ELECTRIFYING PASSENGER RAIL IN VIRGINIA

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For Virginians for High-Speed Rail

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Contents

Disclaimer

The author conducted this study as part of the program of professional education at the Frank Batten School of Leadership and Public Policy, University of Virginia. This paper is submitted in partial fulfillment of the course requirements for the Master of Public Policy degree. The judgments and conclusions are solely those of the author, and are not necessarily endorsed by the Batten School, by the University of Virginia, or by any other agency.

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Executive Summary

This is a proposal for a plan to electrify passenger rail in Virginia that Virginians for High-Speed Rail can use to generate policy momentum in the state government. The project aims to provide a foundation for the Virginia General Assembly to further study electrification with the goal of implementation between Washington, DC and the North Carolina border.

Currently, there are no electrified rail operations in Virginia, but there should be. The recent "Transforming Rail in Virginia" initiative has demonstrated that the commonwealth is willing to invest big in its rail infrastructure. Electrification has been recently studied as part of the Caltrain Modernization Program in California and for electrifying lines of the Massachusetts Bay Transportation Authority (MBTA) in Boston(Caltrain, 2021),(Levy, 2021). These programs have demonstrated the potential benefits of electrification, including improved energy efficiency, reduced greenhouse gas emissions, and increased reliability.

Hybrid locomotives are the recommended alternative for electrifying passenger rail in Virginia, although battery-electric locomotives and overhead catenary systems were also considered. Hybrid locomotives combine the benefits of electric and diesel power to allow for improved fuel efficiency, reduced emissions, and increased reliability. The three criteria used to evaluate the feasibility of electrification were reliability, per-mile cost, and political feasibility. The recommended alternative meets these criteria, with the potential to significantly improve rail transportation in Virginia while also being financially viable and politically feasible.

The Virginia General Assembly should study the feasibility of electrifying passenger rail in Virginia, with a focus on hybrid locomotives. By further investing in rail infrastructure, Virginia can help ensure a more sustainable, efficient, and reliable future for its residents and businesses.

Introduction

Virginia has embarked on a $3.7 billion initiative to transform rail within its borders (Luczack, n.d.). This generational investment raises the possibility of further improvements to its passenger rail network beyond right-of-way acquisition and increased service. Amtrak's Northeast Corridor (NEC) operates between Washington DC and Boston, providing frequent and reliable service to 12.5 million people annually (Lazo, 2019). The NEC is Amtrak's most profitable service, and part of the reason it is not fully integrated within the commonwealth is due to the lack of electric infrastructure on Virginia tracks, causing trains to have to switch from catenary to diesel locomotives before crossing the Potomac River. This disintegration prevents Virginia's passenger rail system from reaching its full potential at a time when it is expanding, but there may be a solution.

There are at least three different ways passenger trains can be electrified: through overhead catenary, battery-electric locomotives, or hybrid locomotives. Pursuing any of these methods would be a costly endeavor, one that the Virginia General Assembly would require a Joint Legislative Audit and Review (JLARC) Study for before debating adoption and implementation.

This report seeks to act as a proposal for the General Assembly to study rail electrification by suggesting possible alternatives, evaluating them, and presenting a recommendation. Hopefully, this proposal will generate sufficient interest for legislators to fund a full JLARC study.

Problem Statement

Virginia's nearly 1 million Amtrak passengers lack reliable, well-integrated, electrified rail along the 375 miles of track between Washington DC and the North Carolina border (Lazo, 2021). Moreover, the Virginia General Assembly has insufficient information at present to determine the best path to electrification. As such, the Virginia rail system remains unreliable, unsustainable, and inefficient.

Client Overview

VHSR is a 501 (C) (3) not-for-profit coalition of citizens, businesses, localities, community organizations, and economic development agencies that educate for the need for the expansion of fast, frequent, and reliable rail service connecting our communities to destinations along the eastern seaboard to increase the economic potential of the Commonwealth. They were founded in 1994 as a partnership between the RVA Chamber and the Future of Hampton Roads (*About*, n.d.).

Danny Plaugher, executive director of Virginians for High Speed Rail, has advocated for a $3.7 billion, 10 year plan for the commonwealth to expand and streamline its commuter, passenger, and freight rail systems (McGowan, 2021). Additionally, Plaugher has publicly shared ideas about how Virginia could pursue rail electrification, like suggesting a hybrid model where trains operate on battery power for 100 miles between the NEC and Petersburg before switching back to catenary (Gordon et al., 2023).

