Regional Rail Electrification:

Costs, Challenges, Benefits

Abstract

In this report, TransitMatters explains why electrification of the MBTA Commuter Rail network is a critical investment in the region's mobility future. We call for total electrification of the existing system and all future extensions, and the adoption of electric multiple unit (EMU) trains. Doing so will greatly decrease trip times, improve operating expenditures, and reduce the carbon footprint of transportation, both by removing local pollution from the rail network and making transit competitive with single occupancy vehicles. Moreover, we argue that the Commonwealth pursue the use of overhead catenary, the most proven technology for mainline rail electrification, at least for the current footprint of the rail network.

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p. 8 Caltrain bullet regarding substations deleted.
p. 17 Additional information added in the comparison matrix for Denmark and Britain.

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Introduction

Regional rail systems across the world have generally shifted from diesel locomotion to electrification. Electric trains are capable of faster acceleration, higher speeds, and substantially better reliability than the diesel locomotives used by railroads like the MBTA commuter rail. Electrification is among the most beneficial investments that major suburban railroads can undertake.

Some systems have been electrified since mainline rail electrification was first put into use in the 1900s, for example parts of New York, London, and Paris's networks. Others are only being wired today, such as Auckland (opened 2014-5) and most of Israel (which has opened in stages starting in 2020). The largest, mostly diesel commuter rail network is Chicago's Metra, which focuses on suburban 9-to-5 commuters working in the Loop, precisely the 20th-century thinking we propose Metro Boston move away from.

EMUs outperform other trains in every respect: speed, acceleration, energy consumption, passenger comfort, operating costs, reliability, procurement costs, and maintenance costs.

The case for electrification remains as strong today as ever. Modern electric trains, using subway-like electric multiple units (EMUs) rather than electric locomotives hauling unpowered coaches, distribute traction along the entire length of the train. This provides superior acceleration, somewhat similar to an all-wheel-drive car on a slick roadway, because railroad tracks have naturally low friction. Europe has a large market for regional EMUs that run at a maximum speed of 100 to 125 mile-per-hour and accelerate so quickly that, on a 100 mile-per-hour line, a station stop only costs 45 seconds in acceleration and deceleration time, plus 30 seconds of door opening time ("dwell time").

EMUs outperform other trains in every respect: speed, acceleration, energy consumption, passenger comfort, operating costs, reliability, procurement costs, and maintenance costs. Combined, these allow electric trains to cover routes more quickly, and allow significantly more service to be provided with the same number of resources. Like other electric trains, they require investment in wires and substations, but such investment is cost-effective on lines with frequent use and closely-spaced stations, especially in a metropolitan context like Eastern Massachusetts.

Rail electrification in metropolitan areas is a long-established international best practice, and equipment and rolling stock is mostly standardized and off-the-shelf. In fact, the traction power system in use by Amtrak (25 kV 60 Hz AC) is the most widely-used system in the world, and expanding it would by no means be reinventing the wheel. We call for Massachusetts to prioritize electrification, to ensure a fully electrified rail network is in place ideally by 2027, and in the worst case by 2035. Judging by the experience of Israel, Norway, Denmark, and New Zealand, it takes 6 to 8 years to get from the proposal stage to full electrification if things go smoothly, or 10 to 15 years if they do not. This commitment is essential if we want to reduce traffic congestion in Metro Boston, and it is an unavoidable prerequisite to meeting the governor's call for zero emissions by 2050.

We call on Massachusetts to learn from the best-run recent rail electrification projects, and not the worst-run ones. Israel, Denmark, and New Zealand have had political and technical challenges, but they have done better than the examples closest to home, namely the electrification projects of Toronto and of the San Francisco Bay Area, whose high price tags are attributable to poor cost control. Based on these successful projects, the MBTA can electrify its entire network for between $800 million and $1.5 billion.

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Costs

The cost range for most electrification projects in high-income countries is about $2–4.5 million per route-mile. There are high-end outliers, as in Toronto and California, whose projects have suffered from avoidable mistakes in planning and engineering. India is currently fully electrifying its rail network for less than $1 million per route-mile, but this is in a country with low labor costs and it would not be fair to assume this would be replicable in a higher-wage country.

