutely devoured by self-centered sociopaths who refuse to acknowledge any rules, like Elon Musk, or Travis Kalanik, or the late Steve Jobs.
>
> If the existing constraints don't let you do the right thing, your job is to *change the existing constraints*. Don't go publishing reports that downplay the advantages of the Right Thing. Make detailed, clear, unequivocal arguments for the right thing. Give politicians the ammunition to demand that freight owners get out of the way. Give the public ammunition to demand better of their politicians. Make sure nobody can even think about the problem without the immediate thought "Oh but this constraint is stupid, why do we even have it?"
>
> Outside of technical physics, feasibility is a matter of political will and consensus, which is a matter for the politicians to worry about. Expert bodies' recommendations should be based on their technical expertise, not on doing the politicians' job for them…
>
> Any report that says "electrification is not feasible system-wide" instead of "electrification would be far superior to the alternatives listed here but requires state regulation of private monopolists" is demonstrating either ignorance or careerist cowardice. The former should be a firing offense; and the latter can be corrected for by making it also a firing offense: Courage is simply being more afraid of running away than of facing the threat.

The real leaders in clean rail propulsion are the major railroads around the world, which have operated the bulk of their mainline passenger and freight trains with electricity. Technical expertise, manufacturers, vendors, and construction managers experienced in rail electrification from around the world need to be brought to California. We don't need to re-invent the wheel. The knowledge is already out there, and the same goes for providers of economical and reliable rail electrification technology.

The Class I railroads can be challenged on electrification

In discussions about rail electrification in North America, private track ownership is often assumed to automatically bar electrification. It seems as if the Class I roads always come up with an excuse not to electrify.

North American Class I railroads have a history of rolling out experimental, highly publicized (and publicly subsidized) "green" locomotives which then fail, or at least turn out to be major disappointments in real-world revenue service. These results are then used as an excuse to say: "We tried that and it didn't work, so we can only do diesel", while throwing up their hands and saying conventional electrification is prohibitively expensive. They never show any real economic analysis of why that is so, despite it being proven to be more economical than diesel all over the world for moving heavy freight. The powers that be in America accept the excuse, as it fits nicely with Wall Street's need to minimize railroad capital expenditure to maximize short-term yields and keep using only diesel locomotives. This cycle has been repeated several times since the energy crisis of the 1970s. Meanwhile the portion of rail powered by electricity keeps growing in the rest of the world,

[11] https://pedestrianobservations.com/2022/01/29/quick-note-california-gets-electrification-wrong/

while here in North America, aside from a handful of exceptions, diesel is still in use everywhere. Though diesel emissions and fuel economy per mile of North American railroad operations have improved somewhat, diesel exhaust is still awful and includes GHG emissions that can easily be eliminated with electrification.

Utilizing whatever alternative fuel or propulsion technology is trendy at the time (diesel multi-gensets, CNG, LNG, hydrogen), the Class I railroads have in reality offered only locomotive options that are distractions. They are intended to fool the public, government officials, and even environmental groups into thinking the US doesn't need mainline rail electrification. These audiences are perhaps somewhat easily misled, because North Americans are largely unfamiliar with electric rail technology around the world. But, especially with the climate crisis, times are changing. Such out-of-date assumptions must be challenged with facts.

In its Rail Project Dashboard[12], CARB makes the astounding claim that only 22 overhead catenary locomotive projects exist in the world, compared to 25 hydrogen and 32 battery-electric locomotive projects. In fact, there are tens of thousands of electric locomotives operating freight and passenger trains all over the world each day, very reliably and economically. There are many experienced vendors, manufacturers in the US and around the world who know how to provide reliable and economical electric rail. By contrast, there are no experienced providers of hydrogen locomotives, just a handful of dubious locomotive-scale experiments and the lightweight Stadler and Alstom hydrogen multiple units. Battery rail propulsion is not much more developed. When it comes to heavy rail, we cannot waste precious time tinkering with technologies that we already know won't be a real solution. We need to start planning right away for overhead wire installation on the nation's main rail lines.

The problem in North America is the financial/political bias against any kind of capital expenditure by private railroad companies that does not have a return on investment period of five years or less. This has hampered development not only of electrification, but also investments in track capacity and new freight terminals that would increase market share, etc. This is an arbitrary business dilemma, imposed largely by Wall Street, that needs to be remedied at the federal level. The rest of the world's railroad tracks are for the most part publicly owned. This makes feasible longer payback of capital investments like electrification, which are ultimately better for the railroad and wider society.

Whatever technical/safety issues that the Class I roads raise up can be resolved. Overcoming the Class I resistance to overhead electrification is not impossible. It has been done and is being done. US Class I railroads have long operated freight under electrified wire, even if the locomotives themselves are diesel (the last Conrail electric train ran in 1981). Freight trains regularly run on the Northeast Corridor and several of its branches, including double-stacked container trains in Pennsylvania. Between Los Angeles and Fullerton (22 miles), BNSF Railway has agreed to California High Speed Rail Authority installed over tracks on the busy Southern Transcon mainline it owns, with overhead catenary wires high enough for double-stacked container freight trains to run under them. UP will continue to operate freight trains on the Caltrain corridor under electric catenary wires, as well as under HSR wires between LA and Burbank.

Especially since the Class I railroads are feeling regulatory pressure lately, it is past time to vocally push back against the tired old corporate intransigence about electrification. The increasingly untenable positions of Class I roads are being publicly exposed by the recent Senate hearings, the Surface Transportation Board cases on Gulf Coast passenger rail, Justice Department litigation, critical railroad industry journalists, poor customer service, and safety problems. The arguments the big freight railroads make against electrification can be debunked with facts and case studies from around the world. Americans in the past few decades seem irrationally adverse to investing in infrastructure (public or private). A lot of that can be attributed to the Wall Street owners of large US railroads, bent on minimizing capital expenditure to maximize short-term profit. They are against electrification much as they are against any reasonable large capital investment, such as installing more track capacity that would grow the business and serve their own customers better. The freight customers of US railroads, including some corporations larger than the railroad companies themselves, have

[12] https://ww2.arb.ca.gov/applications/zero-emission-rail-project-dashboard

thronged the Surface Transportation Board complaining of bad service and price-gouging.

The "Class I's are adamantly opposed" knee-jerk argument has been used for years and years by US public agencies and many others as the excuse for why we cannot even think of overhead wire electrification here. It seems that putting up catenary wires over tracks owned by BNSF or Union Pacific is so unthinkable and assumed to be so horribly expensive that it could never, ever be considered as an option for California corridor and regional trains. Thus, working backwards from that assumption, the only "zero emissions" rail technology that could possibly be considered are unproven hydrogen and battery technology. However, the practicality of these options for rail applications is severely limited by the laws of physics: hydrogen or batteries alone just cannot move a large heavy train very far compared to diesel, and never as fast or as far as an all-electric train. There is also the downside of poorer energy efficiency, more potential points of failure, especially with hydrogen.

Hydrogen and battery(only) powered locomotives and multiple units have their best applications in lightweight and short distance zero-emissions applications (railyard switching, branch lines). For heavy freight or genuinely high frequency or fast passenger rail going mush distance, the overhead wire is essential. Period. Nor will technological advances change this very much. In the end, it is laws of physics which prevent trains powered only by hydrogen or batteries from providing fast enough intercity rail travel for any substantial distance. It is simply irresponsible to keep chasing the illusion that these means of propulsion are viable for heavy or long-distance mainline trains.

It is also high time that freight railroads paid back their debt to society--in particular, the effects of dirty diesel pollution on people who live near the tracks and railyards. The environmental justice pushback to the freight railroads is picking up wide support, especially in the wake of the East Palestine disaster. People are tired of being treated as negligible "externalities" when serious health problems, even death, are caused by railroad operations. The kids with asthma growing up next to railyards don't care about Class I railroads' vague public relations statements on how the greater energy efficiency of rail means that the freight lines should be allowed to continue burning diesel fuel. More elected leaders are taking notice of railroad pollution harming their constituents. The railroad industry will have to face the fact that future traction options available to it will be forced on it externally and won't be part of an internal industry transition, as occurred with steam to diesel. The industry requires guidance, advice, and analysis to support investment decisions and make informed choices. Rail electrification for freight will prevail in the end, especially on heavy mainlines between California ports and inland terminals--the physics and environmental reasons are too strong. The question is whether it can happen soon enough.

The electrification of the Caltrain corridor between San Francisco and San Jose, and subsequent CHSR plans, provide a technical and operational model for statewide passenger rail electrification, by developing experience in electrification construction, implementation and operations. For example, electrification and other upgrades to the Burbank-LA-Anaheim corridor by CHSRA, in collaboration with those made by other public agencies and BNSF, would be a great public benefit to both passenger and freight rail service. The heavy train traffic of this corridor would lead to improved economics and higher utilization of electric rail infrastructure if used by both electric passenger and freight trains.

The 'blended' CHSRA Burbank-Los Angeles-Anaheim-Irvine corridor could serve as a catalyst for electric regional passenger and freight rail for the rest of Southern California. An existing model for "blended services," combining electrified higher-speed/high-speed passenger trains and express freight trains, can be found in Germany and other countries. Freight trains in Germany operate in mixed traffic with commuter, regional, long distance, and high-speed passenger trains on lines with maximum speeds of up to 150 mph. Electric freight trains in Germany typically operate at 60-70 mph.

In Europe, many HSR lines share some of the track with conventional passenger trains or even freight trains, at least in terminal areas. Where the track is shared with other types of traffic, the HSR trains are generally limited to no more than 155 mph. Almost all high-speed rail trains in Europe access city terminals on the conventional network at conventional speeds. However, the general characteristics of freight trains in the US generally prohibit such shared operation. US freight trains are comparatively long, heavy, and slow. Nevertheless, a large amount of lightweight and time-sensitive freight currently hauled by truck in the US could be moved on trains similar to European freight trains, allowing the shared use of conventional trains and some HSR trains. Freight-passenger combination trains should also be investigated for California. For example, express or lightweight freight trains could offer passenger service to underserved rural areas of the state such as the Central Valley and the Central Coast.

There are a variety of possible models for public- private partnerships where the host railroad doesn't have to pay upfront for overhead wire infrastructure. Also, the tracks at the Ports of LA and Long Beach, along with the Alameda Corridor, are entirely publicly-owned, as are other parts of the Metrolink network.

The 2016 CARB reports on locomotive emissions have left a legacy that obstructs support for much-needed rail electrification

In the spring of 2016, CARB released two reports evaluating clean freight rail technology for California[13]. While in some respects an admirable effort on behalf of the state, these two studies had significant shortcomings in evaluating electric freight rail. One of these reports was purportedly written by CARB staff, and the other by University of Illinois Rail Transportation and Engineering Center (RailTEC). Neither CARB nor RailTEC had any prior experience in design, engineering, construction and operation of electric freight locomotives, especially as long practiced outside North America. In the years since these CARB rail reports were released in 2016, they have been heavily criticized by rail experts around the world; and they have caused lasting damage to efforts for zero-emissions rail in California. For example, European freight locomotives tend to be less powerful than their North American counterparts, which leads to a common misconception on this continent that all-electric locomotive technology is not powerful enough for U.S. freight rail. As described by the Spring 2016 CARB RailTEC report[14]:

> One-for-one replacement of conventional diesel-electric locomotives with electric locomotives is conceptually possible if a new generation of purpose-built electric line-haul freight locomotives are developed for the North American market. Current European designs develop sufficient horsepower but lack the number of axles, axle loads and adhesion required to match the tractive effort of a North American line-haul diesel-electric locomotive.

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[13] *Draft Technology Assessment: Freight Locomotives.* California Environmental Protection Agency, Air Resources Board, Transportation and Toxics Division, April 2016.
https://www.arb.ca.gov/msprog/tech/techreport/freight_locomotives_tech_report.pdf

Transitioning to a Zero or Near-Zero Emission Line-Haul Freight Rail System in California Operational and Economic Considerations, Final Report. Prepared for State of California Air Resources Board by University of Illinois at Urbana-Champaign Rail Transportation and Engineering Center (RailTEC), Spring 2016.
https://www.arb.ca.gov/railyard/docs/uoi_rpt_06222016.pdf

[14] *Transitioning to a Zero or Near-Zero Emission Line-Haul Freight Rail System in California Operational and Economic Considerations, Final Report.* Prepared for State of California Air Resources Board by University of Illinois at Urbana-Champaign Rail Transportation and Engineering Center (RailTEC), Spring 2016, pg. 20.
https://www.arb.ca.gov/railyard/docs/uoi_rpt_06222016.pdf

As further discussed by the April 2016 CARB freight locomotive report[15]:

> An all-electric freight line haul locomotive would be powered solely by electrified catenary. Currently, all-electric freight line haul locomotives operate in other parts of the world (e.g., Europe, China, and Russia). However, these locomotives are typically built for greater speeds, to reduce slowdowns for high speed passenger trains that share the same rail electrification system. Therefore, all-electric freight locomotives have significantly less pulling power (i.e., up to two-thirds less –though they are typically higher horsepower for speed) than U.S. diesel-electric freight interstate line haul locomotives.…U.S. freight railroad electrification requires power levels ranging between 18 to 24 MW for per freight train, compared to 6 to 10 MW for freight trains in Europe. The U.S. freight train power level is much higher and will require strong utility networks, traction substations, and catenaries.
>
> The major differences in freight rail electrification in Europe and other countries are the power needs and system design. In most cases around the world, railroad electrification has been built for speed, to support high speed passenger trains. In other parts of the world, all-electric freight locomotives are typically built for speed (i.e., with high horsepower) to reduce congestion and delays for the high speed passenger trains sharing the same electric rail system. This is typically at the expense of pulling power.
>
> For comparison, European all-electric freight trains typically pull about ten times less tonnage (i.e., about 1,000 to 2,000 tons) than U.S. diesel-electric freight trains (i.e., 10,000 to 20,000 tons). A typical European all-electric freight locomotive has about 70,000 pounds of force of pulling power or tractive effort, whereas U.S. diesel-electric freight locomotives can approach 200,000 pounds of force of tractive effort.