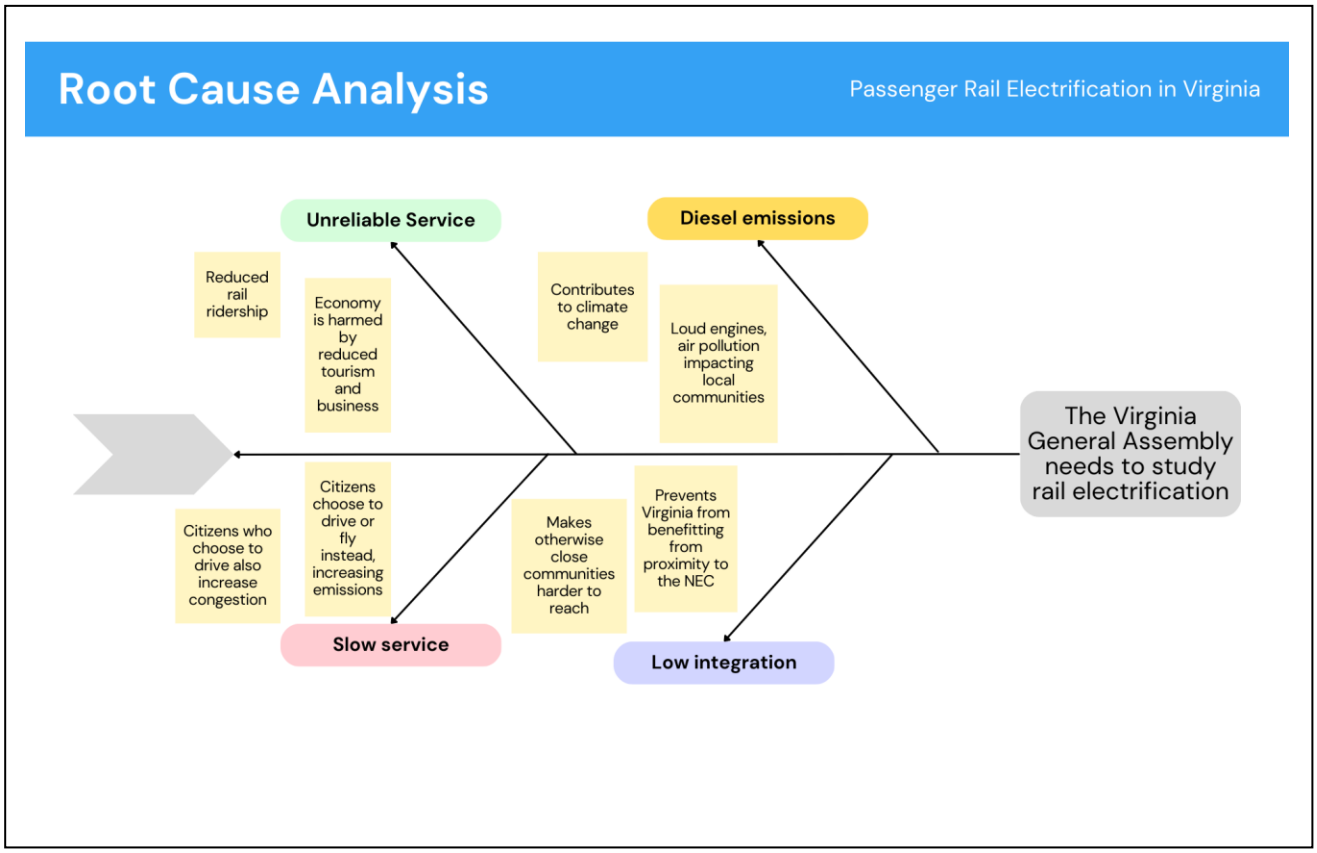
> *"Triple the number of Amtrak Regional trains serving Virginia; reduce their travel times by up-to 35 percent; increase their on-time reliability to over 90 percent; and reach over 80 percent of Virginians"*

VAHSR's expressed goals are "to triple the number of Amtrak Regional trains serving Virginia; reduce their travel times by up-to 35 percent; increase their on-time reliability to over 90 percent; and reach over 80 percent of Virginians."(*About*, n.d.). Rail electrification touches on two of these, reliability and travel times. Electrification relates to on-time performance because of maintenance, as electric locomotives are less prone to breakdowns. Electrification could reduce travel times too, as trains can more quickly accelerate and decelerate than their combustion counterparts. Additionally, train service in Virginia must pass through Washington, DC to enter the Northeast Corridor. At Union Station, there is a roughly half-hour long locomotive exchange process, where crews must transfer between combustion and electric systems. If

the commonwealth adopted electrification, this exchange may not be necessary, and could significantly reduce travel times on local service.

Background

Causes



The above root cause analysis describes the problems that stem from not electrifying Virginia's rail network, and while proceeding with this project may seem like a simple choice, there are reasons it has not happened yet. The Class I railroads own most of the right-of-way in Virginia and lack a financial incentive to electrify their tracks. This is because the catenary would interfere with their cargo, and a third rail configuration would be far more expensive (*Oppose Rail Electrification & Support Sensible Climate Policy*, 2021). It is possible that Dominion Energy, the state electric utility company, is not readily able to implement such a system either. The combined lobbying influence of these entities could converge on the General Assembly to prevent any proposal that hints of rail electrification from advancing.

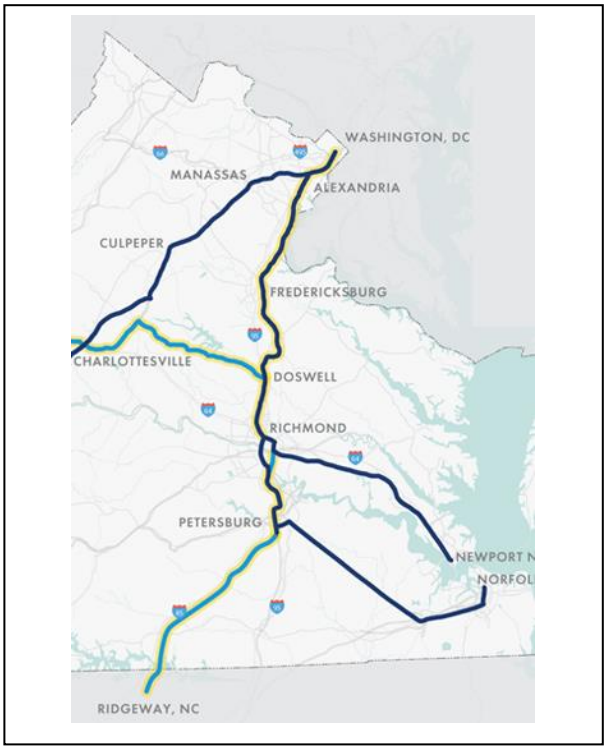


Figure 1- The north-south yellow highlighted 375-mile corridor between DC and Ridgeway is the proposed study area for electrification

Source: *Railwayage.com*

Presently, Virginia's government is 2/3 controlled by the GOP(*Youngkin Wins, Flipping Virginia Red - POLITICO*, 2021). The Governor, who is responsible for setting priorities, has not mentioned rail electrification as part of his agenda. The House of Delegates is also controlled by the GOP, and they have not signaled support for this policy. The past Governor's administration, with assent from the Democratic-controlled General Assembly, implemented the Transforming Rail in Virginia initiative, which suggests Democrats may be more inclined to take up a proposal to study electrification (Thomas, 2022). Only the Virginia Senate is controlled by Democrats, and narrowly so. Fossil fuels interests will also play a role here, as conservative politicians are reluctant to pursue spending that might jeopardize jobs in this industry. Any reduction in diesel fuel consumption, like a reduction that would come from rail electrification, would likely alarm politicians who sympathize with fossil fuel interests, such as Senator Richard Stuart, who sponsored a bill to pull Virginia out of the Regional Greenhouse Gas Initiative (Budryk, 2023).