Based on this per-mile estimate, electrification of the MBTA Commuter Rail system should thus cost $800 million to $1.5 billion. The capital cost estimates we provide cover wires, poles, and substations, but not the purchase of rolling stock. The exclusion of rolling stock is deliberate. The MBTA needs to replace its diesel and coach fleet soon regardless of whether it electrifies. As such, the fleet purchase cost should not be included in the cost of electrification itself. Electrification reduces rolling stock costs, as EMUs are cheaper than the diesel locomotives and coaches they would replace, and can be used more efficiently, so to provide the same level of service may not require as large a fleet.

The Providence Line is already wired and only requires trace amounts of new construction. We also do not include expansion of Regional Rail service such as to Cape Cod and New Hampshire. Finally, in a future technical analysis report, we detail why the Needham Line should be converted to Orange and Green Line service rather than connected to Regional Rail, hence we omit it here.

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Line	Length (miles)	Cost	Notes
Stoughton	4.0	$15m	Piggyback off Providence substation.
Franklin	20.7	$90m	
Fairmount	9.2	$30m	Piggyback off Providence substation.
Old Colony	81.0	$210m	Cheap single-track wiring, though this will change with full doubling of the bottleneck.
Worcester	44.3	$180m	
Fitchburg	53.4	$210m	
Lowell/Haverhill	55.2	$180m	
Eastern	59.6	$200m	Branches have lower costs due to being single-track.

Table Notes:

"Old Colony" refers to the Middleborough/Lakeville, Kingston/Plymouth, and Greenbush lines.

"Eastern" refers to the Newburyport/Rockport line.

The Issue of “Extras”

When a railroad system is electrified, it usually also engages in other concurrent investment. This is because the purpose of electrification is to enable better rail service, and often it’s advantageous to also build other simultaneous improvements. In our Regional Rail proposal, this consists of high platforms and some double-tracking of single-track segments. In some of the case studies below, extras include double-tracking and junction reconstruction.

> ***The purpose of electrification is to enable better rail service, and often it’s advantageous to also build other simultaneous improvements.***

With these extras lumped in, the headline cost of electrification can be much higher than the \$2-4.5 million/mile range. This is especially notable in Britain, where electrification is sometimes bundled with bridge reconstruction, which is not necessary in Massachusetts thanks to more generous American right-of-way clearances.

Our figures exclude these concurrent investments. This is for three reasons:

1. In the case of the Boston region, these other investments consist of high platforms and some double-tracking, both of which have already been undertaken by the MBTA in recent decades. This allows us to directly look at local costs for our budget estimates.
2. The cost of level boarding varies depending on local conditions, including two side platforms versus one island platform, right-of-way constraints (such as for stations along the Turnpike in Newton or for double tracking along the Old Colony route in Dorchester and Quincy), and vertical circulation, such as stairs and elevators. In contrast, the costs of electrification are fairly constant.
3. In some places, the costs are unusually high due to restricted clearances on overpasses. Britain has had some projects at \$13 million/mile because of this. This is a unique special circumstance, one that does not exist in the United States.

Case Studies

Israel

Israel Railways began its program of modernization with the opening of the three-track, four-station Ayalon Railway through central Tel Aviv in 1993, providing through-service between trains going north and trains going south and southeast; previously, trains from points north could only travel south by taking a bypass around the Tel Aviv urban area.

All trains nationwide converge on the Ayalon Railway. Rail managers consider the line to be at capacity at 8-12 trains per hour (tph) on each of the two main tracks; among the reasons they cite for the reduced capacity is the slow braking and acceleration rate of diesel locomotives on a short-hop urban line. As the state builds more lines, including a tunneled line to Jerusalem, electrification is the next step.