The 2016 CARB reports use the example of fast, lighter electric freight trains typical in Europe as the only type of all-electric freight train. What is not discussed are the heavy all-electric freight trains used in China, Norway, Russia, Australia and South Africa, which are more appropriate electrification examples for US freight rail. In fact, the heaviest all-electric ore and coal trains in these countries are much heavier than US line-haul freight trains. As noted above, electric locomotives can and do in fact have higher horsepower, tractive effort and adhesion than what diesel units are capable of.

Europe's relatively small freight train sizes arise from circumstances particular to that continent's railroad network, not because of the limitations of electric locomotive technology. European freight train length and weight are limited by the infrastructure they run on, and limited in distance travelled, due to still-remaining differences in rail standards between European countries. To allow for a higher volume of passenger traffic, European freight and passenger trains sharing the same track operate at similar speeds, and braking distances are similar for all trains. Consequently, European freight cars have lower limits on axle weight and drawbar strength compared to their US counterparts. Despite these fundamental differences with US freight rail operations, European all-electric locomotive technology can still serve as a basis for US electric freight locomotives. As described by the 2012 SCAG freight rail electrification study[16]:

> A variety of … high horsepower electric freight locomotives [are] in operation in Europe, such as the DB Schenker EG3100 (8,837 hp), or the Bombardier Swiss Class 482 Traxx Locomotive (7,614 hp). However, in their present configurations, these units do not offer sufficient starting tractive effort to move typical

[15] *Draft Technology Assessment: Freight Locomotives.* California Environmental Protection Agency, Air Resources Board, Transportation and Toxics Division, April 2016, pg. VIII-3 to VIII-6. https://www.arb.ca.gov/msprog/tech/techreport/freight_locomotives_tech_report.pdf

[16] *Task 8.3: Analysis of Freight Rail Electrification in the SCAG Region (Final Technical Memorandum)*, prepared by Cambridge Systematics, Inc. for Southern California Association of Governments, April 2012, pg. 2-5. http://www.freightworks.org/DocumentLibrary/CRGMSAIS%20-%20Analysis%20of%20Freight%20Rail%20Electrification%20in%20the%20SCAG%20Region.pdf

> high-tonnage trains up the critical mountain passes that must be crossed to enter or leave the L.A. region (i.e., the Cajon Pass on BNSF/UP and Beaumont Hill on the UP).
>
> For purposes of this analysis, the assumed locomotive type will be one with similar specifications to the Bombardier IORE, due to its relatively high tractive effort (which is necessary to get long and heavy U.S. freight trains moving), six-axle design, high horsepower, and its potential adaptability to the U.S. freight railroad operating environment. While some adjustments would be necessary to prepare these locomotives for U.S. operations (such as additional weight to increase tractive effort), they should be relatively minor.

Apparently not considered by authors of this report is operating two or more electric locomotives at the head-end and mid-train (as is common with diesel locomotives to reach the required horsepower. Also, given the higher power possible per unit with electric locomotives, global experience has shown not only do they provide more power for pulling heavy freight trains up grades (like was done in the Cascade and Rocky Mountains in the early 20th century)- one electric can replace two diesel units. In addition to reduced energy costs, electric locomotives require less maintenance than diesel-electric locomotives. Due to their decreased mechanical complexity, electric locomotive maintenance costs are 40%-50% lower than those of a comparable diesel-electric locomotive fleet and have longer operating lives[17].

Energy consumption of electric rail, effects on electric utility loads

Typical Electric Power Equivalent of Railroad Trains[18]

Light Rail or Subway	1 MW or less
Commuter Trains	3 to 4 MW
High Speed, Intercity Passenger Trains	4 to 8 MW
Very High Speed Passenger Trains	8 to 20 MW
Long-Haul U.S. Freight Trains	18 to 24 MW

With proper planning, supplanting diesel with electrical propulsion will not unduly burden the grid. As shown in the table above, a single large line-haul freight train can consume the equivalent of over 20 MW of electric power. The 2016 CARB RailTEC report estimated that UP and BNSF locomotives operating in the South Coast Air Basin, about 130 line-haul freight trains per day, currently consume the equivalent of 435,000 MWh/year, or about 50 MW average load[19]. The 2016 CARB studies estimated that powering all line-haul freight locomotives with electricity would require just over 400,000 MWh of electricity per year (45 MW average load) at present rail traffic levels, and 1,000,000 MWh/year by 2050.

The authors of the 2016 CARB freight locomotive report provide no estimates of transmission losses or their costs. Such power transmission losses are typically around 5%. This level of loss is not considered a significant problem for new natural gas and renewable generation projects, across Southern California region and neighboring states, to serve the LA basin electricity market. Also, the report's choice of five 50 MW (114 MW average load)[20] power plants of 50% capacity factor, of unspecified type, seems to have been chosen

[17] J.P. Baumgartner, *Prices and Costs in the Railway Sector.* Ecole Polytechnique Federale de Lausanne, 2001.

[18] B. Bhargava, *Railway Electrification Systems and Configurations*, SoCal Edison, Institute of Electrical and Electronics Engineers (IEEE), 1999.

[19] *Transitioning to a Zero or Near-Zero Emission Line-Haul Freight Rail System in California Operational and Economic Considerations, Final Report.* Prepared for State of California Air Resources Board by University of Illinois at Urbana-Champaign Rail Transportation and Engineering Center (RailTEC), Spring 2016, pg. 48. https://www.arb.ca.gov/railyard/docs/uoi_rpt_06222016.pdf

[20] *Draft Technology Assessment: Freight Locomotives.* California Environmental Protection Agency, Air Resources Board, Transportation and Toxics Division, April 2016, pg. VIII-6. https://www.arb.ca.gov/msprog/tech/techreport/freight_locomotives_tech_report.pdf

arbitrarily as a source of 1,000,000 MWh/year, or 1 TWh/year, and needs to be scrutinized. This amount of electricity consumption was described as a major disadvantage[21]:

> To meet future freight electrification power demands in the South Coast Air Basin of up to one million MWh by 2050, five 50 MW power plants would be required (assuming those plants operate at 50 percent of capacity on an annual basis).
>
> Finally, it would be critical to build the electricity generating power plants as close to the freight rail operations as possible. The further away the electricity is generated from the rail operations, significant electricity transmission losses can occur, reducing the overall efficiency of the system. Therefore, with transmission losses from electricity generated from power plants outside the South Coast Air Basin or California, more power plants may need to be built.
>
> Current freight diesel-electric freight locomotives can achieve efficiency levels about 40 percent or more. Significant electrical transmission losses, and the use of non-renewable power sources like coal, could reduce the overall efficiency of the rail electrification system to less than 30 percent. This loss in efficiency could potentially offset any gains from fuel savings.

However*, 1 TWh a year is well under 1% of the 2015 annual consumption of the combined Southern California Edison (SCE) & Los Angeles Department of Water and Power service areas.* [2015-2016 electricity consumption figures are used because the authors of the 2016 CARB report did so.] While 1 TWh is not an insignificant amount of energy, it could easily be accommodated in the Southern California grid, with advanced planning, and sourced from renewable energy instead of fossil-fuel generating plants. Moreover, even fossil fuel power plants, with the exception of coal, are cleaner than mobile diesel-fueled sources such as the locomotive engines now in use. Also, the power for electric locomotives can come from zero-emissions sources, including geothermal power, hydroelectric power, nuclear power, solar power, and wind turbines. The authors of the CARB 2016 report mention coal as an energy source, even though it is rapidly being phased out by utilities in Southern California. Again, the authors provide no analysis or evidence of how overall energy efficiency of a rail electrification system could be as low as 30%.

As a comparison, the total solar, wind, and geothermal share of the electricity generated in 2016 within California, approximately 46 TWh, is *forty-six times* the 2050 projected freight rail electric energy consumption for the South Coast Air Basin described by the 2016 CARB studies. The share of renewable energy in the state's electricity mix is growing rapidly. California leads the nation in utility-scale solar energy development, with an installed generating capacity in 2022 of just over 17,000 MW of solar PV, 1,076 MW of solar thermal[22]. A typical solar power plant has an overall capacity factor of 20%. In theory, this would indicate that about 570 MW of solar power generation capacity would be needed to produce 1 TWh of annual electric energy. In 2022, California also had 6,117 MW of wind power generation capacity and 2,693 MW of geothermal. In terms of overall annual electrical energy generated in 2022, solar (PV+thermal) produced 40.5 TWh, wind 14.0 TWh and geothermal 11.1 TWh. Updating the 2016 figures at the beginning of this paragraph, the total solar, wind, and geothermal share of the electricity generated in 2022 within California, approximately 66 TWh, is *sixty-six times* the 1 TWh of projected 2050 projected freight rail electric energy consumption for the South Coast Air Basin described by the 2016 CARB studies. The California High Speed Rail Authority is building 445 acres of solar power generation and a 62 MW/124 MWh battery energy storage facility on land that it already owns, to power future high speed trains[23], showing how electric rail does not even need to be dependent on the existing power grid.

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[21] Ibid., pg. VIII-7.

[22] https://www.energy.ca.gov/data-reports/energy-almanac/california-electricity-data/electric-generation-capacity-and-energy

[23] https://hsr.ca.gov/programs/green-practices-sustainability/sustainability/

Capital costs and financing

The main challenges for electric freight rail are the high upfront capital cost of overhead catenary wire, power supply infrastructure, and new electric locomotives. As a complex undertaking, it would certainly cost at least several billion dollars to electrify the main freight lines of Southern California, for example. However, this cost is not known until a comprehensive feasibility study is completed. Also unknown is the full extent of the economic, environmental, and public health benefits of electrification until such a study is completed. A proper rail electrification feasibility study would include preliminary design and cost estimates for electric catenary and power distribution infrastructure, specific to particular rail corridors. These cost estimates would also include any required modifications to existing overhead structures above or along tracks, such as bridges.

Around the time of the 2016 CARB rail reports, the California High Speed Rail Authority estimated a 25-kV electrification cost of around $8.5 million per route mile for most (~430 miles total) of the Phase 1 route, the majority of which is in the flat, open Central Valley[24]. However, in urban and suburban areas, the figure is much higher. Supposedly using the Caltrain construction cost estimates as a basis, the April 2016 CARB freight locomotive report estimated that freight rail electrification capital costs in the South Coast Air Basin would be about $50 million per route mile[25], with a primary reason for these high costs explained as[26]:

> "To provide vertical clearance for the overhead catenary wires, existing tunnels, overpasses and other structures must be modified or reconstructed where insufficient clearance exists. These projects increase the estimated capital cost of electrification to approximately $50 million per route-mile".

There are no estimates given in the 2016 CARB report specifically for the modification of existing tunnels, overpasses and other structures, where and how many such structures would have to be modified, and the extent of the modification. Such overhead clearance issues are further implied as being a 'dealbreaker' by the 2016 CARB freight locomotive report[27]:

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[24] Alon Levy, Pedestrian Oberservations blog post May 22, 2018:
https://pedestrianobservations.com/2018/05/22/construction-costs-electrification/
".. with the latest cost overrun, the projected [California High-Speed Rail] electrification cost is $3.7 billion* The length of route to be electrified is unclear: Phase 1, Los Angeles to San Francisco with a short branch up to Merced, is a little more than 700 km, but 80 km of that route is Caltrain, to which the high-speed rail fund is only contributing a partial amount. If the denominator is 700 km then the cost is $5.3 million per km."
*Table 4,-p. 14 of California High Speed Rail Authority, *DRAFT REVISED 2018 Business Plan: Technical Supporting Document- Capital Cost Basis of Estimate Report*, June 1, 2018:
https://www.hsr.ca.gov/docs/about/business_plans/DRAFT_2018_Business_Plan_Basis_of_Estimate_Report.pdf

[25] *Draft Technology Assessment: Freight Locomotives.* California Environmental Protection Agency, Air Resources Board, Transportation and Toxics Division, April 2016, pg. VIII-10 to VIII-11.
https://www.arb.ca.gov/msprog/tech/techreport/freight_locomotives_tech_report.pdf

[26] *Transitioning to a Zero or Near-Zero Emission Line-Haul Freight Rail System in California Operational and Economic Considerations, Final Report.* Prepared for State of California Air Resources Board by University of Illinois at Urbana-Champaign Rail Transportation and Engineering Center (RailTEC), Spring 2016 (https://www.arb.ca.gov/railyard/docs/uoi_rpt_06222016.pdf), pg. 20.

[27] *Draft Technology Assessment: Freight Locomotives.* California Environmental Protection Agency, Air Resources Board, Transportation and Toxics Division, April 2016, pg. VIII-3 to VIII-6.
https://www.arb.ca.gov/msprog/tech/techreport/freight_locomotives_tech_report.pdf

> Greater catenary heights and clearances to allow for double stack containers carried by U.S. freight trains may create clearance issues, especially under bridges and tunnels. In the U.S., the railway electrification systems would require higher catenary clearances (23.5 feet) from rails, and could necessitate lowering tracks or raising bridges to provide adequate clearances.