The Governor and both governing parties in the General Assembly have discussed other priorities that do not pertain to rail electrification. The Governor has expressed a focus on k-12 education, tax reductions, and removing Virginia from the Regional Greenhouse Gas Initiative (*Governor Glenn Youngkin | Governor.Virginia.Gov*, n.d.). Meanwhile, Virginia Democrats are concerned with abortion access, the housing market, and expanding clean energy (Dems, 2022).

Finally, the Transforming Rail in Virginia Initiative involves $3.7 billion in public spending. The program is unprecedented in Virginia and the southeast more broadly and would propel the commonwealth to passenger rail leadership. The full extent of the plan will not be realized until at least a decade from now, so starting a new multi-billion-dollar initiative might be viewed as premature (TRVA_admin, n.d.).

Impacts

Direct costs

California's Caltrain electrification project is the only contemporary example to draw on for such a project. They are seeking to electrify 51 miles of track for the price of $2.4 billion, or roughly $47.1 million per mile(Caltrain, 2021). To electrify the 375 miles of track purchased for the Transforming Rail in Virginia initiative, the commonwealth would have to find roughly $10 billion[1]. The cost to society could be calculated on a per-person basis, but this is problematic. First, it is hard to say how much an individual's tax dollars go to a specific project. For instance, if wealthier citizens pay higher income and property tax, it does not necessarily mean they pay more for a theoretical rail project specifically. Second, much of the commonwealth's revenue is derived from sales taxes that are paid by Virginia citizens, but also by the tourists and commerce that pass through. It would be unwieldy to track those payments. Finally, the federal government would have to contribute funding to an electrification project, which theoretically brings in all taxpaying residents of the nation, most of whom will not be directly impacted. The costs of not electrifying trains could be great for the environment, since electric trains emit 222g CO2e per electric vehicle mile, compared to 869g CO2e per diesel vehicle mile(*Rail Emissions | ORR Data Portal*, n.d.). This means a future without electric trains means Virginia will see

[1] The $25.9 million per-mile figure for catenary given in a later section, multiplied by 375 miles, is $9.7 billion (rounded up)

about 75% more emissions from passenger rail. Consider Richmond Staples Mill Station, which saw 361,000 passengers travel an average of 217 miles in 2020(*Amtrak Ridership Data by Station*, 2020). These trips would emit 647g CO2e more per passenger mile, or 50.7 billion more grams of CO2e annually, needlessly contributing to the climate crisis[2].

Externalities

While electrification would ultimately result in reduced carbon emissions from the trains themselves, the power for the new locomotives will largely be produced by fossil fuel consuming plants around Virginia. This could increase emissions in the communities these power plants reside in. A massive construction process like this may also disrupt the communities along the rail corridor, bringing economic peril or simply reducing the quality of life for residents. If freight rail operations are negatively impacted, Virginia consumers could experience price increases on essential goods. At its worst, poor freight operations stemming from construction could cause Virginia businesses to shutter and spread into a regional supply chain crisis. However, electric trains cost at least 25% less to maintain and 50% less to fuel than diesel locomotives (*Electrification of U.S. Railways: Pie in the Sky, or Realistic Goal? | Article | EESI*, n.d.). The excess revenues from these savings could produce at least two positive externalities through lower ticket prices and improved air quality. Amtrak may be inclined to pass on these cost savings to customers. The less money passengers must spend on their tickets, the more frequently they may travel, and the more money they may have to spend at their destinations. Additionally reduced air pollution in urban areas from eliminating diesel locomotives may help residents live longer (US EPA, 2015).

Opportunity costs

$10 billion is an enormous amount for a state of Virginia's size. Setting aside the spending that could occur in housing, education, healthcare, and other policy areas, there is a considerable opportunity cost to other transportation projects. For $10 billion, Virginia could further extend the WMATA rail corridors in Northern Virginia. The commonwealth could expand the Tide light rail in Norfolk or improve the Pulse bus rapid transit system in Richmond. Moreover, there are vast road and highway construction and maintenance projects that could be

[2] Converted km from study to miles. Passenger miles are the number of miles traveled multiplied by number of passengers. (361,000 x 217) = 78.3 million passenger miles , then multiplied by 647

completed. The Hampton Roads Bridge Tunnel is a major infrastructure initiative that greatly expands capacity in the region, at the price of $3.8 billion(*Home | Hampton Roads Bridge Tunnel Expansion*, n.d.). The expansion of I-66 in Northern Virginia cost $2.2 billion, while extending the Fredericksburg Express lanes along I-95 cost a relatively cheap $565 million(*Transform I-66 Outside the Beltway Project, Virginia - Verdict Traffic*, n.d.), (*Virginia's 95 Express Lanes to Fredericksburg Are behind Schedule - The Washington Post*, 2021). Overall, there are many projects the commonwealth could pursue that might provide greater value to citizens in a shorter time frame, and the opportunity cost should be considered.

Known Approaches to Electrification

California

There is one active passenger rail electrification project in the United States. The Peninsula Corridor Electrification Project (PCEP) is intended to upgrade 51 miles of track between San Francisco and San Jose, with construction beginning in 2017 (*Caltrain Celebrates Installation of Final Foundation for Electrification Project*, 2022). Revenue service is expected in 2024, and the project is currently projected to cost $2.44 billion, or about $48 million per-mile (*PCEP September 2022 Board Executive Monthly Progress Report*, 2022). While the latest report claims PCEP is 76% complete, an earlier report reveals that it is four years behind schedule. Moreover, the program is $500 million over its initial budget (*PCEP July 2016 Monthly Report Final*, 2016).

California pursued PCEP for four stated reasons: Improved Train Performance, Increased Ridership Capacity and Increased Service; Increased Revenue and Reduced Fuel Cost, Reduced Engine Noise; and Improved Regional Air Quality and Reduced Greenhouse Gas Emissions (*PCEP July 2016 Monthly Report Final*, 2016). Essentially, the state is

KEY TAKEAWAYS

- Rail electrification projects are expensive
- The only active electrification project is the 51-mile Caltrain Modernization program
- The last Amtrak electrification project was over 20 years ago
- Projects take roughly 10 years to complete
- Electrification projects are often delayed and run over budget

demonstrating its commitment to commuter rail service in the Bay Area through this major infrastructure project.

