Battery-Powered Rail Locomotives at ProvPort?:

Connections & Reflections on My Research Experiences Thus Far

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I. Introduction

Prior to my Research Summer at Brown under the Laidlaw Scholars Program in Providence, Rhode Island, I had in fact written papers and done research before. As a graduating high school senior from my local International Baccalaureate, IB, Diploma Program merely over a year ago, as of writing, I had actually in fact been exposed to academic writing when writing extended papers for my Internal Assessments, exploring the variety of subjects I had taken including Math, English, Chemistry, Visual Arts, and Modern History of the Americas.

By far, however, the longest and most extensive research paper I've written thus far was my IB Extended Essay on the potential environmental viability of using battery-electric locomotives near the Port of Los Angeles to help reduce citywide pollutants and temperatures, a paper that took months to complete in my senior year. While I may have not been in a lab collecting my own data nor supervised under an established research group at a top university, nor did I look into actual realtime data of battery powered locomotives being trialed at the time in the Los Angeles Port area, my paper did go well into the data I found available publicly published by government agencies to nevertheless lead to an established conclusion.

This past summer, I was able to work with Professor Meredith Hastings on her "Breathe Providence" Project, a project that aims to research and mitigate Providence's surprisingly beset air quality issues with its own Low-Cost Sensor (LCS) network and promote sustainable change. While most of the work I did was engineering work on developing, manufacturing, and designing new low-cost temperature sensor assemblies, what I learned from my other undergraduate peers and the project itself tie many of Rhode Island's air quality issues to the Port of Providence. With this new viewpoint, I've decided to look back at my now past Extended Essay to further hypothesize on battery electric locomotives.

II. Backgrounds and Connections

Providence's Air Quality Problems

Without a doubt, Providence and Rhode Island as a whole has, for a long term, shown to be riddled with air quality issues. In fact, "Rhode Island has the highest statewide asthma prevalence in the US and the city of Providence leads the state in child emergency department visits with asthma as the primary diagnosis" (Berg et al. 3), according to the CDC, implying that the air being breathed by residents is not without issue and a crucial motivating metric in the formation of the Breathe Providence Project.

Some of these issues could potentially be attributed to the large volume of transportation within the city, as the city is right in the center of the Interstate-95 Corridor between New York City and Boston, not to mention the hundreds of miles, many states, and people the Interstate connects in the Eastern United States. It is estimated that "almost 200,000 vehicles pass through Providence on Interstate-95 daily" (Rhode Island Department of Transportation). While many cities in the United States, such as Los Angeles, rely heavily on motor vehicles, what makes Providence, a relatively small city with less than a quarter-million residents compared to giants like Los Angeles, is the local government's deregulation and often evident misregulation of citywide emission, infrastructure, and most importantly industries. Regardless of Rhode Island's relatively stagnant economy, the Port of Providence, or ProvPort, is still within an active industrial center that is home to a nearby scrap recycling company and not too far from an asphalt plant in neighboring Pawtucket. The Port itself, in general, likewise harbors primarily industrial supplies, such as refined metals, asphalt, and even refined petroleum, amongst others and is a hub for marine, road, and rail transportation.

RIDEM, the Rhode Island Department of Environmental Management, has historically only relied on one of four environmental monitoring stations as the state's "supersite" to pass EPA regulations, possibly on behalf of a vast majority of Rhode Island's population and its area as a state. "However, it is located in a majority-white, East Providence neighborhood with a lower rate of asthma than the county average. While the reference network exceeds regulatory requirements, it was not designed to collect hyperlocal air quality information nor to reflect population vulnerabilities" (Berg et al. 3).

Hence, after complaints from locals over years of things such as physical reactions, unnatural odors around the areas of the port, and even smoglike condensation buildup on windows, it was clear that there was indeed an issue in the city's air quality. "Advocates have called for a more comprehensive air monitoring network that prioritizes areas with the greatest environmental burdens and most vulnerable populations", all outlined in Providence's 2019 Climate Justice Plan, "a strategy for the city's 'just transition' away from fossil fuels published by the Racial and Environmental Justice Committee" (Berg et al. 3). This hence motivated Breathe Providence's formation, as many institutes around the country and communities have operated low-cost sensor networks like Breathe Providence does now to gain more insight on hyperlocalized pollution and generate an overall picture that less prevalent monitoring such as RIDEM's supersite cannot account for within a community.