However, it has long been established practice for electric trains to just 'glide through' very short unelectrified sections on a line, and several new and improving technologies are allowing tighter clearances for electric wires going under bridges and tunnels:

- Under-cable support structures (shown in picture below).
- Conductor bars
- Insulating covers/coatings (combined with surge arresters)
- Deliberate placing of neutral sections (which are actually required by OCS systems, spaced between different power sections).

CARB's overall OCS cost estimate of $50 million per route mile is far higher than the cost of any rail electrification scheme ever built in the world and is not based on a detailed analysis of existing rail routes or rail electrification rail projects recently completed rail electrification projects. Caltrain's electrification project is mentioned, while that project's costs were exceptionally high (as described above), but the electrification aspects of the larger CalMod program was about half of the $50 million per route-mile.

Overhead catenary system maintenance costs were estimated by the 2016 CARB RailTEC report to be $30,000 per route mile, per year. The higher the train frequency for a particular track segment, the more economical electrification will be. Factoring in the social benefits of reduced pollution, electrification for several key Southern California freight and passenger lines was economically favorable, according to a cost-benefit analysis done by Paul Druce in 2015[28]:

> [with social, environmental and economic benefits] combined, we see that it takes 21-29 bidirectional frequencies for benefits to match the costs of railroad electrification [for passenger rail].
>
> In California, this would indicate that it would be justified to electrify Caltrain between San Jose and San Francisco. With increased service, electrification would also be justified on Metrolink's San Bernardino

[28] Paul Druce, *Reason & Rail* blog, September 5, 2015: http://reasonrail.blogspot.com/2015/09/a-cost-to-benefit-analysis-of-railroad.html

> Line as well as LOSSAN between Burbank and Irvine (Metrolink and Pacific Surfliner) and Oceanside and San Diego (Coaster and Pacific Surfliner).
>
> For freight trains, the decreased fuel costs play a much larger role, and more importantly, the only one that the board of directors actually care about, resulting in break even at fewer frequencies. From the 2014 STB R-1 reports, we see that, for the Class I railroads, there is an average consumption of 6.92 gallons per train-mile; a comparable figure for electric traction would be 86.5 kWh per train-mile. Because of the significantly greater fuel consumption, the payoff is much quicker: Only 9 trains per day are needed in each direction with social benefits included or 15.4 when only considering fuel costs. Of course, private companies aren't going to be using Federal discount rates and will likely be seeking money on the open market. While this will be more expensive, it won't be enormously so. Union Pacific recently sold 40-year bonds at 3.875%; if I've done the math correctly, this would come out to $212,374 per mile of track, pushing the break-even points to 10 and 17.3 frequencies. In Southern California, this would justify the electrification of the Alameda Corridor, Sunset Corridor, and Southern Transcon.

The high upfront capital costs for rail electrification should be viewed in the context of the several-decade lifespan of the infrastructure investment, the cumulative avoided cost of diesel fuel and locomotive maintenance, and the pollution impacts of diesel locomotives. The experience of railroads around the world has shown that the lower operating and maintenance costs of electric locomotives will result in lower costs over the long run.

Since their publication, the CARB 2016 reports have been cited by public agencies in California to justify their opposition to rail electrification

In various public forums over the past eight years since the 2016 CARB electric locomotive reports were published, environmental and rail advocates have voiced criticisms of both AAR and CARB on this issue. We have seen AAR perpetually trashing overhead wire electrification by wildly exaggerating the costs and drawbacks while seemingly denying the existence of the wide variety of successful examples of electric freight and passenger rail operations around the world. We also see CARB as taking a very simple-minded approach to rail emissions that could cause a lot of problems, not just for the railroad industry, but California's general mobility and environment, if there is a regressive mode shift from the rails to road.

CARB's reports have hampered development of rail electrification in California, being cited by other key parties as a justification for opposing rail electrification. An example is the Port of Long Beach January 2018 Pier B On-Dock Rail Support Facility Project EIR response to public comments about rail electrification as a mitigation measure. That EIR response repeats numerous falsehoods from the 2016 report. Under the heading, "Master Response – Electrification of Alameda Corridor and Zero Emission Locomotives" in the EIR response there were "a number of comments [that] expressed views that electrification of the Alameda Corridor should be considered in the EIR and that electric or zero emission locomotives should be used as mitigation for the Pier B On-Dock Rail Support Facility Project". CARB's 2016 locomotive report is cited by the authors of the EIR response as justification for dismissing rail electrification (for more detail, see Appendix 2):

> "While zero emissions technologies are promising, no zero emission switching locomotives have yet been proven to be feasible in port operations nor have yet been fully commercialized. The California Air Resources Board (CARB) prepared *Technology Assessment: Freight Locomotives* (CARB, 2016c), which considered potential advanced locomotive technologies that could, at some point, operate on the existing rail network with emissions below the current national Tier 4 emission levels. The Technology Assessment outlined the numerous technological, costs, legal, and logistical constraints that render zero emission rail operations infeasible. As previously mentioned, electrification of the rail system or use of zero emission locomotives would need to be implemented on a larger scale. In the Technical Assessment, **CARB acknowledges several significant challenges associated with freight electrification, which includes capital costs upwards of $50 million or more per route-mile, further indicating that with up to 500 miles of total major rail route in and around the South Coast Air**

> **Basin (SCAB), the total capital costs could be up to $25 billion or more. [***Emphasis added. This is highly misleading; these cost figures are wildly exaggerated by CARB.]* In addition, CARB also found that a basin-specific rail electrification system has the potential to create delays in operations. As an example, CARB states that an all-electric operation in the SCAB [South Coast Air Basin] would need to change locomotives at an exchange point to connect to the North America diesel-electric freight rail system for the remainder of the trip. Another significant challenge is the need to build a substantial electricity-generating system. According to CARB, UPRR and BNSF generate up to 400,000 locomotive megawatt-hours (MWh) or more of electricity in the SCAB. By 2050, up to one million MWh would be needed by UPRR and BNSF to operate in the SCAB. **A significant level of electric power infrastructure would be needed to meet the electricity demands of heavy hauling freight rail operations in the SCAB and in the rest of California** *[Emphasis added. This is also highly misleading. The amount of new electric power infrastructure needed would be small compared to that needed by electric trucks carrying the same amount of cargo***.]"**

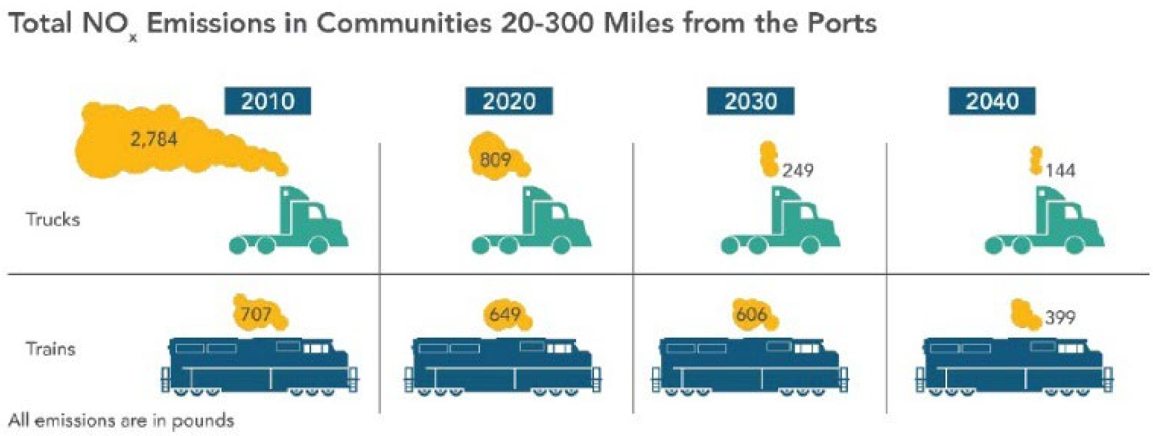
The 2020 AAR pamphlet titled "Oppose Rail Electrification" cites CARB as justification

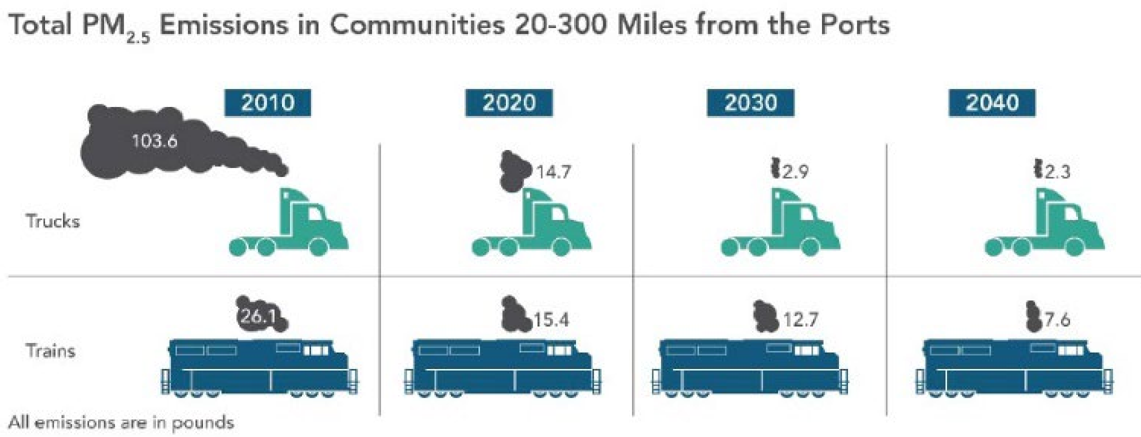
In 2020, the Association of American Railroads (AAR) released a "fact sheet" titled *Oppose Rail Electrification & Support Sensible Climate Policy*[29], which claimed that rail electrification is too expensive and is unnecessary. However, AAR's position and analysis on rail electrification has been widely criticized by rail experts and economists as unsupported by facts and being too simplistic[30]. This AAR document cited CARB's 2016 report to support its claim that rail electrification is impractical and should not be pursued! AAR and CARB are thus allied in spreading misinformation about overhead wire electrification, claiming OCS costs would be $50m/mile and electric locomotives couldn't handle heavy trains. What is now so ironic is that AAR, which in essence opposes zero emissions policy in favor of its diesel status quo, is suing CARB on this same issue.

CARB has presented a misleading picture of rail vs. truck emissions

The graph below released by CARB is highly deceptive because (a) it assumes that electric trains do not exist, (b) it completely ignores the far greater amount of energy required to move a ton-mile of freight by rail than by truck, and (c) it also ignores associated GHG emissions. This vast disparity exists due to the mechanics and friction of steel wheels on steel rails versus rubber tire on pavement.

[29] https://www.railwayage.com/wp-content/uploads/2021/02/AAR-Electrification-Fact-Sheet.pdf
[30] https://www.railwayage.com/news/dont-dismiss-freight-rail-electrification/





The above CARB graph is not considering:

- The energy efficiency of rail compared to trucks emissions per ton-mile of freight moved. CARB's 2016 locomotive reports asserted heavy draw on the power grid as a reason not to electrify railways. *Yet CARB is now being a cheerleader for electric trucks replacing ALL rail despite a much high-power grid demand.* It requires over three times the amount of electric energy to move the same ton-mile of freight via electric truck compared to electric train.

- That zero-emissions, all-electric locomotives exist and could be deployed today in California.

- The far greater release of carbon emissions and other pollutants needed to manufacture dozens of trucks to carry the load which could be pulled by one locomotive, including mineral processing, transportation, and pollution from manufacturing of batteries, steel, rubber, etc.

- Rubber tire and brake dust pollution caused by trucks.

- Road wear and tear, and pavement dust.

- Runoff pollution to watersheds from trucks (rubber and road wear dust, leaking oil/fuel, etc.).

- Road accidents caused by trucks; per ton mile of freight moved. Trucks have much higher accident rates than rail.

The inherent differential in energy efficiency between rail/steel wheel versus road/rubber tire will not be altered by “rapid evolution of cleaner diesel engines and ZE technology in long-haul trucking.” An electric train will use at least 75% less energy per ton-mile moved than an electric truck. Being “cleaner” in regards to PM2.5 and NOx emissions does not necessarily mean that there will be any reductions in GHG emissions. Empirical evidence needs to be provided to back up CARB’s assertion that trucks in California are already (in 2023) cleaner, in terms of NOx and PM emissions per ton-mile, than trains.

CARB has repeatedly emphasized that they only care about tailpipe emissions at the vehicle, and not where the electricity or hydrogen comes from (or how much energy, water or emissions is used to produce it). CARB has also never publicly acknowledged the energy efficiency difference of rail vs. road travel . Why do they not mention how much more electricity it would take to move the same tons of cargo via electric rail vs electric truck? Because they are working under the assumption that electric freight trains will never exist. They of course assume that electric trucks would be 100% powered by renewable energy, yet the 2016 CARB locomotive report tried to denigrate electric freight rail by implying new coal-fired plants would have to be built to power it. “Zero-emissions trucks” all have an embedded GHG emissions footprint for their manufacture and mining of materials. The lifecycle GHG emissions of “zero-emissions” trucks will thus will not be zero. Particulates from tire and road wear are a significant source of particle pollution from trucks and a problem completely avoided by trains. CARB and Caltrans need to consider tire and road wear pollution in their environmental evaluation of trucks.