PCEP began at the state and regional level. Caltrain's operator, The Corridor Joint Powers Board (JPB), completed its first draft study in 2004 and received further assent from the Federal Transit Administration in 2009. Beginning in 2009, the California Legislature, the California High Speed Rail Authority (CHSRA), and the Metropolitan Transportation Commission (MTC) started brainstorming a joint system for Caltrain and the future high-speed rail service. Because of the systems blended nature, the Caltrain corridor was able to receive Proposition 1A bond funds that would benefit the electrification project in the short term (*Project History- Caltrain*, 2014). Proposition 1A was a 2008 ballot measure that authorized the California Transportation Commission (CTC) to allocate $950 million in bonds for improvements to intercity, commuter, and urban rail systems that would connect to the high-speed train system (California Transportation Commission, n.d.).

There has long been an understood need for commuter rail improvements in the Bay Area. Weekday Caltrain ridership grew from 21,000 passengers in 1992 to 47,000 in 2013. Behind this growth is increased "reverse-commutes" from San Francisco to the South Bay and greater "off-peak" travel. Downtown San Francisco alone is expected to have 17% growth between 2010 and 2040, while the peninsula is expected to grow by 29% (*Project History- Caltrain*, 2014). The 2014 PCEP environmental impact review also noted roadway congestion, rising fuel prices, and climate change as motivation for implementing the project (*Project History- Caltrain*, 2014)

New England

Amtrak's last major electrification project occurred in the 1990's. Congress passed the Amtrak Authorization and Development Act requiring Amtrak to establish high-speed rail passenger service between New York City and Boston, reducing a once 4.5 hour trip to under 3 hours. Electrifying a 157 mile railway between New Haven and Boston was essential to this effort(*Amtrak New Haven to Boston Electrification Project*, n.d.). Congress earmarked $230 million (1991 dollars) and ultimately spent $1.2 billion ($2.1 billion in 2022 dollars) by the time the project was completed in 2000 (Lueck, 1999). Included in that spending were 15,000 poles to install the overhead catenary and a multimillion dollar high speed rail training facility for operators (*Building the Infrastructure for Acela Express — Amtrak: History of America's Railroad*, n.d.). Overall, the federal

government spent $13.4 million per mile to complete this electrification project allowing for Acela express service today, meaning they may be willing to fund an electrification project in Virginia today. The environmental statement was completed in 1993, construction began in 1996, and service initiated in January of 2000.

Available Information

All sources arise from contemporary journalistic sources, agency websites, or published government reports. It is possible that some sources, like Amtrak or Caltrain, may want to frame their projects in a more positive light. Consider that these institutions stand to benefit from positive historical coverage of their use of public dollars. Indeed, the stated benefits of the Caltrain project may have been embellished to justify the billions of dollars spent on a project spanning a relatively short distance. Amtrak had the benefit of consistent support from the federal government during the conception and execution of its electrification project in New England, and journalism covering the project only seemed to celebrate its project. However, the Acela corridor was a brand-new concept in the late 1990's, and similar projects were nonexistent at the time. Today, we can point to the beleaguered California High-Speed Rail (CHSR) and Boston's Big Dig as examples of multibillion dollar projects receiving high political scrutiny (Vartabedian, 2019).

There is scarce available evidence of the political dealmaking process that resulted in the federal government studying the New England electrification project, and the same is true for PCEP. The benefit of privately proposing a project to a legislator is flexibility. If the legislator is sympathetic, then they may still want to adjust the details of the proposal before bringing it up on the floor of a political body, because it would need to withstand political and public scrutiny. Therefore, any publicly available evidence relating to the initial proposal process is likely to only represent the results of earlier negotiations that took place in private.

Generalizability

PCEP and the New England project both offer lessons for any Virginia rail electrification initiative. In the Northeast, there lies an example of a project with ample political support, along with glowing media coverage that followed the four-year construction process. In the West, we have a contemporary project that shows how even a project with public and political support can end up behind schedule and far over budget.

However, neither project is of the same scale as the over 300-mile project in Virginia. Moreover, Virginia lacks the political environment of California, where consecutive years of one-party political control and referenda can fuel the progress of a major infrastructure project such as this. Even the PCEP is expected to take 3 years longer and, at present, cost millions more than the New England project that occurred with earlier technology and was over 100 miles greater in scale. Finally, both example projects occurred on passenger-only corridors, while Virginia's project would involve some shared track with freight rail operators.

Limitations

The evidence relies on the government being a trustworthy source of information. Furthermore, there is limited evidence detailing the political situation surrounding both projects. At present, there is limited, if any, journalism covering the negotiations that resulted in congressional assent to the earlier project or California legislative assent to the present one.

Existing journalism on both projects appears to be sympathetic to their aims, even while acknowledging their arduous paths to completion. Sources that represent steadfast opposition to electrification projects may be required to fully appreciate the political environment surrounding this issue.

This report also does not consider California High Speed Rail (CAHSR) or other global rail electrification projects, because their circumstances are substantially different from a project that would occur in Virginia. CAHSR is a fully grade separated project on newly constructed alignment, whereas most of a Virginia electrification project would occur in existing alignment (California High Speed Rail Commission, 2023). The U.S also faces uniquely high costs compared to other countries when it comes to transportation, severely limiting the value of including overseas examples of similar projects (Demsas, 2021).

Alternatives and Criteria

Criteria

The three selected criteria for implementing passenger rail electrification are reliability, cost on a per-mile basis, and political feasibility. Each criterion is critical to the success of new infrastructure, and the alternative that scores the best overall will be preferred. Alternatives are scored either high (1), medium (2), or low (3). The alternative with the "lowest" numeric score will be preferred.

Reliability

Maintenance and quality-of-service are important considerations for rail operations. Passengers should expect their trips to have high "on-time" performance (OTP), with few delays in arrivals and departures. OTP is affected by numerous conditions, including but not limited to locomotive engines, freight train interference, weather, staff shortages, and track conditions. Furthermore, safety is a major component of reliability. Electric locomotives, and their related infrastructure, should not pose great risk to passengers, crews, or local communities. Environmental concerns like potential for carbon reductions are also considered within this metric. The reason safety is not being considered as its own criterion is because trains are already dramatically safer than cars, and any gains would be marginal (Diller, 2022). Environmental concerns also lack their own criterion because two of the three alternatives are fully electric and can run on renewable resources, with the main concerns being disruptive activity during construction, which is covered under the political feasibility criterion. An alternative ranking high in reliability will have the greatest potential for integration with the NEC, and also do well with carbon neutrality and lack new safety concerns.