The project began in earnest in 2011, when the state appropriated 11.2 billion NIS ($3 billion). This covers much ancillary spending, including resignaling with European Train Control System (ETCS), rolling stock, double-tracking, and trenching a segment in Haifa. In 2015, the 2 billion NIS ($550 million) electrification infrastructure construction contract was awarded to the Spanish firm SEMI for wires, substations, a control center, and 25 years of maintenance. A total of 420 kilometers of route (260 miles) are to be electrified, some double-track and some single-track. In 2015, the plan was to complete the project by 2019. However, it has been delayed to 2023; costs have also risen by 160 million NIS, or $45 million. The delays have come from two sources: a lawsuit by a competing bidder, which alleged improprieties in the bid process, delayed construction by three years; and Israel Railways' refusal to allow adequate construction windows, limiting it to 4-5 hours each night and often to just one track at a time on double track. No trains run on Saturdays in Israel due to religious laws, but no construction may take place either, even on an otherwise-accelerated schedule.

Politics in Israel are contentious and polarized, but the electrification project has not suffered from political interference. It is not a point of partisan controversy, nor is it visible enough that politicians take an active interest to try to time project milestones for their own career ambitions; the project has been guided internally by the Ministry of Transportation and Israel Railways. Thus, despite the delay, the project has cost about $2.2 million per route-mile.

Denmark

Copenhagen was one of the first metropolitan areas in the world to run a frequent, electrified regional rail network: the S-Tog opened in 1934, when the local lines were converted from steam to electric operations. However, there was no other electrification in the country, nor plans for any, until 1979. Only two lines were electrified in the 1980s and 90s.

Plans for more expansive electrification began in the 2000s, but there was no steady investment. In 2009, the state decided to delay electrification and prioritize ETCS signaling instead. But in 2013 it reversed direction and decided to advance funding for electrification, while in 2017 it announced a 7-year delay in ETCS installation from 2023 to 2030. In 2015, funding was released, aiming for electrification of all lines on the plan by 2026, covering 800 miles, which together with existing electrification will cover 80% of Danish railways.As the national project is still in the design phase, cost figures are not yet known. However, segments that have been electrified recently have consistently come in at about 20 million DKK per kilometer, or about $4 million per mile[1], all for double-

1 *For a list of projects, see "The Danish Electrification Programme: A huge commitment," Global Railway Review https://www.globalrailwayreview.com/ article/21473/the-danish-electrification-programme-a-huge-commitment/. Costs can be found in the following articles: "Esbjerg electrification approved in four-point Danish transport plan," Railway Gazette, February 10, 2012 (https://www.railwaygazette.com/news/infrastructure/single-view/view/esbjerg-electrification-approved-in-four-point-danish-transport-plan.html) and "Danish investment plans to be chopped back," Ibid, May 19, 2016 (https://www.railwaygazette.com/news/policy/single-view/view/danish-investment-plans-to-be-chopped-back.html). Of note, all currency conversions are in purchasing power parity (PPP) dollars.*

track lines. These costs cover all infrastructure required for electrification; double-tracking of single-track lines to be electrified is a separate item, as is rolling stock.

Norway

Norway is a sparsely-populated country, with less than 1/20th the population density of Massachusetts. Its rail network is thus less used than those of denser countries like Germany, Denmark, or even Sweden, and the country has quite a lot of domestic aviation, as the population does not justify large-scale high-speed rail investment, especially given the foreboding terrain between many of its coastal cities. Nonetheless, thanks to cheap hydroelectric power, 64% of the network is electrified.

Norway is studying battery-powered trains for its sparsest line, which goes north of the Arctic Circle. But on the commuter lines around Trondheim, which run hourly and have fewer riders than any line in Metro Boston, it is electrifying with catenary. The 2018-29 national infrastructure investment plan allocated 3 billion NOK ($300 million) for electrification of two lines totaling 200 km (125 miles), or about $2.5 million per mile.[2]

New Zealand

New Zealand has long had some electrified rail segments. In Wellington, the commuter trains were electrified between 1938 and 1955. Moreover, most of the North Island Main Line, connecting Auckland and Wellington, was electrified between 1984 and 1988 because of the mountainous terrain and numerous tunnels; but diesel gaps remain, and there are proposals but no concrete plans to close them. The biggest recent electrification project in New Zealand has been in Auckland, a larger but more auto-oriented city than Wellington. In preparation for regional rail modernization, the state decided to electrify 80 km (50 miles) of route with a total of 196 single-track km (122 miles). The diesel equipment used in the Auckland area was approaching end of life and was increasingly unreliable, so instead of buying diesel trains for another generation, the state and the region decided to electrify and buy EMUs.