The 2018 California State Rail Plan, section 3.1.7 (p. 116), “Policy 3: Reduce GHG Emissions and Other Air Pollutants” states:

> “A 2009 FRA study reported that a double-stack container-trailer-freight rail car moves freight three to five times more fuel-efficiently than a truck.[162] Each freight train carries much more total weight than a single combination truck, so each train movement reduces truck traffic on highways and reduces GHG emissions.”

Electric trains are the most energy efficient way to move freight on land, moving a ton with as little as one-tenth the energy used by diesel truck. Moving a ton-mile of freight by rail requires at most a third the energy of moving it by truck, due to the difference in mechanical friction of steel versus rubber wheels. Every truck on the road still adds to congestion, crash risk (trains being statistically much safer per freight ton-mile), tire/road wear, and brake dust pollution (the human health impacts of brake dust are only beginning to be understood). A truly transformative zero-emissions transportation future would involve electric trains transporting goods as much as possible, instead of merely converting trucks to a different fuel source. In one prime example, the Alameda Corridor was designed with enough overhead clearance for catenary wires over the tallest double-stack container trains. CARB should recommend electric trains using OCS on the publicly owned three-track railroad corridor for the Ports of L.A. and Long Beach. It is currently operating at well under half of its throughput capacity, something one cannot say about the 710 Freeway, with if clogged with electric or hydrogen-powered trucks is still a clogged freeway.

The road-to-rail mode shift scenario provides an opportunity for much-needed freight rail electrification in the LA Basin and Inland Empire, with a captive electric locomotive fleet operating between the ports and Barstow/Yermo/Indio. A 2016 CARB report on freight locomotives stated that about 60% of all locomotive diesel fuel energy (and resulting pollution) consumed by all freight trains in Southern California occurs on the--steep grade--Cajon Pass segments of BNSF and Union Pacific, between the Inland Empire and Barstow. The Barstow/High Desert area is already a major solar power generation hub, so a ready clean source of power for electric trains is already available. Coincidentally, in 2022 the BNSF Railway announced its Barstow International Gateway project, a proposed large ‘inland port’ on the west side of Barstow. Contained in this proposal are plans for short-haul intermodal freight trains between Barstow and the Ports of LA/Long Beach, which would potentially get thousands of trucks off Southern California highways each day.

Building an overhead wire rail electrification system is expensive, but it is going to be less expensive overall than moving the same amount of freight with electric trucks. This is largely because trains with steel wheels and rails use a small fraction of the energy needed to move a ton-mile of freight compared to a truck with rubber tires on pavement. Electric rail is vastly more energy efficient than electric trucks, which is an important consideration for not overstressing the power grid with electric transportation.

CARB's own *2022 Scoping Plan for Achieving Carbon Neutrality*[31] states a goal to "achieve a per capita VMT reduction of at least 25 percent below 2019 levels by 2030 and 30 percent below 2019 levels by 2045." While this 2022 scoping plan document makes vague mention of improved public transit as a means to reduce VMT, it makes no explicit mention whatsoever of rail transit (streetcar, light rail, subway/BART/metro), intercity/regional passenger rail, or mode shift of freight from truck-to-rail. CARB needs to realize that rail transportation is absolutely essential for reducing VMT. There is in fact no way for car or truck VMT to be reduced in California by 30% without greatly *increased* use of rail transportation. [also of note, this 2022 report also asserts that "Line haul and passenger rail rely primarily on hydrogen fuel cell technology" without any explanation or justification as to why, or any analysis given for different alternatives.]

Battery power for rail is not as practical as CARB assumes

The first electric locomotive ever built, in 1837, was a battery-powered locomotive. Lightweight railcars or multiple-unit trains were battery-powered on a few lines from the early to late 20th century in the US, New Zealand, Ireland, the UK and Germany. Small battery-powered trains were first used in underground mines in 1917. Battery-powered maintenance trains have long been used by large urban rail transit agencies around the globe, for maintenance and repair work when the traction power system is de-energized. But there is a reason that starting in the late 1800s, electric trains powered by an external source (overhead wire or third rail) are what caught on.

Batteries of course have far more energy and power capability today and are steadily improving. For several years, Alstom battery-catenary hybrid switcher locomotives have been working in European freight yards. Alstom light battery trains, for local branch passenger rail service, have been in revenue service in Germany since early 2022. Here in the US, several locomotive manufacturers have demonstrated full-sized battery electric freight locomotives. However, even if the current state of battery technology were to double in energy density or onboard storage capacity, locomotives or multiple units powered by batteries alone would only have a small fraction of the range of those powered by diesel. Therefore, it is important not to get carried away with the idea of batteries powering a 'full-sized' train. The energy density of on-board battery energy storage realistically means that for a mainline, large freight train (or even a long passenger train like the 16-car consist of the *California Zephyr* in 1990s), only short distances are possible on battery power alone, since the batteries would need to be recharged after a few dozen miles at most.

Anytime a battery pack is introduced to a train, the cost goes up. Battery trains are about twice as expensive as a standard EMU: ~ $5 million per 'US-length railcar', based on a recent order of €100 million for 11 'three-car' Alstom battery trains in Germany. Operations and maintenance costs of a locomotive or multiple-unit with a battery pack will always be higher than that of an equivalent 'straight-electric' unit without one, and overall energy efficiency will be somewhat less. There are also environmental problems unique to batteries: (1) the impacts and GHG emissions from their manufacture and from material sources, and (2) recycling and disposal. There are also issues such as the additional weight and space requirement on trains for batteries which could reduce passenger accommodation space.

[31] https://ww2.arb.ca.gov/sites/default/files/2023-04/2022-sp.pdf

In addition, due to the cost of the batteries, battery electric train sets initially cost much more than electric sets powered by overhead catenary wire, or overhead contact systems (OCS); and they are also much more expensive to maintain and operate. There is the cost of battery mid-life replacement and used battery disposal (necessary after only a few years of use). Also, because of mid-trip charging requirements, more battery electric train sets would be required to cover this requirement. To facilitate a fast recovery from a service outage, even more battery train sets would be required, since they are constrained from a quick reversal at stations by the need to charge batteries. All these additional costs must be included; and they will erode much, if not all, of the perceived cost advantage of the battery electric system.

The key factor favoring OCS technology is the impact of weight and speed on the power requirements. The critical advantage of the overhead catenary system is its ability to “offload” the power source to stationary power sources. This “off-loading” avoids significant vehicle weight by eliminating thousands of pounds of fuel cell, hydrogen fuel, or batteries. Simply put, batteries and hydrogen fuel cells will never be light enough or have the on-board energy storage density to match the power efficiency of overhead electrification for high-speed rail operations. Overhead electrification is “off the shelf” technology with decades of proven service and continuous technological improvements. In addition, there is a ready pool of manufacturers experienced in the rail electrification technology and trains.

In the end, it is laws of physics which make it very difficult for trains powered by battery alone from providing higher speed rail travel, or moving a heavy freight train, for a distance of more than a few dozen miles. Only OCS will give California a zero-emissions intercity transportation system that is fast enough to get people out of their cars, and out of airplanes for travel within the state.

While battery electric propulsion service can start on a small scale, the trade-off between battery weight/train performance, battery expense, range, time required for charging, and the significant off-site expense of meeting high electricity demand at the terminal charging facility can create operational issues longer-term. It becomes a significant challenge (operational performance vs. battery weight and battery expense) trying to cram enough batteries into the rail car to get sufficient performance for acceleration and climbing grades, while having enough range to complete the route.

Extremes in temperatures are also a factor negatively impacting battery range. If charging time is required during the daily schedule cycle, then equipment utilization is adversely affected and additional trainsets are required to maintain published schedules. OCS trains pull their power load balanced across the utility’s multiple power grid circuits as the train travels along its route. Battery electric trains would pull a high-power load at specific terminal endpoint charging stations in the range of several megawatts (MW). This would require a substantial investment in utility electrical infrastructure beyond the rail line. Current technology requires at least several hours for a battery train to be fully recharged. Battery-powered trains have lower overall energy efficiency than OCS electric trains, so more electrical energy from the grid would be required for the same level of train service.

Finally, the safety hazards of a large onboard battery pack cannot be overlooked. Due to the laws of thermodynamics, ‘thermal runaway’, causing fires and explosions, is a much higher risk with a multi-MW battery pack than a smaller one for an electric car, because a train battery pack would be a greater ‘thermal mass’ which requires more cooling systems. EV batteries regularly catch fire spontaneously. A battery train crash or derailment would be particularly hazardous and could require a haz-mat clean-up operation.

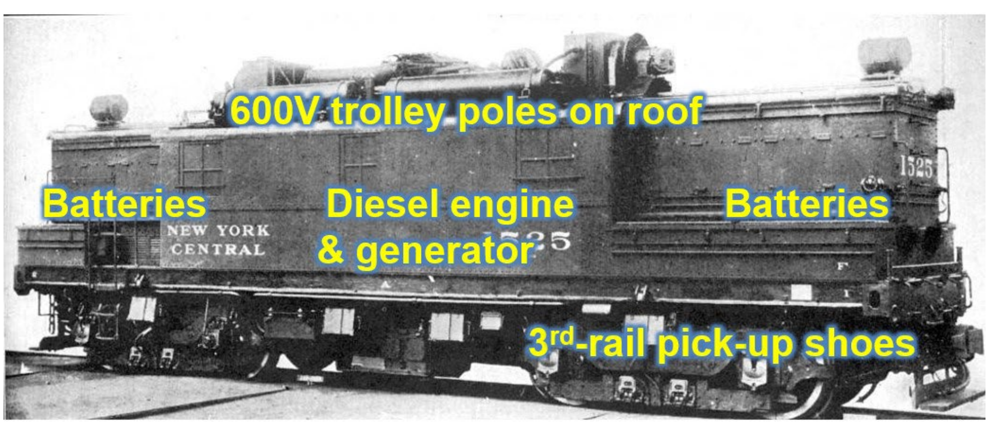
While there is often a comparison between the flexibility of battery electric propulsion vs. the operational efficiency of complete electrification, there is a blended alternative that combines the advantages of both while at the same time mitigating many of the challenges involved with each technology. Using battery power on an electric locomotive or multiple-unit, in a hybrid combination with an overhead pantograph, enables it to move between sections of overhead wire. This eliminates the need to electrify each mile of track, whether it’s a terminal service track, low volume connecting track or siding, etc. In select sections it could avoid needing wires; e.g., where there is opposition to catenary through historic neighborhoods, scenic line segments, etc.

Electrifying selected line segments through incremental electrification, combined with battery electric propulsion, can potentially address many of the shortcomings of both technologies. The first step would be to target initial electrification at terminal station tracks, stations with high acceleration requirements, and the key grades of the route. This significantly reduces the cost of catenary electrification and allows electrified operation to begin with battery electric trainsets. However, with the availability of catenary power in high power demand line segments and battery recharging as trains travel along key route segments, the number of on-train batteries would be decreased, thus reducing weight, improving efficiency, and lowering vehicle cost. Also, with segment catenary at high power demand points and enroute charging, range and full utilization during the service day would be possible, since the trains would not have to stop and charge for a few hours.

As train frequency increases, to improve acceleration (to reduce travel times), and also to improve operations, additional miles of catenary can be added. Segment electrification with battery electric trainsets also facilitates lower cost by way of service to lower volume branches and secondary lines which do not have the train frequency to warrant investment in overhead wire. Another benefit of segment electrification is that it can reduce the risk of lawsuits from lineside stakeholders over catenary construction. These lawsuits have been a major barrier to rail electrification projects in the past. With traditional electrification a lawsuit delays the entire project and costs rise, until the lawsuit is settled. With the incremental staging of electrification and the flexibility of battery operation, the remainder of the project can continue; and service can begin while the lawsuits are resolved. However, in addition to battery-hybrid technology, new policies or laws are needed which mitigate NIMBY lawsuits against rail electrification. In California's case, an exemption to the California Environmental Quality Act (CEQA) for overhead catenary wire rail electrification infrastructure is long overdue.

While there is commercial operating experience with battery combined with an external power source (catenary or third rail) dating back over a century, this operational experience is very limited. Battery-catenary hybrid electric, 75-ton locomotives were introduced to the Utah Copper Company rail line in the late 1920s; they were capable of up to six hours of 'off wire' operating time. Around the same time, the New York Central was using a 'three-power boxcab' locomotive capable of being powered by either a diesel engine, batteries, overhead trolley wire or third rail (see photo below).

All-electric locomotive operation has been required, & hybrids used, in New York City since the 1920s



GE "three-power boxcab", 1928
New York Central #1525

Despite these early battery rail innovations, from the late 1800s until the present, railroads around the world have electrified in logical, incremental phases (while phasing out steam or diesel) without the need for any form of battery propulsion as a "bridge" while the overhead wire infrastructure was built out in stages. Diesel-catenary or third rail electric hybrids have existed for a long time also. A notable example is the Bombardier ALP-45 diesel-catenary hybrid used by New Jersey Transit, which also turned out to have significantly higher upfront and maintenance costs than a straight-electric locomotive.

For any particular rail line and service scenario, the cost of overhead wire infrastructure versus the higher costs of O&M and new rolling stock, which also is an upfront capital cost, must be carefully weighed. Saving costs by reducing the length of a section of catenary wire installation may end up being "pennywise but pound foolish" in the long run if such savings are offset by the higher upfront cost and O&M costs of rolling stock equipped with batteries. In much of the world, the cost of a mile of overhead catenary would be around the same cost as adding batteries to a single electric locomotive or EMU.