Los Angeles's Own Issues

Like in Providence, Los Angeles, the second largest city in the country, has had its own issues, particularly with heat, as I'd learned in high school. Emission of nitrous oxides (NO_x) in the Los Angeles Area specifically have been a problem, as they have been a proponent of rising temperatures in the area and poor air quality. As a result, the city could anticipate almost 3 times as many heat-related deaths per year due to extreme heat by 2050 (Atlantic Council Climate Resilience Center). "For example, in 2006 a heatwave in California resulted in 16,000 emergency-room visits and 650 deaths, costing $5.3 billion" (Atlantic Council Climate Resilience Center). Combined the direct impacts of heat on health, The Los Angeles area and California entirely has faced difficulties with wildfire and drought, "which can both be triggered by and compound the physiological impacts of heat on LA's population" (Atlantic Council Climate Resilience Center). Moreover, NO_x promotes the formation of smog and haze, chemicals which have historically impacted LA.

Especially after the pandemic in 2020, a significant rise in port traffic had been reported, with supply chain issues in the following years being extremely prevalent. Per 1,000 Twenty-foot equivalent units (or TEUs), 2021 was likely the busiest the port has been over the last 10 years since 2011, harboring an immense 10,879,000 cubic feet in volume of containers that year ("Port of Los Angeles: Throughput"). From my research then, I also learned that citywide temperatures also saw major negative increases through extended greenhouse gas emissions and the urban heat island.

III. Inspiration from LA Port: Battery Powered Locomotives

Transportation's Share in LA's Air Problems

LA's air quality, from what I uncovered, is in part greatly influenced by simply the sheer volume of transport influx, especially after the economy. In general, transportation related air pollution must be the greatest in volume in the state, emitting nearly 140 million metric tons of carbon dioxide (CO_2) in 2021, which is more than double the amount of the next highest emitting sector, industrial power. This means that in 2021, 38.2% of greenhouse gas emissions in California were accounted for by transportation, according to a report by the California Air Resources Board (CARB, "California Greenhouse Gas Emissions…" 12). Emission of nitrous oxides in the Los Angeles Area specifically has been a problem, as they have been a proponent of rising temperatures in the area and poor air quality. Of these transport forms, although seemingly more obsolete and less versatile, without a doubt California and the United States as a whole still rely on freight trains to haul immense amounts of cargo and resources. And though large diesel electric locomotives that rumble through the port are not necessarily clean burning, they do, as CARB shows below, do currently emit less than diesel road vehicles.

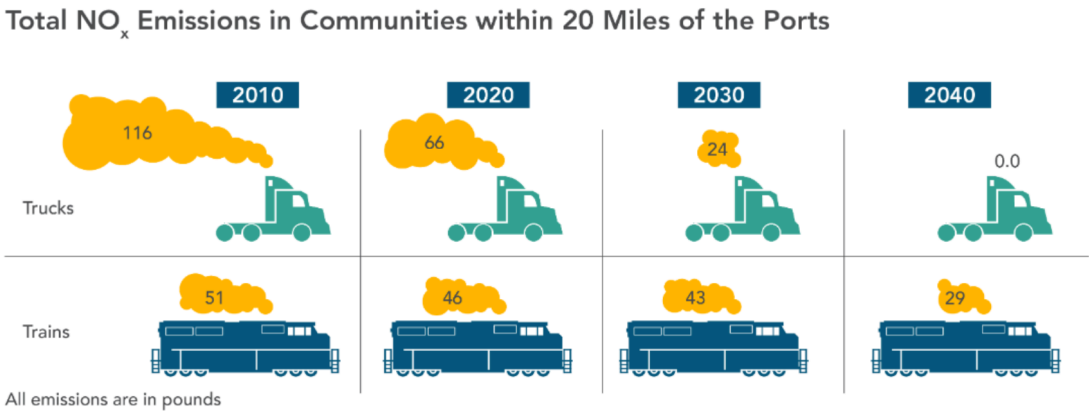

Fig. 1. Total NO_x emissions from trucks and trains in communities within 20 miles of California ports, 2010–2040.
Source: CARB, "Truck Vs. Train Emissions Analysis."