The plans for electrification were announced in 2007,[3] targeting a completion date of 2013. The entire cost of the project was set at 500 million NZD, or about US$350 million. This would include new rolling stock; the wire infrastructure installation alone cost 80 million NZD, [4]or about US$1.1 million per mile excluding substations. Electric service opened in 2014–5, with an increase in frequency and large growth in ridership, from 10 million per year in 2010–3 to 22 million in 2019.[5] Subsequently, the region has been investing money in a short city-center tunnel permitting through-service, like the North-South Rail Link in Boston, but on a smaller scale.

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2 *See "Nordic Rail 2015: Project Overview," Jernebaneverket, https://www.banenor.no/contentassets/8be0d4e9357f4d97b05accc11b8bb081/nordic-rail-2015-project-overview.pdf and David Burroughs, "Norwegian government proposes 4.4% increases 4.4% increase to rail budget," International Rail Journal, October 7, 2019, https://www.railjournal.com/financial/norwegian-government-proposes-4-4-increase-to-2020-rail-budget/.*

3 *See: Auckland Regional Council and Auckland Regional Transport Authority, "21st Century Public Transport for Auckland." Scoop: Politics, May 17, 2007. https://www.scoop.co.nz/stories/PO0705/S00304.htm.*

4 *See: Romy Uganda, "An electrifying start." Stuff, February 25, 2010. http://www.stuff.co.nz/auckland/local-news/3367763/An-electrifying-start.*

5 *See monthly data at: "AT Metro Patronage Report." AT Metro. https://at.govt.nz/about-us/reports-publications/at-metro-patronage-report/.*

Britain

Britain has one of the least electrified networks in Europe: only 38% of route-length is electrified. Most commuter rail lines in London are electrified, but among intercity mainlines, only the two most important, the West Coast and East Coast Main Lines, are fully wired. So unelectrified is the system that the Crossrail project, a massive east-west through-running regional rail tunnel in Central London, has had to include surface electrification of some lines heading west of London.

Britain is wiring the busiest remaining lines, including the next most important intercity lines and the commuter rail lines of the major secondary cities, with a particular emphasis on short branches, as electrification is especially beneficial when stop spacing is short.[6]

The headline costs are high. There is wide variation within Britain, and the most expensive examples, such as the Great Western Main Line, are nominally well beyond $10 million per route-mile[7]. And yet, these costs reflect far more than mere electrification. The RIA Electrification Cost Challenge report[8] includes a comparison of many British lines together with a few Continental Europe ones, skewing toward the upper end, that is about $4.5 million per route-mile. It points out that costs vary based on the need to increase clearances for electrification. A just-announced project to electrify the Midland Main Line costs about $7.2 million per route-mile, but the line is triple-track, raising costs[9].

In Britain, and nowhere else in the world, railway clearances, also known as loading gauges, are uniquely restricted. The most common EMUs used in Britain, the Electrostar family, are 12' 4" high, three feet shorter than the MBTA's Kawasaki bilevels. The loading gauge is too low to allow any bilevels, unlike in Continental Europe or the United States, and needs modification to allow even single-stacked containers if the containers are hi-cube. Worse, the bridges over the tracks in Britain tend to be arched, which means that even if it is easy enough to fit a wire underneath the center of the arch, it is harder to fit a train pantograph, which is wider. Britain had to invent new technology, called *surge arrestors*, to permit smaller clearances between fixed structures and high-voltage wire than are typical elsewhere. Even then, expensive bridge modifications are required, adding to the cost. Such modifications are not needed in the United States, where the loading gauge is generous and a 16' 4" bridge is considered low.