The use of battery electric locomotives for high-speed rail, or heavy mainline freight rail, is not tenable. Reliance on battery technology creates an extremely high risk because there is no viable fallback. Currently there are no prototypes or designs for battery electric high-speed rail trainsets. The handful of battery-electric locomotives and battery-electric train sets that exist in the world today have only a range of at most 50 miles (at moderate speeds) before needing to be recharged. Improvements in battery technology over the next ten to fifteen years might increase this range to perhaps 100 miles.

In California, Caltrain is slated to pilot a catenary-battery electric hybrid Stadler multiple unit train between San Francisco and Gilroy, which will receive power on the electrified segment through San Jose[32].

Hydrogen is NOT the solution for California rail

In its reports and discussions on zero-emissions rail, CARB seems to imply that hydrogen propulsion is somehow equal in status to, or even superior to, conventional overheard wire rail electrification. However, conventional rail electrification, using an overhead wire, is more environmentally friendly and reliable than hydrogen propulsion in almost every respect.

Despite the state of California's embrace of hydrogen rail technology, the laws of physics mean the hydrogen-trains will always have inferior energy efficiency and be more complex (with higher O&M costs and poorer reliability) than conventional electric trains using an overhead wire. The primary problem with using hydrogen to power trains is the element's low energy density compared to other fuels, and poor overall energy efficiency of multiple necessary steps: producing hydrogen, then storing it by energy-intensive compression or cooling, and then running it through a fuel cell, which then mostly charges a battery, which then goes to the traction motors[33].

[32] https://www.caltrain.com/news/caltrain-pilot-first-nation-bi-level-dual-electric-and-battery-powered-train-expand-zero
[33] https://riagb.org.uk/RIA/Newsroom/Publications%20Folder/Why_Rail_Electrification_Report.aspx

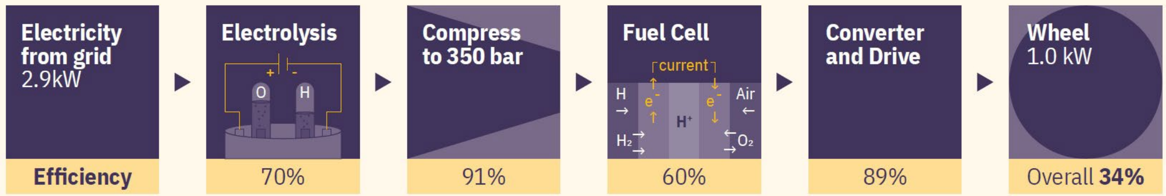


Figure 16 Typical overall efficiency of hydrogen trains

Hydrogen trains have the worst roundtrip energy efficiency of any rail propulsion technology: it takes *3 to 4 times the amount of electricity* to produce renewable hydrogen, which would have the same useful train-propulsive energy as powering a train directly with renewable electricity. [diagram from UK Railway Industry Association, *Why Rail Electrification?* report, 2021]

In terms of overall energy efficiency, conventional electric trains are about three times more efficient than diesel or hydrogen, and about 1.2 times more efficient than battery trains[34]. According to a March 12, 2023 *Railway Age* article by Mike Iden[35], total 'input-to-wheel' energy conversion locomotive efficiency was calculated to be:

- Catenary wire electric- 90%
- Catenary wire electric with battery tender- 86%
- Battery electric- 77%
- Green hydrogen- 39%
- Diesel with battery tender- 36%

Other disadvantages stem from the inherent complexity of hydrogen supply chains, on-board storage systems, and power (fuel cell+battery) drivetrains. More complex systems onboard mean more potential points of failure, higher equipment costs, and higher O&M costs than a conventional electric train. While hydrogen technology is still emerging, future technological developments will not change these fundamental physical facts.

The hydrogen-powered Alstom and Stadler multiple-unit trains now entering the market are very much in the category of 'light rail': closer in power and weight to a large bus than they are to a locomotive. The much-hyped Alstom iLint hydrogen trains in Germany have proven to be a disappointment. At a March 2023 conference in Los Angeles put on by DB, the CEO of the Hamburg/ Lower Saxony region rail operator EVB gave a presentation about running the world's first commercial hydrogen train fleet of 14 iLint hydrogen trains. He candidly discussed the difficulties they have faced, and gave these interesting facts:

- In the first few months of operation, as the units were going through acceptance trials, the average availability of 14 iLint fleet was only about 20% (though reliability after acceptance was reported to be 95%). The current target is full reliability and 90% availability by the end of 2024, a significant delay.

- EVB had to continue operating the existing diesel fleet of similar size, which caused a big strain on staff and facilities to maintain/fix, etc., both fleets at the same time. The severity of overall O&M cost increases for the EVB operations was unexpectedly high, and the time period needed to keep *all* the diesel fleet in operation was unexpectedly long. For introducing new hydrogen trains, a "high level of dedicated resources" is needed; and additional costs and delays are to be expected.

[34] https://www.rssb.co.uk/en/research-catalogue/CatalogueItem/T1145

[35] https://www.railwayage.com/mechanical/locomotives/follow-the-megawatt-hours-hydrogen-fuel-cells-batteries-and-electric-propulsion/

- The actual practical range of the iLints in real-world operating conditions was about 300 miles on a full tank of hydrogen--less than half of what was promised. This is a major factor in their low availability rating, and the need to keep the diesel trains running to compensate.

- The fueling station was more expensive and complex than expected. The trains run on gray (dirty) hydrogen, from one of the large chemical complexes in the region and sourced from fossil fuels. The plan is to have an electrolyzer built at the site of the fuel station, powered by wind power. In three years hopefully the process would then be "just add water". A trucking company interested in hydrogen trucks asked if it could co-locate a truck fueling station and the train hydrogen station, but the difference in setups made this impossible.

- For EVB, the deal overall turned out to be “too expensive for just 14 trains”.

The executive concluded that the most important way passenger rail can reduce carbon emissions is by winning new customers for public transport, independent of propulsion technology. In other words, flashy new technologies should not distract from the primary mission of providing passenger rail service that fits people’s needs.

Railroad companies and public agencies have used the promise of future hydrogen trains as an excuse not to electrify, and hydrogen locomotives are actively promoted by oil and gas companies[36]. Environmental advocates are coming out against using hydrogen as transportation fuel[37]. Compared to conventional electric rail technology, hydrogen trains and locomotives are inherently much more complex and more expensive to maintain, with far more potential points of failure--many of them dangerous, considering hydrogen leaks more easily than natural gas. Hydrogen-powered fuel cells alone cannot provide enough instantaneous power to accelerate a train. Thus an onboard battery pack is also needed, in addition to the hydrogen tanks and fuel cells, taking up even more space and adding weight.

Only about a dozen hydrogen full-sized locomotives have ever been built. None have entered regular commercial service. It is not known yet if a hydrogen locomotive could approach the performance standards of conventional diesel and electric locomotives, so we do not know yet if hydrogen could be an appropriate fuel for long distance freight trains, especially on routes with a lot of inclines. The Alstom iLint hydrogen multiple unit trains, introduced recently to branch line passenger service in Germany, have been plagued by reliability problems, particularly in cold weather[38]. By contrast, there are tens of thousands of electric locomotives operating heavy trains (and many thousands more electric multiple-unit trains) around the world each day, very reliably and economically. There are many experienced vendors, manufacturers, etc. around the world who know how to provide reliable and economic electric rail. There are only a handful for hydrogen rail technology, which remains an unproven and very expensive technology.

A recent report from the state of Baden Wurttemberg in Germany concluded that it will no longer consider hydrogen for rail propulsion, as it is more expensive than battery or hard wire electrification by as much as 80%[39]:

> “The positives for hydrogen were: minor impacts upon introduction and during operation, and no changes required to the rail infrastructure. But the negatives were: costly filling stations; low efficiency, high energy

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[36] https://www.chevron.com/newsroom/2021/q4/caterpillar-bnsf-and-chevron-agree-to-pursue-hydrogen-locomotive-demonstration

[37] For further reference see these Sierra Club articles on the disadvantages and environmental harms of hydrogen:
https://www.sierraclub.org/articles/2022/01/hydrogen-future-clean-energy-or-false-solution
https://www.sierraclub.org/press-releases/2023/03/california-ej-and-climate-advocates-urge-greater-transparency-and-community

[38] https://www.trains.com/trn/news-reviews/news-wire/hydrogen-powered-trains-struggle-with-winter-weather/

[39] https://www.hydrogeninsight.com/transport/will-no-longer-be-considered-hydrogen-trains-up-to-80-more-expensive-than-electric-options-german-state-finds/2-1-1338438

> consumption and high cost; the possible need to increase the number of trains because the range would not be sufficient for a whole day of travel; limited availability of green hydrogen; and the need to continually resupply the hydrogen filling stations."

The promises made by hydrogen promoters have already led to some bad excuses in rail planning, in California and elsewhere: "We don't have time or the interest to electrify, so let's use hydrogen instead." But hydrogen rail propulsion isn't proven to have the reliability, performance and overall economics needed for efficient, frequent rail operations. Moreover, the supporting infrastructure is extremely expensive, and takes years to develop, which is exactly what the hydrogen promoters (the oil and gas industry) claim is so bad about overhead wire electrification. And where will all that fresh water come from? We would just have to keep using dirty hydrogen from fossil fuels until we figured that out, which is exactly what is happening with the world's first operating hydrogen rail fleet in Germany.

In general, no one really knows how much a comprehensive green hydrogen infrastructure would cost. We do know that the cost of for SBCTA's demonstration hydrogen multiple-unit train (comprising one Stadler unit and the fueling station) ballooned to $53.2 million at the end of 2022, up from a prior estimate of $37.5 million. This was for just one fueling station for a fleet size of one 2-car multiple unit. For the same amount of money, the entire 9-mile Arrow track between San Bernardino and Redlands could have been electrified, and a full fleet of six electric multiple units purchased. Mike Iden, in the article cited above, estimated that building a hydrogen fueling station for BNSF at Belen would have a capex of roughly $7.5 billion. Not including the cost of a new hydrogen locomotive fleet or continuing costs of providing the fuel itself, a hydrogen fueling station network for the entire BNSF Railway would cost well over $100 billion. Who knows what it would cost for all of North America? Aside from staggering costs, it is noteworthy that SBCTA's hydrogen fueling station adjacent to the San Bernardino main train station is located less than a thousand feet from homes in a disadvantaged community that is already heavily impacted by pollution and accident risk.

It is important for public transportation and infrastructure policy to not waste precious time and money going down technological dead-ends, when those resources should have been spent on a proven model: a rail system with conventional electrification as its backbone (with catenary-battery hybrids for relatively short unelectrified sections). In the Greater Toronto region, GO Transit wasted time and money looking into hydrogen propulsion after intense lobbying by pro-hydrogen interest groups. GO Transit decided against it, and to proceed with conventional OCS electrification after reviewing the evidence. However, the distracted diversion into hydrogen studies unnecessarily delayed and drove up the costs of the inevitable electrification project. UK Network Rail's 2020 *Traction Decarbonisation Network Strategy* report concluded that, for the currently unelectrified lines in the UK, rail decarbonisation requires electric, hydrogen and battery traction operating on respectively 86%, 9% and 5% of the rail network[40]. As concluded by a 2021 report by the UK Railway Industry Association:

> Evidence does not support the view that electrification is unnecessary, thanks to hydrogen and battery systems improving rapidly: hydrogen trains are inherently less efficient than electric trains, due to the physical properties of the gas. Expert opinion predicts that battery capability might double by 2035. *Yet, whilst this might affect the hydrogen / battery traction mix required for decarbonisation, it is unlikely to change significantly the requirement for electrification.*
>
> The laws of nature make electrification a future-proofed technology that is a good investment, offering large passenger, freight, and operational benefits. Furthermore, railways cannot achieve net-zero carbon emissions without a large-scale electrification programme.

As part of the "in-use locomotive" regulation approved by the CARB, technology re-evaluation is planned to occur in 2027. This regulation was proposed to review results of the hydrogen and battery locomotive

[40] https://www.networkrail.co.uk/wp-content/uploads/2020/09/Traction-Decarbonisation-Network-Strategy-Interim-Programme-Business-Case.pdf

demonstrations and pilot departments. However, there should also be evaluation of 25 kV overhead catenary electrification projects currently under construction (Caltrain, Central Valley HSR, and Brightline West). Perhaps the biggest danger of hydrogen, aside from its literal explosivity, is the opportunity cost of the money, time and resources that will be wasted on it, compared to conventional rail electrification. While a lot of recent transportation planning has emphasized implementing advanced technology as a goal, one cautionary factor is that the pursuit of new technology could become an end in itself, resulting in a deferral of investment in proven systems. Moreover, we need to have a global perspective when viewing passenger and freight rail investments. For example, high quality passenger rail service levels (and fast frequent freight trains), which many Americans may consider as being 'futuristic' or 'unrealistic', are, in fact, what Europe and Asia have had available for decades. There is a wealth of global experience and proven "off the shelf" technology that the US can utilize to address its transportation issues, particularly for rail electrification.