OVERVIEW

Criteria

- Reliability
- Cost Per-Mile
- Political Feasibility

Alternatives

- Battery Electric Locomotives (BEL)
- Overhead Catenary
- Hybrid Locomotives

Per-mile Cost

Cost presents a barrier to implementing electrified rail and should be minimized where possible. The few instances of modern rail electrification have occurred under differing regional and political circumstances, and at different times. While these circumstances present a limitation for this criterion, costs will be converted to 2020 dollars to better rank alternatives relative to one another. The alternative with the lowest cost of construction per-mile will rank the highest.

Political Feasibility

Transportation politics present opportunities for unique, often bipartisan coalitions to emerge. Passenger rail issues do not fall neatly into conservative or liberal politics, although all modern electrification projects have occurred under Democratic trifecta's at the state level. Virginia's present government is headed by a Republican, with a divided legislature. However, the current GOP administration appears to remain committed to the Transforming Rail in Virginia (TRV) project started under the previous Democratic administration. Evidence for this criterion is limited by a lack of public discussion surrounding rail electrification among state politicians. The highest-ranking alternative will be the one deemed most likely to receive bipartisan support.

Alternatives

The Baseline: Diesel-Electric Engines

Before describing the alternatives for electrification, it is necessary to identify the current standard: the diesel-electric locomotive. Although these trains are called "diesels", they are electrically driven. The diesel engine drives an alternator, which produces the electricity to run electric motors mounted on the locomotive's axle (*Diesel Electric Locomotives*, n.d.). A helpful analogy might be to think of these trains as mobile power plants, rather than a close relative of the engine system common in automobiles. Diesels can tow passenger train cars at speeds of up to 125 miles per hour, and boast 20 percent greater thermal efficiency than gas engines(Nice & Homer, n.d.). Although the average price for a diesel locomotive in the US is $3 million, the total cost of ownership (TCO) for diesel-electric trains can range from $6-12 million, with maintenance representing about $1.1 million of that cost (Ahluwalia & Laboratory, n.d.) . A

major drawback of diesels is their CO2 emissions. All US diesel locomotives, including freight, emit 35 million tons of CO2 annually and contribute to 1,000 premature deaths. These emissions account for $6.5 billion in health damage costs annually(Chao, 2021). However, Amtrak has ordered 150 new ALC-42 "Charger" locomotives between 2018 and 2022. These new diesels are designed to replace the Amtrak P40 and P42's that are currently in use. The Chargers reduce nitrogen oxide emissions by 89 percent, and particulate matter by 95 percent. They were purchased at a cost of $2 billion for the locomotives themselves and subsequent maintenance support(Report, 2022). While the leading cause of delays for Amtrak is freight train interference, it can be inferred that diesel engine maintenance is related to the system's reliability. The current baseline remains problematic despite the current planned investments

Battery-Electric Locomotives (BELs)

BELs work similarly to diesels, except they are charged rather than supplied by fuel. There are not currently any BELs in operation in the United States, and thus information on their true implementation cost is limited. However, freight railroads are participating in research to improve existing BEL technology, indicating they may be supportive. One known cost example is Union Pacific's purchase of 20 BELs in 2022 as part of a $100 million deal, which is the largest investment in the technology by a Class I railroad (Doll, 2022). In the Northeast, two jurisdictions have recently expressed interest in BELs for the non-electrified segments of their systems. The Long Island Railroad in New York spent $800,000 on a study to retrofit its diesel engines to battery power. However, the estimated cost of $18 million per mile for 160 miles, or roughly $2.9 billion was deemed prohibitive and seats would have to be removed for the technology(*LIRR Shelves Battery Power, Cites Cost, Reliability Issues - Newsday*, n.d.) . New Jersey Transit expects their BEL project to cost $46 million in total, and would create a beneficial redundancy in their power system in case the overhead wires malfunction(Higgs, 2021). Implementation in Virginia would involve constructing brand new charging stations along the Northeast Regional and S-line corridors and contributing

BEL QUICK FACTS

Power Supply
- On-board battery
- Charged Electrically

Existing Uses
- Major investment by Union Pacific
- No U.S Passenger Operations
- NJ Transit is considering implementation

Limitations
- Nascent technology

funds for Amtrak to purchase the new locomotives. After a JLARC study, and General Assembly approval The Virginia Passenger Rail Authority (VPRA) would seek federal grants and collaborate with Amtrak to determine the number of BELs necessary to serve passengers in the commonwealth. The process of releasing a Request for Proposal (RFP), manufacturing, and phasing in of BELs on Virginia railways would take 7-10 years. The benefits include quieter service (BELs produce less sound than diesels), less infrastructure installation than catenary, and lower emissions. Wabtec, a BEL manufacturer, estimates every battery locomotive that replaces a diesel will remove 3,000 tons of CO2 from the atmosphere annually (Vartabedian, 2019). Furthermore, BELs may offer speed and acceleration benefits over diesels. However, it is difficult to estimate how much a standard BEL will cost since the market is so nascent. A BEL-only system operating in Virginia would still face a locomotive exchange at Union Station to enter the Northeast Corridor, as they do not necessarily have the capacity to operate from existing overhead catenary systems. A government study would struggle to identify the best locomotive type and reliably price a BEL system but would benefit from reduced opposition from Class I's.