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6 *"Rail HLOS electrification by 2019," Department for Transport; accessed via Wikimedia Commons, https://upload.wikimedia.org/wikipedia/commons/1/17/UK_rail_electrification_by_2019.pdf. Note the blue-colored lines on the map, added to the plan in the early 2010s, including Cardiff's commuter rail network and some remaining branches of the red-colored Great Western Main Line that feed into London.*

7 *"Great Western electrification scheme 'one year behind schedule.'" BBC News, February 24, 2015. https://www.bbc.com/news/uk-england-hampshire-31610849*

8 *"RIA Electrification Cost Challenge Report." Railway Industry Association, March 2019. https://www.riagb.org.uk/RIA/Newsroom/Stories/Electrification_Cost_Challenge_Report.aspx*

9 *Aaron Morby, "Bidders day for £500m Midland Mainline electrification." Construction Enquirer, June 2021. https://www.constructionenquirer.com/2021/07/06/bidders-days-for-500m-midland-mainline-electrification/*

What Not to Do

While the normal range of electrification cost in the developed world is about $2 to $4.5 million per route-mile, there are outliers. Regrettably, these include the most recent geographically closest projects to Boston, namely those of Toronto ("RER") and the San Francisco Bay Area's Caltrain service. But these costs are high generally due to poor project management. We urge the MBTA to treat Toronto and San Francisco as examples to avoid, not emulate.

Toronto

Toronto is building a regional rail network, centered on electrification. However, there has been no attempt at cost control; a senior consultant on the project, Michael Schabas, explains that the benefit-cost ratio was so high that the planners added 100% contingency to the electrification project, as it would pencil out as a good investment even with this markup.

The cost figure for the Toronto RER project includes not just power but also other elements, such as infill stations and railroad junctions, and those elements are very costly too: a proposed infill station is priced at Canadian $95-120 million,[10] more than five times as much as the recently built Fairmount Line infill stations. As the projected benefit-cost ratio is between 2 and 3, there is no effort to reduce costs, because while the ratio would increase, it is already beneficial. The original electrification costs projected in 2013 were already higher than in the example cases we have used, about US$7 million per mile (adjusted for inflation),[11] but since then there have been further increases coming from lack of interest in value engineering.

San Francisco Bay Area

Caltrain connects San Francisco and San Jose and is an attractive target for modernization. There is more reverse-commuting than on any other American commuter line, and the population density is high by suburban standards, meaning that it is one of the busiest regional rail lines in the country. Electrification has been studied since the 1990s, but funding was only obtained in 2017.

From the start, the Caltrain electrification project was poorly planned. Caltrain has always received low priority among the Bay Area's fragmented transit agencies for funding. It hoped to piggyback on the California High-Speed Rail project for funds and standards, but then HSR chose to begin construction in a different part of the state. The Caltrain electrification standards were questionable:

» Caltrain has concurrently built a new signaling system, spending hundreds of millions of dollars on a bespoke implementation called CBOSS that ultimately failed, unlike the MBTA's more standard and low-cost ACSES signals.

» Caltrain's electrification and PTC projects were not designed in an integrated fashion, and thus cables for the signal system were placed in conflict with infrastructure for electrification, leading to further delays and overruns.[12]

Thus the overall cost per mile was about $14 million excluding rolling stock[13] even before the most recent cost overrun[14]. This makes Caltrain electrification a good example of what not to do, and makes cost comparisons to Caltrain ill-advised.

10 *"Initial Stations New Business Case." Metrolinx, November 2018. http://www.metrolinx.com/en/greaterregion/regions/docs/newstations/2018-11-28a-IBC-Highway-27-Woodbine.pdf*

11 *This is the maximum electrification option in "The GO Electrification Study." Neptis Foundation. https://www.neptis.org/publications/go-rail-and-regional-express-rail-network/chapters/go-electrification-study*