Zooming in on Rail

The infographic above is based on an estimate of a typical freight train running four locomotives with 130 cars and 260 containers as opposed to 260 trucks carrying each container. Hence, based on this infographic, trains, despite emitting less pounds of NO_xcurrently, are still projected to be emitting substantial amounts in the coming years because of the state's pledges to operate carbon neutral zero emission EV road vehicles. Annually, across the whole state of California in 2022, locomotives were projected to emit over 29,800 tons of NO_x (CARB, "Truck Vs. Train Emissions Analysis") .

While these numbers may not have looked promising, at the time I had argued in my paper that rather than taking this as a negative, what can be for certain is that battery electric locomotives could indeed derail these air pollutants.

Locomotive Model	Type	Weight per Locomotive (MT)	Traction Power per Locomotive (MW)	Usable Energy Capacity per Locomotive (MWh)	Minimum Number of Locomotives Required (FOS: 1)	Minimum Number of Locomotives Required (FOS: 2)
Typical Diesel Locomotive[9]	Diesel	218	3.2	65.2	4	4
SD70J-BB[10]	Battery Electric	245	5.7	10.44	4	4
FLXdrive Heavy-Haul[11]	Battery Electric	209	3.2	5.04	8	9
SD70J	Battery Electric	194	3.2	5.76	6	8

Table 1. Comparison of diesel and battery-electric locomotive models by weight, power, and energy capacity.
Source: CARB, "Feasibility Analysis: Port of LA to Barstow."

The table above was generated from a 2024 study that CARB put out, which tested three battery electric locomotives that at the time became recently commercially available from various manufacturers against a typical diesel locomotive. The locomotives listed below in the

table were assigned to pull a 130-car train containing 283 shipping containers, replicative of a typical intermodal train that may travel from the Port of LA to Barstow, which unexpectedly is a very similar consist, or configuration of a train's freight cars and locomotives, to the one referenced in that short infographic. Based on the infographic, it was clear that these locomotives can in some cases produce as much, if not more, tractive effort than or as a typical diesel locomotive. However, all these battery-electric zero emission locomotives lacked usable energy in megawatt hours, meaning their operating time is much less than a diesel locomotive. While this data may seem unsatisfactory and suggests that battery electric power is not quite up to the standards of traditional diesel locomotives, the test in the end was deemed a success for battery electric, as this test run is likely the best it had ever performed.

At the time, I also referenced a 2021 test where these engines were placed together in a hybrid consisting of diesel and battery electric locomotives together and noted positive savings and reductions of both fuel consumption and Nitrous oxide emissions, as shown below in the respective scatterplot from that study.

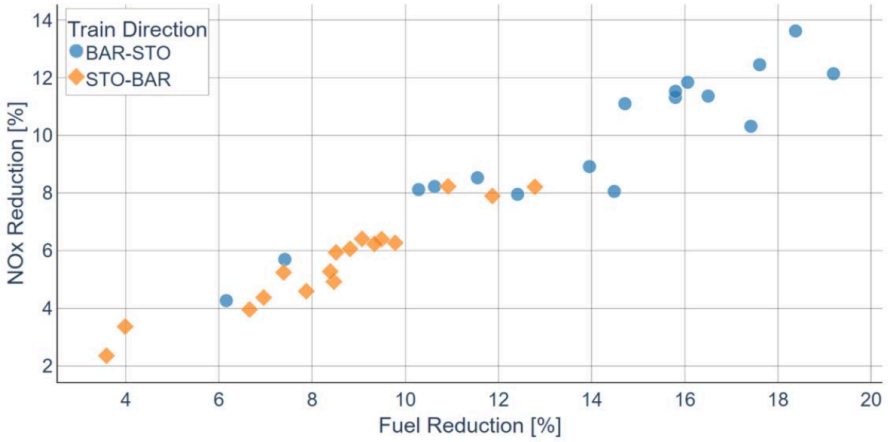

Fig. 2. NO_x reduction vs. fuel reduction for a hybrid diesel–battery-electric locomotive test, Barstow–Stockton route.
Source: Garrett Anderson et al., "BNSF ZANZEFF Data Acquisition Support."