Sources of hydrogen

Despite some much hyped renewably-powered, electrolyzer hydrogen production pilot projects (which consume a lot of fresh water), the vast majority of hydrogen used in the world today comes from natural gas. This is why oil and gas companies are lobbying heavily for hydrogen propulsion in California and elsewhere. For example, the California Hydrogen Business Council receives financial support from fossil gas companies SoCalGas and Pacific Gas & Electric[41]. These companies sell fossil fuels extracted out of the ground, and hydrogen derived from these hydrocarbons is a way for them to continue doing just that. The promise that economical hydrogen produced from renewable energy is "right around the corner" has been played on repeat since the 1970s. It hasn't yet happened. The cost of renewably-produced hydrogen is still several times that of the fossil fuel-sourced variety. Almost all hydrogen trains in use today get their hydrogen from fossil fuel sources, with overall carbon intensity per passenger-mile on par with normal diesel-powered trains. There are promises to produce all the hydrogen required by these trains using electrolysis powered by renewables, but this has not happened yet. We are told to wait a few years, while fossil fuel sources will continue to supply hydrogen. However, hydrogen promoters have been continually promising that the economical green hydrogen is "only a few years away" for decades now. At present, renewably-produced green hydrogen is far more expensive compared to hydrogen sourced directly from fossil fuels. As a result of market forces (supply/demand/market speculation), the price of hydrogen for the EVB trains in Germany skyrocketed just as these trains were introduced. In this case, the hydrogen was coming from Russian gas.

Poor overall energy efficiency and higher electric power demand

Hydrogen trains are inherently far less efficient than all-electric trains powered by overhead wire, due to the fundamental physical properties of the gas. Hydrogen power for rail applications has very poor overall energy efficiency of about 34 percent, compared to about 90 percent for an electric train using an overhead wire[42]. The energy required to produce and store hydrogen requires three times more electricity than that needed to power an equivalent train directly with overhead wire from the grid. That means that trains using all-electric locomotives with pantographs will always have at least three times less impact on the environment than those using hydrogen. Even if the hydrogen comes from green sources, a train would require three times the amount of overall energy compared to an electric train connected directly to the grid[43]. Hydrogen vehicles powered by hydrogen from electrolysis--cars, trucks, and trains--would therefore make at least three times the demand on the power grid as vehicles powered directly by electricity. That means two-thirds of the energy used to produce the hydrogen is wasted.

[41] https://californiahydrogen.org/aboutus/chbc-members/
[42] https://www.railwayage.com/mechanical/locomotives/follow-the-megawatt-hours-hydrogen-fuel-cells-batteries-and-electric-propulsion/
[43] https://www.riagb.org.uk/RIA/Newsroom/Why_Rail_Electrification_Report.aspx

Water demand of hydrogen electrolysis

The fresh water demand of electrolysis would stress California's water supply. What if California is locked into a severe drought in the decades ahead? Combined with high stress on the power grid, the water demand of electrolyzers would add insult to injury. For a clean transportation backbone, Southern California needs to build extensive overhead catenary electric rail now, and not wait around for questionable technologies to Producing hydrogen from electrolysis requires fresh, distilled water. In dry regions like much of California where water is scarce, the available water supply is a serious limitation. Making hydrogen from salt or brackish water requires desalination, with all the additional energy consumption and local environmental impacts that entails.

In addition to the poor overall energy efficiency of green hydrogen, the fresh water needed to produce hydrogen by electrolysis may not be in sufficient supply in dry regions such as California. Using seawater as a source would have the same siting issues and environmental opposition faced by coastal desalination plants. As described by Mike Iden in a recent *Railway Age* article[44]:

> Looking at a fuel cell-for-diesel replacement scenario, in 2019 BNSF reported pumping up to 300 million gallons of diesel fuel annually at Belen, N.Mex. (population 7,423). Assuming all diesels through Belen were replaced with fuel cell locomotives, the 300 million gallons of diesel would be replaced by 300 million kg of hydrogen. Making that much hydrogen will require 12-to-20 million gallons of water every day (4.4 billion to 7.3 billion gallons every year), equal to 18% of neighboring Albuquerque's water demand for 563,000 people. Recall that the Santa Fe Railway first dieselized across Arizona and New Mexico 1940-1942 to overcome the lack of "good" boiler water. And the southwestern U.S. is now in a monumental drought. Will there be enough water and renewable electricity? "Maybe" is not a sufficient answer for a major project.

Complexity, expense and 'embodied environmental impacts' of hydrogen propulsion systems

The hydrogen supply chain, on-board storage systems, and drivetrains are highly complex. That means more points of potential failure, less reliability, and higher maintenance and operating costs. Moreover, hydrogen-powered locomotives are several times more expensive upfront than standard electric locomotives powered from overhead catenary. The significant upfront capital cost of rail electrification infrastructure is often given as reason to use hydrogen power instead. However, rolling stock is also a significant upfront capital cost. Hydrogen propulsion will greatly increase the capital cost of new rail fleets.

A hydrogen-powered train requires both batteries and fuel cells, which require rare materials that require mining (lithium, platinum, rare earth elements). In turn, obtaining these materials results in significant embodied carbon and local environmental impacts of mining, processing, and shipment. Directly powering a train with electricity, using an external source (overhead wire or third rail), avoids the 'embodied' environmental impacts of hydrogen fuel cells and batteries.

Hydrogen trains are expensive--about four times more expensive than a standard electrical multiple unit (EMU) passenger train: ~$11 million per 'U.S.-length railcar' (based on recent order of € 500 million for 27 'two-car' Alstom hydrogen trains in Germany). Battery trains are about twice the cost of a standard EMU: ~ $5 million per 'U.S.-length railcar' (based on a recent order of € 100 million for 11 'three-car' Alstom battery trains in Germany). Caltrans announced on February 14, 2024 that $127 million of our tax dollars

[44] https://www.railwayage.com/mechanical/locomotives/follow-the-megawatt-hours-hydrogen-fuel-cells-batteries-and-electric-propulsion/

would go to Stadler (an amount sure to increase) for six additional hydrogen trains[45]. That works out to just over $21 million per small trainset. The first order was $80 million for four hydrogen trainsets, or $20 million each[46]. Caltrain 7-car double-decker EMUs reportedly cost $55m each[47]. But one must compare the overall number of passengers with a 2-car single-decker hydrogen FLIRT costing $21 million per trainset[48] .

Caltrans has provided no technical evidence, analysis, or adequate explanation for why the state has decided to purchase hydrogen multiple-unit trainsets, with an option to buy many more, while electric alternatives were ignored. Both Caltrans and CARB have long been dismissive of rail electrification advocates in California, always ignoring rail electrification, the voluminous technical, economic and scientific data on it, and voices critical of hydrogen. Hydrogen promoters are automatically given the benefit of the doubt. Due to the lack of a robust technical evaluation process, unfortunately hydrogen trains were purchased without public discussion.

RailPAC asks Caltrans the following questions:

- Why did Caltrans sign this MOU before the first one has ever been delivered to and tested by SBCTA?
- Were other propulsion options even seriously considered?
- To what was the cost/benefit estimate for the hydrogen propulsion option compared?
- Was more conventional rail electrification even considered?
- If so, what are the reasons it was not chosen?
- Can the relevant documents relating to this procurement be the subject of a public records request?
- Why is it already decided that hydrogen is the way trains will be powered?
- What if the Stadler hydrogen multiple units turn out to be expensive failures? Why is Caltrans "betting the farm" on this one model of train?

Leakage/safety issues of hydrogen

Leakage of hydrogen from pipelines and storage tanks is a serious problem, not least because hydrogen itself is an indirect greenhouse gas. Also, hydrogen storage and fueling stations pose dangers to residents living near them. For example, the San Bernardino County Transportation Authority hydrogen train fueling station in San Bernardino is less than 400 feet from homes. Delivering hydrogen to rail fueling stations with trucks also poses dangers to the wider public.

Hydrogen storage facilities, pipelines, and fueling stations would have a disproportionate impact on low income/disadvantaged communities beside rail facilities. Leakages and explosion hazards from hydrogen rail support infrastructure will be quite serious. For conventional overhead electric rail, the trackside infrastructure needed (traction power substations, paralleling and switching stations) presents far less safety risk to local communities than hydrogen. Hydrogen also induces metal embrittlement and implies the need for specialist handling, storage and dispensing technology at a cost that would need to be recovered in any project using this fueling option.

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45 https://dot.ca.gov/news-releases/news-release-2024-007
46 https://dot.ca.gov/news-releases/news-release-2023-034
47 https://www.caltrain.com/media/31269/download
48 https://www.stadlerrail.com/en/flirt-h2/details/

Reliability and performance

With regard to passenger trains, it is uncertain if hydrogen propulsion will have the “sparks effect” phenomenon documented around the world, where electrification caused significant increases in ridership because of reduced trip times, increased frequency (in part due to lower operating costs), fewer train breakdowns, and the enhanced comfort of a quieter, smoother, smokeless ride.

The real-world operating experience of hydrogen trains in Germany has been plagued by reliability problems and very high-cost overruns. In 2022, the EVB regional railroad in Lower Saxony, Germany was the first in the world to introduce a fleet of hydrogen-powered trains. However, as mentioned previously, these hydrogen trains have turned out to be a disaster, with horrible reliability problems, massive cost overruns, and half of the promised range on a full tank of hydrogen. Lower Saxony’s public transportation authority recently announced that no more hydrogen trains will be pursued and that the remainder of the diesel fleet will be replaced with electric trains that use batteries combined with overhead wires. Another state in Germany, Baden-Württemberg, has come to the same conclusion, rejecting hydrogen rail propulsion, after an extensive study[49]. In February 2024, the states of Bavaria and Baden-Württemberg announced a conventional electrification plan for currently un-electrified lines[50].

It is noteworthy that the hydrogen trains that failed in Lower Saxony are rather light rail trains, put in service on less-used branch lines: the very application that the manufacturer Alstom said would be an ideal application. The drivetrain is not nearly powerful enough to move a heavy train. Based on real-world operating data of these hydrogen trains, they are up to 80% more expensive over their lifetimes than comparable battery or conventional overhead electric trains working the same lines.

[49] https://www.hydrogeninsight.com/transport/will-no-longer-be-considered-hydrogen-trains-up-to-80-more-expensive-than-electric-options-german-state-finds/2-1-1338438

[50] https://www.railjournal.com/infrastructure/electrification-plans-for-south-german-regio-s-bahn-network-agreed/

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Appendix 1: Electric power consumption of electric rail in the South Coast Air Basin

Energy consumption of electric rail, utility participation-

Electric utilities must be involved in planning for rail electrification from the outset. These utilities will provide the electric energy, build up new substation infrastructure to service electrified track, and construct or upgrade distribution and transmission lines. While there would be a need to construct new electric power infrastructure to serve electrified freight rail lines, electric utilities should see the new loads from freight trains as a business opportunity. In fact, the region's utilities are concerned about losing revenue from more and more customers, particularly large industrial and institutional ones, through their investment in distributed self-generation projects such as rooftop solar. Utilities also would benefit from being able to transmit or distribute power via rail rights-of-way. Existing transmission and distribution grid infrastructure needed to service electrified track in the Los Angeles area tends to be in industrial areas and alongside rail lines. The power for electric locomotives can come from zero-emissions sources, including hydroelectric, geothermal, solar and wind power, providing a larger market for these resources.

Energy storage, as well as SCE and LADWP's self-generation incentive programs, are also changing their utility business model. In the SCE planning area, the peak output of customer self-generation by solar photovoltaic (PV) sources is projected to increase to as much as 2,500 MW by 2026, and as much as 1,300 MW for non-PV source[51]. In the LADWP planning area, the peak output of customer self-generation by PV sources is projected to increase to as much as 340 MW by 2026, and as much as 240 MW for non-PV sources[52]. California's largest utilities are also now required to procure progressively larger amounts of energy storage capacity in the years ahead. Energy storage connected to electric rail catenary, and trackside charging systems for locomotives with batteries, could be located at passenger train stations and along freight railroads. A sufficient level of energy storage along a rail line could provide backup power in case of a local or regional power outage.