12 *For more detail, see analysis by the rail activist Clem Tillier at Caltrain-HSR Compatibility Blog. Regarding grade crossing protection: "Grade Crossing Trouble Ahead," December 8, 2018. https://caltrain-hsr.blogspot.com/2018/12/grade-crossing-trouble-ahead.html. Regarding positive train control: "The End of CBOSS," February 24, 2018. https://caltrain-hsr.blogspot.com/2018/02/the-end-of-cboss.html. Regarding electrification delays: "Electrification Delayed," September 1, 2019. https://caltrain-hsr.blogspot.com/2019/09/electrification-delayed.html.*

13 *The line is 50 miles long and the cost is just short of $700 million. See: "Caltrain inks contracts with Balfour Beatty, Stadler for electrification project" Progressive Railroading, August 17, 2016. https://www.progressiverailroading.com/passenger_rail/news.aspx?id=49177*

14 *Nico Savidge, "Caltrain electrification delayed to 2024, and the price tag is rising too." San Jose Mercury-News, June 3, 2021. https://www.mercurynews.com/2021/06/03/caltrain-electrification-delayed-to-2024-and-the-price-tag-is-rising-too/*

Challenges

Electrification is a generally straightforward investment. Usually, the only serious challenge is that the cost is higher than the return on investment on long, low-density lines, such as the freight mainlines in the Western United States, or lines with infrequent passenger service, like many of Amtrak's long-haul routes. On passenger lines running roughly hourly or better peak service, such as those of Metro Boston, the costs are uniformly justified.

Three challenges remain.

First, low-cost construction requires adequate construction windows. Since service disruptions are rarely acceptable, these windows must be at night, for 5-6 hours at a time; Israel's 4-5 hour windows would be feasible as well but are not optimal and have led to a noticeable project schedule slip.

Second, there may be opposition to wires on aesthetic or other grounds. In Israel, some activists made specious claims about dangerous radiation from high-voltage wires. (Actual safety issues are nonexistent, in the few cases where people have been injured by railroad electrification, it has invariably involved serious cases of trespass on railroad property) The city of Haifa claimed the wires would block access to the waterfront and won a concession to build a short trench burying the tracks to improve beach access. However, in Massachusetts, wealthy suburbs like Sharon did not oppose Northeast Corridor electrification in the 1990s, and have since grown accustomed to it. In any event, a robust citizen engagement and education process is always advisable in advance of construction; engagement in this region is more likely to be positive, based on that recent experience.

Third, it is necessary to integrate electrification with other ongoing projects. The MBTA's PTC resignaling project was not done with electrification in mind, although unlike Caltrain's, it uses a conventional off-the-shelf technology at far lower cost. Thankfully, the current slate of track upgrades, such as high-platform station rebuilds, are done with futureproofing for electrification.

The Benefits of EMUs

Performance

EMUs do not have to transport a diesel generator and fuel or a set of batteries - they get power from the wire (and, when they are decelerating, can easily return energy to the grid). This allows them to deliver much more power to the wheels than diesel trains. Modern regional EMUs have a power-to-weight ratio of 18 to 21 kilowatts per metric ton, about the same as the MBTA's older diesel locomotives without any passenger coaches attached. Put another way, EMUs carry passengers like non-powered coaches but have the performance specifications of a diesel locomotive hauling no coaches at all.

As they lack a dedicated locomotive, EMUs are also quite light. Continental European products would weigh about 44 short tons per US-length car. Thus the high performance does not require high energy consumption. This is a full 100 tons less than the MBTA's diesel locomotives, which weigh just shy of 144 tons[15], reducing track wear as well.

> ***EMUs will significantly improve the MBTA's ability to provide more capacity and more frequent service, consistent with increased ridership drawn to the Regional Rail service model.***

Finally, EMUs have traction at every axle, or at least on half of the axles, depending on the type of train. This dramatically reduces the potential for wheel slip and allows much more power to be transmitted at a time, meaning that they can accelerate faster, just as a four-wheel drive car accelerates better than a two-wheel drive car on a slick road. EMUs will significantly improve the MBTA's ability to provide more capacity and more frequent service, consistent with increased ridership drawn to the Regional Rail service model.