Union Pacific's FLXdrive locomotive
Source: *Trains.com*

Overhead Catenary

Catenary is a system of overhead wires used to supply electricity to a locomotive that is equipped with a pantograph. The pantograph presses against the underside of the lowest overhead wire, the contact wire. Although this locomotion system is commonly found on streetcars and light-rail units, the

CATENARY QUICK FACTS

Power Supply
- Overhead wires

Existing Uses
- Northeast Corridor
- South Shore Line
- Metra Electric District

Limitations
- Very Expensive
- Class I opposition
- Locomotives must change when exiting catenary corridor

Northeast Corridor between Boston and Washington, DC features 600 miles of catenary. Since the power supply is off-board, catenary offers the lightest trains, the greatest acceleration, and the fastest speeds among the alternatives. Overhead catenary is the earliest attested mode of electrification, originating from New York City and New Haven's systems at the turn of the 20th century. Catenary is uncommon in the United States because freight railroads (Class I) own the vast majority of right-of-way and are generally opposed to the infrastructure(Ohlhaber, 2017). Opposition from Class I's is related to operational concerns, as they believe the catenary restricts them from using double-stacked containers. Implementation of catenary in Virginia would involve convincing the Class I's to allow installation along the over 300-mile shared right of way between Washington, DC and Richmond. Then, further catenary would be installed along the 75-mile state-owned corridor between Petersburg and the North Carolina border. Specifically, VPRA would work with Class I's to reach a contract agreement that allows the commonwealth to construct the catenary. The governor's administration would almost certainly be involved with mediating this process, as would Amtrak. With so many state and private actors working on a project of this scale, federal regulators in the form of the Surface Transportation Board (STB), may also step in. Then an RFP process for the catenary construction and locomotive purchase would begin, and then over the course of at least a decade, catenary would be installed. VHSR has suggested methods to implement clean energy with such a project, like adding solar panels atop train station parking lots to help power the system. California's current passenger rail electrification project, expected to be completed in 2024, is priced at $2.44 billion for the 51-mile corridor, or $48 million per-mile(Caltrain, 2021). Boston's commuter rail electrification project, with a proposed 2035 deadline, could be completed for $800 million to $1.5 billion (Levy, 2021). The New England network features 400 miles of track across 14 commuter lines, meaning a per-mile cost of $3.75 million at the higher end. Given the wide range of prices, the per-mile costs of the east and west coast projects will be averaged to produce a single number, $25.9 million. Therefore, a catenary style electrification program in the commonwealth along the 350 miles of track could

cost $9.1 billion. Catenary suffers from several challenges, including vulnerability to severe weather, safety hazards for maintenance crews working with live wires, and aesthetic concerns for local communities. A government study interested in catenary electrification would benefit from recent studies in other states and reporting on current projects but would face the fiercest resistance from Class I's.

Amtrak's Acela Train
Source: *VisitPhilly.com*

Hybrid Locomotives

Amtrak has recently unveiled the bidirectional "Airo" locomotive that is seemingly capable of battery power, diesel, and catenary operation. Airo is set to go into operation in 2026 and seeks to replace nearly 50-year-old locomotives in operation today. Amtrak announced the purchase of 83 Airo trains manufactured by Siemens in 2022, at a $7.3 billion total investment, with $3.4 billion of that figure for design and manufacture. The initial rollout will only feature on the *Cascade* service but will soon be rolling on all *Northeast Regional* services as well. This proposal would suggest bringing hybrid locomotives to services operating in Virginia on a speedier timeline than might otherwise occur. The process would unfold with similarity to BELs, and on a similar timeline, with the key difference being much of the work has already been done on Amtrak's end. This means VPRA's main job would be to work with Amtrak to expand their existing hybrid locomotive plans and bring the service to Virginia sooner. Since there are three possible configurations, this alternative appears to offer the greatest flexibility. VHSR has suggested a system where a train could charge along the Northeast Corridor while on catenary, then operate on battery power

HYBRID QUICK FACTS

Power Supply
- Can switch between Diesel, BEL, and catenary

Existing Uses
- None yet, planned rollout on Amtrak *Cascade*

Limitations
- Nascent Technology

through northern Virginia, before transitioning back to catenary in Petersburg(Gordon et al., 2023). Indeed, hybrids may offer greater speed than diesels, and avoid the time-sink of changing locomotives at Union Station. A government study would struggle to find accurate pricing information for implementing cutting edge technology such as this hybrid system (most public articles were published in 2022 and are light on technical information). Although, a government study for a flexible technology like this would benefit from reduced Class I opposition, and technical support from Amtrak if the appropriate relationships are developed.

Amtrak's Airo Locomotive
Source: *Reddit.com*

Findings

The Virginia General Assembly has already embarked on the Transforming Rail in Virginia Initiative(TRVA_admin, n.d.), which seeks to expand passenger rail service in Virginia. However, the state has not yet explored rail electrification, and needs groundwork upon which to fund a more expansive study. The client, VHSR, seeks to have this study conducted.

There are three alternatives available for electrifying passenger rail in Virginia, including Battery-Electric Locomotives, Overhead Catenary, and Hybrid Locomotives. These are the only available electric technologies available, and although hydrogen fueled trains may be on the horizon, the technology was too nascent to be considered (Hirschlag, 2020). Importantly, this document does not seek to elevate one alternative over the others. Rather, these alternatives will be weighed against the criteria, and then the commonwealth should fund a study through the Joint Legislative Audit and Review Commission (JLARC) to further investigate the best path forward.

Alternative 1: Battery-Electric Locomotives (BELS)

Description

BEL locomotives operate using battery fuel cells, and are a nascent technology (*Leading The Charge*, n.d.). While not yet used for passenger operation, they hold potential for implementation nationwide. Freight companies have invested in the technology.

Reliability

BELs have the lowest reliability ranking of the three alternatives. The technology is new, and untested in the United States for passenger service (University, 2023). Since BELs have not been perfected, breakdowns and unexpected costs could hamper the performance of services using these locomotives. Moreover, BEL-only locomotives would still need to be exchanged for those compatible with the Northeast Corridor (NEC), so there are operational risks (Gordon et al., 2023). The upside is that they may be able to accelerate faster than the diesel locomotives currently operating (*Electrified Trains - What Are the Benefits?*, 2014). (3)

Per-mile cost

The Long Island Railroad produced the most recent study on the cost of converting to BELs, while Union Pacific recently purchased 20 BEL's at the cost of $100 million(*For LIRR, a Potential First: Battery/Third-Rail 'BEMU' - Railway Age*, n.d.), (Morris, 2022). It will be assumed for all alternatives that new maintenance facilities cost a flat $30 million. For precision, the average per-mile cost of the Long Island Project and the Union Pacific deal is $10.2 million, making BELs the least expensive alternative on a per mile basis. (1)