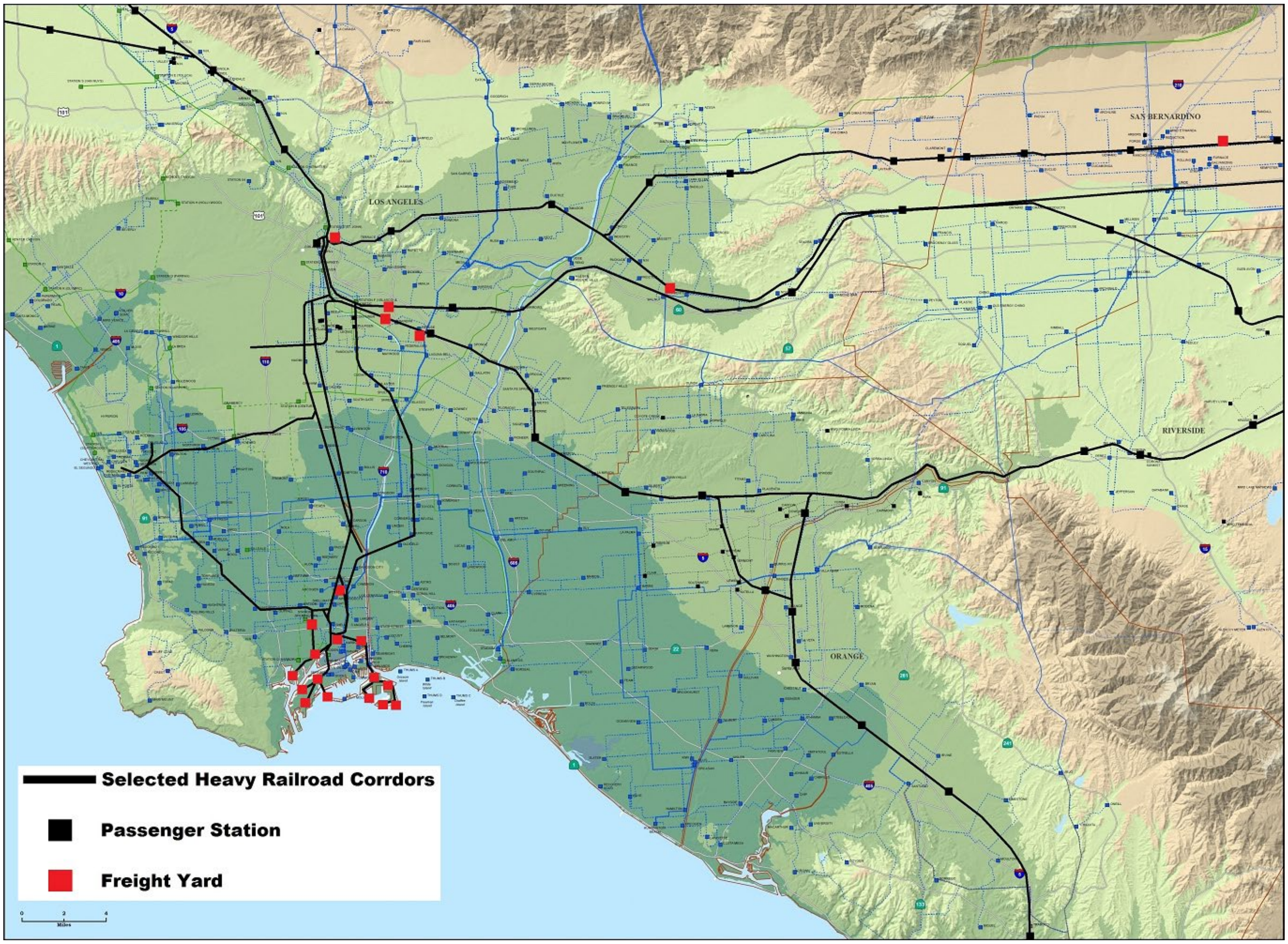
These rail energy storage systems also could provide a new business opportunity for electric utilities. Under utility control, these storage systems could be charged at off-peak hours, provide power to the local distribution grid during periods of peak demand, and provide ancillary services (e.g., voltage and frequency support, reactive power), or aid integration of distributed solar energy systems. California utilities should consult the experience of other countries with both extensive electric rail and high percentage of renewable energy generation, such as Germany and Spain. Both nations have populations greater than California's, meet

[51]*California Energy Demand 2016-2026 Revised Electricity Demand Forecast, Volume 2: Electricity Demand by Utility Planning Area*, California Energy Commission, January 2016, pg. 43: http://docketpublic.energy.ca.gov/PublicDocuments/15IEPR03/TN207438_20160115T152222_California_Energy_Demand_20162026_Revised_Electricity_Demand_Fo.pdf

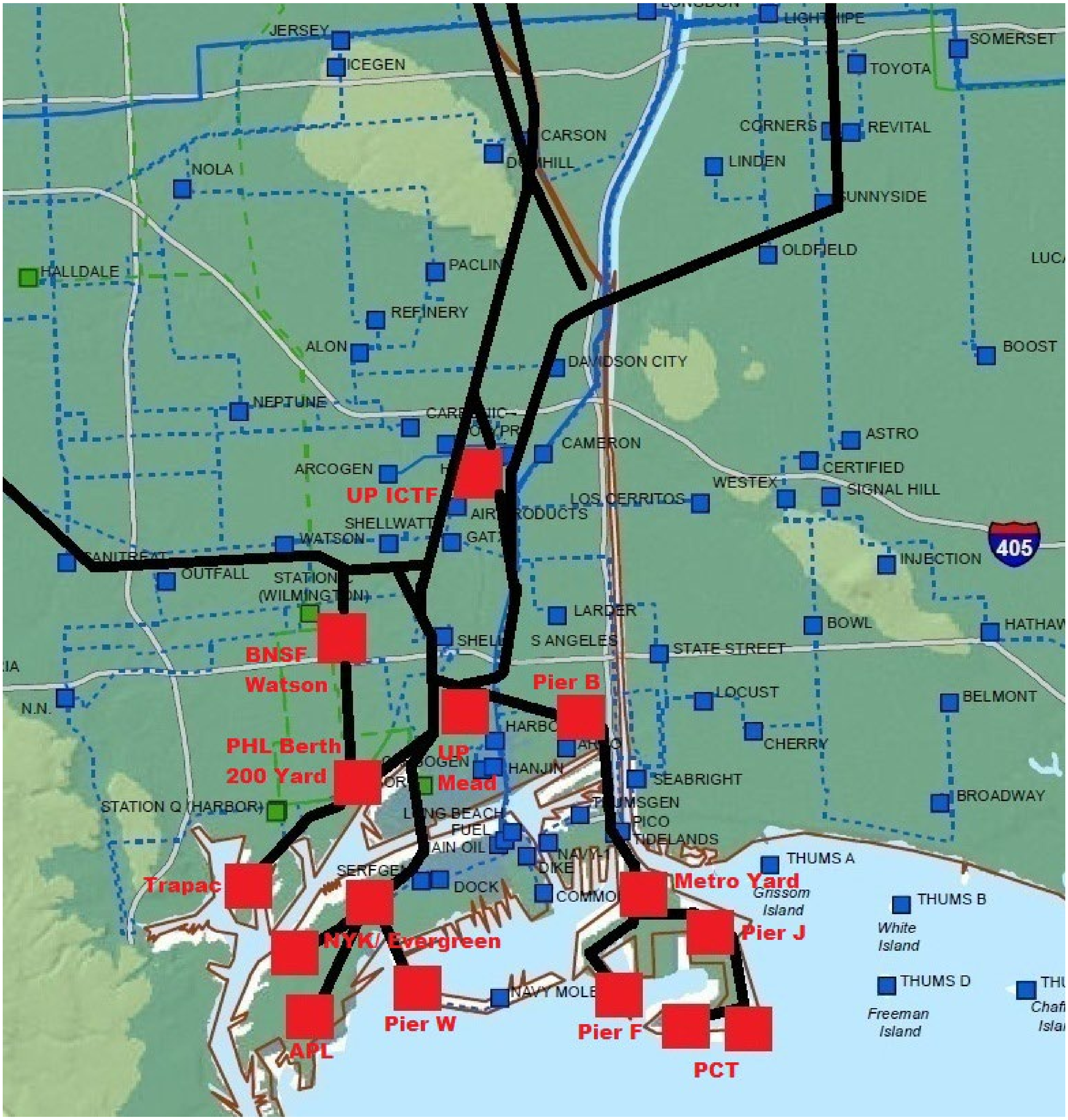
[52]Ibid., pg. 108.

more than one-third of their overall electricity needs from renewable sources (excluding large-scale hydroelectric), and have a rail system electrification rate of at least 60%.

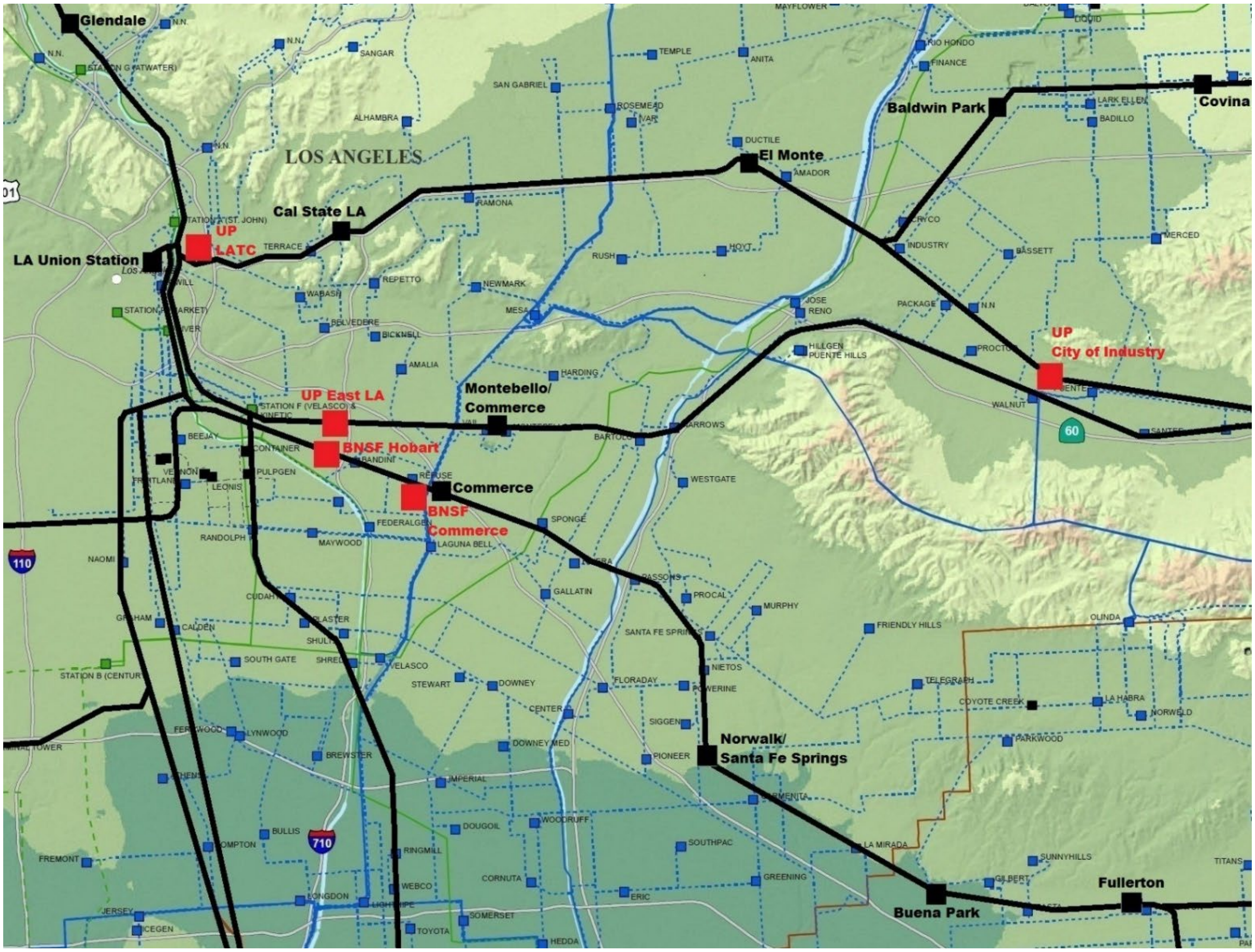
Existing transmission and distribution grid infrastructure needed to service electrified track in the Los Angeles area tends to be in industrial areas and alongside rail lines, as shown on the three maps below.



Selected heavy rail corridors, passenger stations and freight yards in the Los Angeles basin, overlaid on map of existing electric utility transmission lines and substations.
Background map: California Energy Commission



Selected heavy rail corridors and freight yards (red squares)- San Pedro Bay harbor area, overlaid on map of existing electric utility transmission lines and substations. Port of Los Angeles on the left side of harbor, Port of Long Beach on the right.
(Background map: California Energy Commission)



Selected heavy rail corridors, passenger stations (black squares) and freight yards (red squares)- central Los Angeles and east, overlaid on map of existing electric utility transmission lines and substations.
(Background map: California Energy Commission)

The projected future loads from electric freight trains need to be put in perspective of the greater LA region's overall electricity consumption. Table 4 below shows the California Energy Commission's projected electric energy demand, by selected sector, for the designated utility planning area of SCE, which also includes municipal utilities surrounded by SCE's service area, and that of LADWP. As can be seen in the table below, the present combined industrial annual electricity demand for the SCE and LADWP planning areas of 24 TWh is projected to stay flat or increase only slightly by 2026. The utilities would likely treat electrified freight rail as a large industrial load. The utilities are already planning for electric vehicle demand, not including electric rail, which is projected to increase to 4 TWh/year by 2026 in the combined SCE and LADWP planning areas. In fact, electric transportation (automobiles and rail) is the only load type that California utilities expect to increase significantly, as energy efficiency and customer self-generation is expected to slow the growth of electric utility load for most other uses.

Table: Present and projected 2026 electric energy demand in SCE and LADWP utility planning areas[53]

Designated utility planning area	2015 estimated annual total electricity demand (TWh)	2015 estimated annual industrial electricity demand (TWh)	2026 Maximum projected annual total electricity demand (TWh)	2026 Maximum projected annual electricity savings from energy-efficiency programs (TWh)	2026 Maximum projected annual electricity consumption from non-rail electric vehicles (TWh)
SCE	110	20	122	32	3
LADWP	25	4	28	8	1
Total SCE + LADWP	135	24	150	40	4

Both LADWP and SCE have goals of meeting 33% of total electric energy demand from renewables by 2020, and 50% by 2030, reflecting the state of California's goal. LADWP has pledged to completely phase out coal-generated electricity by 2025. In 2016, about 20 TWh of solar electricity was generated in California (not including roof-top solar projects on homes and small businesses), while wind generated about 13.5 TWh and geothermal contributed about 12 TWh[54].

As a comparison, the total solar, wind and geothermal share of the electricity generated in 2016 within California, approximately 46 TWh, is *forty-six times* the 2050 projected freight rail electric energy consumption for the South Coast Air Basin described by the 2016 CARB studies. The share of renewable energy in the state's electricity mix is growing rapidly. California leads the nation in utility-scale solar energy development, with an installed generating capacity of about 10,000 MW in 2016[55]. At least 15,000 MW of solar energy capacity is in various stages of development in the state[56]. A typical solar power plant has an overall capacity factor of 20%. In theory, this would indicate that about 570 MW of solar power generation capacity would be needed to produce 1 TWh of annual electric energy.