In fact, if an Orange Line train (all subway trains are EMUs) leaves Ruggles parallel with a diesel Commuter Rail train on an adjacent track, the Orange Line train will quickly outpace the Commuter Rail train, only being overtaken when it slows to stop at Roxbury Crossing. On lines with closely-spaced stops, for example, in Newton, Melrose, and West Roxbury, the faster acceleration will save significant time. Where there is more space between stops, like on the Providence and Lowell lines and the outer portion of the Worcester Line, the ability to accelerate to a faster top speed more quickly will also pay dividends in faster operations and lower crew costs, not to mention a more competitive product for riders.

Reliability

EMUs easily outperform diesel locomotives when it comes to reliability, the factor that perhaps more than any translates directly into an improved rider experience. The main metric used to measure reliability in the rail industry is called Mean Distance Between Failures (MDBF). The MBTA's older diesel locomotives have an MDBF of 5,000 miles. Even the newer diesels, introduced into MBTA service in 2014, only manage about 25,000 miles. New EMUs outperform the newer diesels by a factor of 5 to 20, with an MDBF deep into the 6 figures; the range in the examples we have found is about 150,000 to 450,000 miles.

With the legacy diesels of today, a rider on a line like the Providence or Framingham/Worcester Line would be on a train that breaks down somewhere on the route once every 12 weeks. But failures cascade as one broken down train delays the others behind it on the same line, so a rider is likely to experience a delay due to a breakdown every few weeks. With an EMU that breaks down only once every 400,000 miles, a rider would be on a broken-down train once every 18 years, or once every few years taking cascading delays into account.

15 *"MPI HSP46." Wikipedia. https://en.wikipedia.org/wiki/MPI_HSP46*

Today, platform assignments at North and South Stations are announced shortly before departure, because any train may have to substitute for another train going out of service. Passengers have to gaze at the departure board and shuffle once the track number is announced. In contrast, German and Japanese railroads are reliable enough that they announce track assignments when they announce the schedule, months in advance. This is the approach that the MBTA needs to take as well, and electrification makes this goal easier to attain.[16]

Reliable equipment would also let the MBTA have tighter schedule tolerances. Trains are never scheduled to run as fast as possible, because then they cannot recover from delays for their next trip. On Japanese high-speed trains, the schedule is padded 4% or even less, as it is a controlled environment without interface with any less reliable service. Switzerland, the only country in the world with an all-electric rail network, pads 7%, as its network is complex and has delicate junctions. But American commuter railroads routinely pad 15-20%, not just because of a lack of electrification, but also complex service patterns and lack of level boarding where a busy stop can require several minutes to load and unload passengers.

Altogether, the improvements in performance and reliability mean that transitioning to EMUs and level boarding would cut 30-45% off the trip times of MBTA commuter trains, with higher figures on lines with closely-spaced stations at peak hours, and lower figures for lower-ridership times and express trains with fewer stops. For instance, an EMU could run between Boston and Worcester making all stops from Framingham out in 45 minutes, 21 minutes faster than today's diesel-hauled Heart-to-Hub,[17] which runs nonstop from Worcester to Lansdowne.

Lifecycle costs

A Dutch analysis from the late 2000s found that on a lifecycle basis, the cost of procuring and maintaining an EMU is half as high as that of maintaining a Diesel Multiple Unit (DMU).[18] Electric trains are more reliable, so they do not require emergency repairs as frequently as diesels. They are also cheaper to buy; outside of the United States the market is thicker and more competitive, especially for high-performance products, since railroads that want high performance almost universally electrify.

> *An 8-car train per hour is enough to generate a 3.5 to 8% financial ROI from electrification, not counting improvements in speed.*

Working from the difference in operating expenses between the MBTA and all-electric SEPTA, it looks like pure operating costs would fall by perhaps a quarter to a third simply by transitioning to EMUs; we believe further cuts in costs are possible from other projects under the Regional Rail umbrella, as higher off-peak frequency would spread fixed costs across more service. In such an environment, the return on investment is around $20,000 per mile times the number of cars per peak hour; an 8-car train per hour is enough to generate a 3.5 to 8% financial ROI from electrification, not counting improvements in speed.