Political Feasibility

Virginia Democrats would likely support efforts to reduce carbon emission within the commonwealth, provided the price tag is reasonable (Paullin et al., 2023). Virginia Republicans, however, will likely be skeptical of any additional spending beyond their proposed tax cuts (Rankin, 2023). Localities may be supportive because the air quality would be improved by the transition (Stein, 2021). Furthermore, there is no new infrastructure required that would interfere with Class I operations, so their stance would likely be neutral. The low-cost relative to the other alternatives could be a basis for individuals across the political spectrum to ultimately support implementation. Amtrak would likely push for a locomotive system that integrates with the NEC, and any resistance they put up could jeopardize grant funding from the federal government (*Potential Improvements to the Washington-Richmond Railroad Corridor*, 1999). This alternative receives a medium score. (2)

Alternative 2: Overhead Catenary

Description

Overhead Catenary supplies power to the locomotive using wires that are constructed above the alignment(*What Is a Catenary?*, n.d.). This allows trains to accelerate faster, brake efficiently, and travel at higher speeds without carbon exhaust(*What Is a Catenary System, and What Are Its Benefits? | MAC Products*, n.d.). Catenary has not yet been constructed in Virginia, with the nearest system using the technology being the NEC beginning in Washington, DC.

Reliability

Catenary is a tried-and-true method of electrification. These locomotives have been in service along the NEC for decades, and there is a lot of technical expertise available to ensure high quality service(*Amtrak Year-by-Year: 1976 — Amtrak: History of America's Railroad*, n.d.). Catenary power systems are quieter, cleaner, and faster than their diesel counterparts (*Electrification of U.S. Railways: Pie in the Sky, or Realistic Goal? | Article | EESI*, n.d.). Additionally,

catenary would provide integration with the NEC, allowing for faster and possibly more frequent service throughout the commonwealth. This receives a high reliability score. (1)

Per-mile cost

California's current passenger rail electrification project, expected to be completed in 2024, has costed $2.44 billion for the 51-mile corridor, or $48 million per-mile (Caltrain, 2023). Boston's commuter rail electrification project, with a proposed 2035 deadline, could be completed for $800 million to $1.5 billion (Levy, 2021). The New England network features nearly 400 miles of track across 14 commuter lines, meaning a per-mile cost of $3.75 million at the higher end(*Commuter Rail Safety and Resiliency Program | Projects | MBTA*, n.d.). These prices have already integrated the maintenance along the route. A catenary style electrification program in the commonwealth could cost between $1.4 billion and $18 billion for 375 miles of track upgrades. For precision, the average was taken, making catenary the most expensive alternative, costing $25.9 million per-mile, giving it a low score. (3)

Political Feasibility

This alternative is the toughest sell of the three. Not only would constructing the overhead catenary along 350 miles of track be a costly and disruptive process, but it would face fierce opposition from the Class I railroad operators. The Association of American Railroads released a report detailing the industry's concern about the cost effectiveness of electrification, and how it would ultimately lead to more trucking (*Oppose Rail Electrification & Support Sensible Climate Policy*, 2021). The Virginia Passenger Rail Authority (VPRA) also has an agreement with CSX, a Class I operator, that tracks have to be interoperable in Virginia, meaning public construction should not interfere with freight operations (Gordon et al., 2023). Republicans and Democrats alike would be lobbied to change course by the Class I's. Localities would be ambivalent because construction would be disruptive, but the service would be quieter and produce no emissions. Amtrak would be supportive because catenary would allow for seamless integration with the NEC. This receives a low feasibility score. (3)

Alternative 3: Hybrid Locomotives

Description

Since there are three possible configurations, this alternative appears to offer the greatest flexibility(*Amtrak Contracts With Siemens Mobility for Hybrid Trains*, 2021). VHSR has suggested a system where a train could charge along the

Northeast Corridor while on catenary, then operate on battery power through northern Virginia, before transitioning back to catenary in Petersburg. The implementation of this project would involve VPRA first working with Amtrak to bring these locomotives online, then asking the Federal Railroad Administration (FRA) for grant funding to construct the catenary from Petersburg to the North Carolina border. Furthermore, new maintenance facilities would need to be constructed by Amtrak to maintain the locomotives.

Reliability

Of the three alternatives, hybrids have the most potential for reliability. If the battery power supply fails, the on-board diesel electric engine could activate to keep the train moving. A northbound train originating in Virginia could more quickly switch from diesel to catenary operations at Union Station, improving travel time. Moreover, these trains are meant to be deployed soon by Amtrak, which will allow operators and maintenance crews to develop expertise. The primary drawback of hybrids is that they are a relatively new technology, meaning that existing expertise is limited. There may be new maintenance troubles that arise, like an unforeseen defect that reduces the locomotive's capacity to switch between power modes. Overall, while not as reliable as catenary, the technology behind hybrids is further along than BELs, and planned deployment for passenger operations is near. This receives a medium score. (2)

Per-mile Cost

Amtrak announced the purchase of 83 Airo trains manufactured by Siemens in 2022, at a $7.3 billion total investment, with $3.4 billion of that figure for design and manufacture (Abrams, 2021). Adhering to VHSR's vision, only the 75 miles south of Petersburg would need to be electrified via catenary, which would cost $3.6 billion based on the Caltrain numbers. Assuming Virginia would only pay a fraction for the trains needed to provide service in Virginia, perhaps a fourth of the price of $4 billion, and that the federal government would also be able to provide grants through the Federal Railroad Administration, the cost to the commonwealth is lower than catenary. So, at a rate of $2.6 million per- mile, even including the maintenance costs, hybrids receive a high score[3]. (1)

Political Feasibility

The concept of hybrid vehicles is easily digestible by lawmakers and their staff. Considering that infrastructure would not have to change in Virginia if electrification is not pursued, yet the option remains on the table in the future, hybrids can draw support from Republicans and Democrats alike. It can be

[3] $1 billion, one fourth of the $4 billion, divided by 375 miles.

marketed as a compromise solution to improving passenger rail operations in the commonwealth without upsetting Class I's or local communities along the right-of-way (ROW). Since Amtrak has already purchased the locomotives and funded their research, representatives from the company can vouch for hybrid technology at General Assembly committee hearings. Climate advocates and high-speed rail purists may not be entirely satisfied because this alternative stops short of "full electrification", but they may be assuaged knowing this is an improvement over the status quo. This receives a high feasibility score. (1)

Outcomes Matrix

	Battery Electric	Overhead Catenary	Hybrid
Reliability	3	1	2
Per-Mile Cost	1	3	1
Political Feasibility	2	3	1
Total Score*	6	7	4

lowest score is preferred

Recommendation

These findings, as summarized by the above outcomes matrix, point to **hybrid locomotives as the preferred alternative**. All alternatives present pros and cons, and JLARC may weigh these criteria differently, or identify new ones to expand the matrix. The specific tradeoffs from selecting the hybrid option involve losing the greater reliability of catenary, and the complete carbon neutrality of BELs. Overall, hybrids seem to offer the most value for the public dollar, and have the potential to overcome political challenges to reach implementation. This finding seeks to provide a foundation for a more robust study to be conducted by the General Assembly.