IV. Reflecting On My Findings from Before

In retrospect, while it was true that battery electric locomotives were a new technology that would potentially bring emissions as a whole closer to net-zero in the state, my findings did not account for the cost of the new technology and more importantly the impact of its range explicitly in my original paper. Rather, I concluded that there was indeed potential for environmental change, but not in the sense of pulling all freight trains.

Looking back at small shortline railroads and industrial railroad locomotive uses, what is clear is that battery locomotives perform seemingly as well as diesel locomotives and are capable. Moreover, most diesel locomotives can be converted to battery power. In normal diesel electric locomotives, a prime mover, or the diesel engine itself, will power an electric generator that powers the electric traction motors, which turn the wheels and allow the train to operate under its own power. On the other hand, a battery electric locomotive simply has large batteries to help power the DC traction motors directly, which would bypass the diesel prime mover and generator or even entirely require the removal of those parts, hence phasing out the need for diesel fuel and reducing the locomotive's emissions to zero (CARB, "Zero Emission Locomotive Conversion" 7).

While more complex than this, the conceptual idea is the same and likewise for a few years many railroads have tried to actually rebuild old diesel locomotives to have batteries instead of a diesel-guzzling prime mover. This way, many railroads have been able to economically rebuild their aging diesel locomotives and potentially in fact save on fuel prices, as many of these locomotives can be charged by the industry's own power grid. Yet, regardless, the main advantage is that with their limited range at the current state, battery electric locomotives still fit the niche for short haul yard and switching work, which typically involves moving cars

around in railyards or to short distances to exchange with longer and larger trains with greater range. Typically, road switcher locomotives are indeed smaller and need less fuel and are most widely used in industrial foundries or factories with rail connections, dedicated railroad yards, and of course, ports with railroad tracks.

By the time I completed my paper near the end of 2024, the Pacific Harbor Line Railroad that manages most of the tracks near the ports accepted funding to order new battery locomotives as the tests of an EMD joule in the port itself were deemed successful (Chirls). At the time during it testing, lots of speculation was being put on this new locomotive, as was in 2023 when the Midwest Terminals, a shipping port based in Toledo, Ohio, rebuilt a locomotive from 1954 to run on 100% battery power and announced a second rebuild in late 2024 after that success (Patch).To recuperate their limited range, ports and industrial settings have used simply their own power grids to recharge these locomotives. In a report, CARB states that only about 600 Megawatt Hours of energy would be needed daily by all switcher locomotives specifically across all major California rail yards (CARB, "Yes, the California Grid…"). Compared to the amount of electricity being produced by the statewide power grid daily (about 532,000 MWh), the amount which all switchers would use is a mere 0.1%. In the same report, CARB used an estimated 75,000 gallons of fuel being consumed by each switcher annually, meaning that it consumes 205 gallons of fuel daily (CARB, "Yes, the California Grid…"). Regardless, the main benefit of using the state power grid to charge battery powered locomotives would be the savings in diesel fuel consumption, and likewise the reduction in air pollution from diesel fuel.

V. Closing and Reflecting

Given that the port of Providence shares much of the same issues as LA port, although at a much smaller scale and volume, it is without a doubt a feasible claim to say that battery electric rail can greatly reduce Providence's pollution issues. In fact, here in the northeastern US, the Massachusetts Bay Transit Authority, MBTA, which is the main commuter rail service to Providence, very recently announced plans to procure new battery powered passenger locomotives on the Providence Line in February 2026 (Massachusetts Bay Transportation Authority). Given that areas such as the lines in Providence currently have infrastructure for electric passenger trains, it potentially even gives battery electric trains their own charging infrastructure, thus combatting needs for electric locomotives limited to lines of overhead catenary wires and potentially the range of battery electric locomotives on a single charge.

Looking back, as a student in high school at the time and a college student who has only worked on sensors for the Breathe Providence project and merely presented that paper on a poster at a research conference here at Brown, I reasonably can only speculate with what I've learned. Likewise, through this paper itself, I did fortunately get a chance to once again look back at this issue with a new understanding of from the lens of my own research summer within the community I now am a part in, and likewise it was fulfilling to be able to make these few connections and possibly set a foundation for more in-depth research and more action.

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