Energy storage, as well as SCE and LADWP's self-generation incentive programs, are also changing the utilities' business model. In the SCE planning area, the peak output of customer self-generation by solar photovoltaic (PV) sources is projected to increase to as much as 2,500 MW by 2026, and as much as 1,300 MW for non-PV sources[57]. In the LADWP planning area, the peak output of customer self-generation by PV sources is projected to increase to as much as 340 MW by 2026, and as much as 240 MW for non-PV sources[58]. California's largest utilities are also now required to procure progressively larger amounts of energy

[53] *California Energy Demand 2016-2026 Revised Electricity Demand Forecast, Volume 2: Electricity Demand by Utility Planning Area*, California Energy Commission, January 2016: http://docketpublic.energy.ca.gov/PublicDocuments/15-IEPR-03/TN207438_20160115T152222_California_Energy_Demand_20162026_Revised_Electricity_Demand_Fo.pdf

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[57] California Energy Commission, January 2016, pg. 43.
[58] California Energy Commission, January 2016, pg. 108.

storage capacity in the years ahead. Energy storage connected to electric rail catenary, and trackside charging systems for locomotives with batteries, could be located at passenger train stations and along freight railroads. A sufficient level of energy storage along a rail line could provide backup power in case of a local or regional power outage.

These rail energy storage systems could be a new business opportunity for electric utilities. Under utility control, these distributed energy storage systems could be charged at off-peak hours, provide power to the local distribution grid during periods of peak demand, and provide ancillary services (such as voltage and frequency support, reactive power), or aid integration of distributed solar energy systems. California utilities should consult the experience of other countries with both extensive electric rail and high penetration of renewable energy generation, such as Germany and Spain. Both nations have populations greater than California's, meet more than one-third of their overall electricity needs from renewable sources (excluding large-scale hydroelectric), and have a rail system electrification rate of at least 60%.

Regenerative braking-

Significant among the benefits of electric locomotives on mountain grades, such as the Cajon Pass north of San Bernardino, is regeneration of power from braking. This recovered power can be used to power other trains nearby on the same line or fed back to the power grid via bi-directional substations. There are potential benefits to utilities from electric rail regenerative braking. From a utility perspective, an electric locomotive feeding power back to the grid would basically be serving as a distributed generation source. SCE and LADWP not only have much experience serving the expanding network of passenger electric rail lines but are already investigating harvesting energy fed back into the grid from the regenerative breaking of electric transit trains, as described below.

For several years, the Los Angeles Metropolitan Transit Authority (Metro) has been testing both on-board energy storage systems and wayside energy storage systems (WESS), to store energy produced by regenerative braking of subway trains[59]. At Metro's Westlake/MacArthur Park subway station, a 2 MW VYCON flywheel WESS system was installed in April 2014[60] . Metro's electric rail transit vehicles are DC-powered, with relatively low voltages, making feeding regenerated power back to the grid more difficult. Electric freight locomotives would use much higher voltage AC power, 25 kV or 50 kV, reducing line losses. The feeding of power back to the grid from an electric locomotive's regenerative braking dates to at least 1909, on the first AC-powered electric trains of the Great Northern Railway in the Washington Cascades. Despite the existence

[59] Los Angeles County Metropolitan Transportation Authority (METRO), *Sustainable Rail Plan*, May 2013, pgs. 10-17:
http://media.metro.net/about_us/sustainability/images/sustainable_rail_plan_final_clean_submitted.pdf

[60] "LA Metro VYCON WESS system saving energy", *Railway Age*, November 4, 2014:
http://www.railwayage.com/index.php/passenger/rapid-transit/la-metro-vycon-wess-system-saving-energy.html?channel

of modern-day AC locomotives feeding power back to the overhead wire, the CARB 2016 RailTEC report was largely dismissive of regenerative braking[61]:

> Like the battery tender concept, regenerative braking offers the potential to further decrease electrical energy consumption and source emissions. The catenary traction power distribution system can be used to transfer energy from electric locomotives in dynamic braking to electric locomotives on other trains that are consuming traction power. Unlike the battery tender concept, however, the regenerated energy cannot be stored. Regenerated power can only be used if there is a nearby train in the same power district to absorb the energy. In Europe, where mainline electrification is common and short passenger trains tend to operate on more frequent headways, train schedules are carefully choreographed to maximize use of regenerated energy (van der Meulen, 2013). Obtaining similar levels of regeneration within the study area is likely to be difficult due to the longer headways between heavy freight trains and the greater schedule flexibility of freight train operations. Due to the substantial daily variation in freight train operating patterns, this study does not consider regeneration in its evaluation of electrification.

The CARB report's assertion that a train's regenerated energy cannot be stored is incorrect. WESS systems under development around the world are proving the practical application of storing energy from a train's regenerative braking. In addition, a number of electric transit vehicles in use around the world store energy from regenerative braking with on-board batteries and capacitors. WESS installations could be coupled with smart inverters that could benefit electric utility operations, as described above. The value of regenerated energy, to not only reduce train energy consumption, but also to be of value to the power grid as a whole, must be studied for Southern California rail electrification.

[61] *Transitioning to a Zero or Near-Zero Emission Line-Haul Freight Rail System in California Operational and Economic Considerations, Final Report.* Prepared for State of California Air Resources Board by University of Illinois at Urbana-Champaign Rail Transportation and Engineering Center (RailTEC), Spring 2016, pg. 19: https://www.arb.ca.gov/railyard/docs/uoi_rpt_06222016.pdf

Appendix 2: Port of Long Beach Pier B Railyard EIR on rail electrification

The Port of Long Beach January 2018 Pier B On-Dock Rail Support Facility Project EIR response to public comments about rail electrification as a mitigation measure repeats and cites numerous falsehoods from the 2016 report as justification for not considering rail electrification:

> **Master Response – *Electrification of Alameda Corridor and Z*ero Emission Locomotives**
> A number of comments expressed views that electrification of the Alameda Corridor should be considered in the EIR and that electric or zero emission locomotives should be used as mitigation for the Pier B On-Dock Rail Support Facility Project.
>
> Electrification of the Alameda Corridor is outside the scope of the proposed Project. The application of zero emission technologies to rail locomotive operations within and beyond Port boundaries is extremely complex. Zero emission technologies for rail operations face implementation challenges due to the need for additional infrastructure and limitations to the Port's authority as it pertains to rail operations, specifically line haul rail operations. Federal law specifically precludes government agencies such as the State and the Port from imposing requirements that interfere with private rail operations (see, e.g., 49 United States Code [U.S.C.] § 10101 *et seq.*). Moreover, the Alameda Corridor Use and Operating Agreement specifically prohibits the Ports from unilaterally mandating rail electrification. Specifically, in Section 2.2(c), the Agreement provides "Neither POLA [Port of Los Angeles], POLB, nor ACTA [Alameda Corridor Transportation Authority] will require the Railroads to operate Through Trains powered by electric locomotives on the Rail Corridor unless the Railroads voluntarily agree thereto, provided however, if electrification is otherwise required, such requirements shall not be a basis on which any party may terminate this Agreement, but if legally permissible, a Railroad may satisfy the requirement to use electric powered locomotives by using locomotives powered by an alternative energy source acceptable to the appropriate government entities" (page 15). As a result, any steps towards electrification in the future would have to be jointly agreed upon by the railroads. To date, the railroads have not agreed to electrification. The Port does not have the authority to implement emission control measures on line haul engines operated by Burlington Northern Santa Fe (BNSF) and Union Pacific Railroad (UPRR), which are separate entities not under control of the Port. Furthermore, electrification of the rail system or use of zero emission locomotives would need to be implemented on a larger scale, rather than in connection with a single rail yard, such as the Pier B On-Dock Rail Support Facility.
>
> Under CEQA, an EIR must describe feasible mitigation measures that could minimize the project's significant impacts. Per CEQA Guidelines Section 15126.4(a)(1), **an EIR need not identify and discuss or analyze in detail mitigation measures that are infeasible [emphasis added].** According to the CEQA Guidelines Section 15364, "feasible" means "capable of being accomplished in a successful manner within a reasonable period of time, taking into account economic, environmental, legal, social, and technological factors." [rail electrification has been feasible for over 100 years!]
>
> While zero emissions technologies are promising, no zero emission switching locomotives have yet been proven to be feasible in port operations nor have yet been fully commercialized. The California Air Resources Board (CARB) prepared *Technology Assessment: Freight Locomotives* (CARB, 2016c), which considered potential advanced locomotive technologies that could, at some point, operate on the existing rail network with emissions below the current national Tier 4 emission levels. The Technology Assessment outlined the numerous technological, costs, legal, and logistical constraints that render zero emission rail operations infeasible. As previously mentioned, electrification of the rail system or use of zero emission locomotives would need to be implemented on a larger scale. In the Technical Assessment, **CARB acknowledges several significant challenges associated with freight**

electrification, which includes capital costs upwards of $50 million or more per route-mile, further indicating that with up to 500 miles of total major rail route in and around the South Coast Air Basin (SCAB), the total capital costs could be up to $25 billion or more [emphasis added-this is highly misleading-these cost figures are wildly exaggerated by CARB]. . In addition, CARB also found that a basin-specific rail electrification system has the potential to create delays in operations. As an example, CARB states that an all-electric operation in the SCAB would need to change locomotives at an exchange point to connect to the North America diesel-electric freight rail system for the remainder of the trip. Another significant challenge is the need to build a substantial electricity-generating system. According to CARB, UPRR and BNSF generate up to 400,000 locomotive megawatt-hours (MWh) or more of electricity in the SCAB. By 2050, up to one million MWh would be needed by UPRR and BNSF to operate in the SCAB. **A significant level of electric power infrastructure would be needed to meet the electricity demands of heavy hauling freight rail operations in the SCAB and in the rest of California [emphasis added-this is highly misleading. The amount of new electric power infrastructure needed would be small compared to that needed by electric trucks carrying the same amount of cargo].**

Therefore, based on the assessment, CARB recommended dual paths for locomotive technology deployment. One path would be to seek significant criteria and toxic pollutant reductions beyond Tier 4 in the near to mid-term with after-treatment technologies, augmented 1 with on-board batteries. The second path would be to develop zero-emission track mile or 2 zero-emission locomotive technologies needed in the mid- to long-term (2025 -2050). As such, it is considered infeasible to require that zero emission locomotives be used as mitigation for the proposed Project.

The current Pacific Harbor Line (PHL) operating agreement is set to expire at the end of 2024. If the proposed Project is approved, the Port would negotiate with the short-haul switching operator to incorporate into subsequent operating agreements requirements to participate in demonstration of and/or implement a new technology if one is determined to be feasible in terms of cost, and technical and operational feasibility.

PHL, which provides short-haul rail transportation services for the POLB and the POLA, will primarily operate the proposed Pier B On-Dock Rail Support Facility. PHL has been a partner with the Ports in demonstrating several technologies, including liquefied natural gas (LNG)-powered and hybrid-electric locomotives. PHL has been recognized as one of the cleanest locomotive fleets in North America as a result of converting its fleet to clean diesel locomotives that achieve “Tier 3-plus” ultra-low emission standards. The Tier 3-plus engines emit 85 percent less diesel particulate matter (DPM) and 38 percent less nitrogen oxides (NOX) emissions compared to the Tier 2 locomotive engines they replaced. To upgrade the locomotives, the Port extended PHL’s operating agreement term for PHL to commit to use the ultra-low emission locomotives in the San Pedro Bay Ports (SPBP) through 2024. In March 2017, PHL began a demonstration of a locomotive developed by Progress Rail that is expected to meet United States Environmental Protection Agency (EPA) Tier 4 emission standards.

Through the Ports’ Technology Advancement Program (TAP), PHL is partnering with VeRail Technologies (VeRail) in the development and demonstration of a locomotive that combines near-zero emission engines with on-board high-capacity storage for compressed natural gas (CNG) and backup diesel-fueled generator sets (gen-sets) that would only be used for peak power needs and as a safety backup. The VeRail near-zero emissions locomotive would be the first locomotive to meet the CARB Tier 4-plus and near-zero emission levels for switcher locomotives. The CARB Tier 4-plus standards achieve a 70-percent reduction below current EPA switcher locomotive engine standards for NOX and particulate matter (PM). The VeRail locomotive will be required to conduct extensive emissions testing, as well as validation and durability testing to ensure the locomotive’s design. The locomotive will be demonstrated in PHL’s day-to-day operations for a period of 1 year to further validate its in-use performance, durability, and reliability.

Recently, VeRail began exploring the design of utilizing batteries instead of the diesel generator-sets that would allow the locomotive to operate in full zero-emissions. Based on VeRail’s estimates, the batteries

> could power the switching locomotive in zero emissions mode for more than 8 hours before requiring a recharge. Should the batteries last for less than a full shift, the locomotive could operate as a fully functional near-zero natural gas locomotive.
>
> As a special condition of the proposed Project, the Port would conduct a periodic technology review every 5 years following the project approval date. New air quality technological advancements are subject to consideration by the Port on the basis of operational feasibility, technical feasibility, and cost effectiveness/financial feasibility.

This particular VeRail project failed- as the company ceased operations. The LNG-powered locomotive tested by PHL is still polluting and emits enormous amounts of GHGs.