Implementation

The six main stakeholders responsible for implementing are Virginia Legislators, JLARC, FRA, VPRA, Amtrak, and the Governor's Office. Without support from all six, implementation will not be possible. The Class I carriers are also a minor stakeholder under this alternative given the shared ROW between Richmond and Washington DC, but absent major construction, it is unlikely they would interfere.

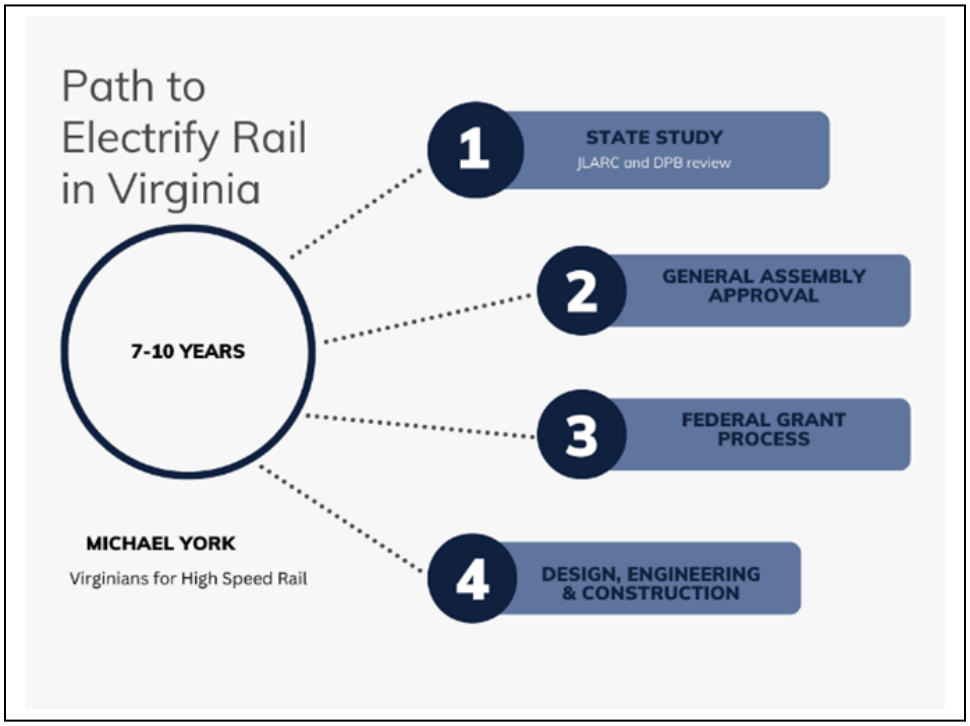
JLARC is responsible for conducting the study upon initial General Assembly approval. It is exceedingly rare that Virginia's government would proceed with any project with spending of this level without studying it first. JLARC itself is a nonpartisan entity, but it is directed by the assembly, meaning all its studies inherently have modest political support. Approval of the study is the first, and lowest bar that this alternative would have to pass to be enacted. The General Assembly would assign a relatively modest amount of money in the budget, likely under $2 million, to study hybrid locomotive operations in the commonwealth. This process could take up to two years.

After the study has been conducted, the General Assembly, with the Governor's support, would then need to move forward with funding the project more thoroughly. This would require allocating tens or hundreds of millions of dollars to construct the maintenance facilities, purchase new locomotives, and possibly construct some catenary south of Petersburg. This is a critical juncture, and debate may occur for up to three assembly sessions (3 calendar years), and possibly longer depending on election outcomes. A coalition of willing legislators would need to be in office, and there would most likely need to be a political trifecta to enact the full project with limited catenary.

The government spending would then be funneled to the VPRA, the authority most directly responsible for overseeing and expanding passenger rail operations in the commonwealth. VPRA's staff would work with the Governor's office to seek grant funding from the federal government in a process administered by the FRA. Additionally, the VPRA would negotiate with Amtrak on the nature of the service in Virginia, ultimately coordinating the date for the new service to begin. Upon receipt of grants from FRA, VPRA and Amtrak would put out a Request for Proposal (RFP) for a team to design and engineer the project, then a separate RFP for construction/delivery. This process may take 3-5 years.

Currently, the General Assembly and Governor's office would require some persuasion to study implementing this alternative in Virginia. Neither entity has

publicly stated support or opposition in either direction, and the General Assembly is under split political control at least until the outcome of the 2023 elections. This means the earliest this process could begin is the 2024 General Assembly session. VAHSR would want to carefully avoid politicizing this issue and would want to have a series of private meetings with key members of the assembly, like the Republican chair of the House Transportation Committee and the Democrat chair of the Senate counterpart. If possible, VAHSR's director would want to have a private conversation with a senior member of the Virginia Transportation Secretary's office to ensure the Governor's administration is onboard. VAHSR may also want to get some modest media attention to draw in public support, which can be converted to political support if deftly executed. VAHSR will want to position themselves as an "educational" or "advisory" part of the process and allow elected leaders to handle the delicate political situation once they are interested in the initial study. A diagram has been provided below to illustrate the implementation process.



Conclusion

Hybrid locomotives may be the future of rail electrification in the commonwealth. With implementation, Virginia can access the benefits of better integration with the NEC and unlock the full potential of its ambitions with the Transforming Rail in Virginia initiative. Virginians deserve a cleaner, more reliable rail service so they can have more choice in their travel. The state economy and environment both stand to benefit. The only way to determine which of the discussed alternatives is truly the best for Virginia is for JLARC to study them.

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