16 *TransitMatters' report, Regional Rail Proof of Concept: How Modern Operating Practice Adds Capacity to the Current Commuter Rail Network (2019), provides an in-depth analysis of implementing this practice on the MBTA. http://transitmatters.org/regional-rail-proof-of-concept*

17 *See the TransitMatters case study report included in the Proof of Concept, How to Provide Frequent All-Day Service on the Framingham/Worcester Line (2019), which includes an additional stop at the proposed West Station. http://transitmatters.org/regional-rail-proof-of-concept*

18 *See reporting at https://www.railwaygazette.com/news/single-view/view/benchmarking-identifies-good-practice-in-rolling-stock-maintenance-1.html.*

Air quality

Diesel engines emit considerable local particulate air pollution, much more so than gasoline engines: half the premature deaths attributed to transportation pollution in the United States are from diesel (mostly trucks)[19]. Europe's extensive use of diesel engines in cars has led to elevated air pollution[20]. Buses almost exclusively use diesel engines and show elevated levels of particulate air pollution as well[21]. Diesel trains are no exception: the diesel engines used by American freight and passenger locomotives are linked to elevated levels of air pollution[22].

Diesel is especially harmful in confined spaces. Back Bay Station has such significant air quality problems that there is a $10 million project just to improve internal ventilation[23]. The other major diesel commuter rail network, Metra, has similar air quality problems at Chicago Union Station[24]. But the bulk of the burden of diesel pollution is not in confined spaces. Rather it comes from repeated exposure near bus garages, high-traffic diesel railroads, or, the worst, major truck routes.

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The MBTA's Commuter Rail trunks pass through high-pollution Boston neighborhoods like Roxbury and Dorchester.[25] This is an especially acute problem on the Fairmount Line, where the acceleration and deceleration cycles produced by the line's many urban stations emit more local pollution. Electrifying the MBTA system is thus a key environmental protection and environmental justice priority.

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19 *"CATF Special Report 2007-1: A Multi-City Investigation of Exposure Diesel Exhaust in Multiple Commuting Modes: Columbus OH, Austin TX, Boston MA, New York City NY." Clean Air Task Force, April 1, 2010. http://www.catf.us/wp-content/uploads/2019/02/CATF_Pub_Diesel_Exhaust_Exposure_Investigation.pdf*

20 *Kim Willsher, "Diesel cars emit more air pollution on hot days, study says." The Guardian: Cities, September 10, 2019. https://www.theguardian.com/cities/2019/sep/10/diesel-cars-emit-more-air-pollution-on-hot-days-study-says*

21 *Nicole S. Ngo, "Analyzing the Relationship Between Bus Pollution Policies and Morbidity Using a Quasi-Experiment." Medicine (Baltimore), Vol. 94 (37), e4999, September 2015. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4635806/. Also see: "NYC Climate Justice Agenda: Midway to 2030: Building Resiliency and Equity for a Just Transition." New York City Environmental Justice Alliance, April 2018. https://www.nyc-eja.org/wp-content/uploads/2018/04/NYC-Climate-Justice-Agenda-Final-042018-1.pdf.*

22 *See: Daniel A. Jaffe, Greg Hof, Sofya Malashanka, Justin Putz, Jeffrey Thayer, Juliane L. Fry, Benjamin Ayers, and Jeffrey R. Pierce, "Diesel particulate matter emission factors and air quality implications from in-service rail in Washington State, USA." https://www.sciencedirect.com/science/article/pii/S1309104215303342; Janae Scott and Hillary Sinnamon, "Smokestacks on Rails: Getting Clean Air Solutions for Locomotives on Track." Environmental Defense, 2006. https://www.edf.org/sites/default/files/5736_SmokestacksOnRails.pdf; Lauren Victory, "New Pre-Owned Metra Locomotives Contribute to Pollution; CEO Says New Locomotives Too Expensive." CBS Chicago, June 12, 2018. https://chicago.cbslocal.com/2018/12/06/metra-locomotive-pollution/. It is possible to reduce the emissions of diesel by requiring better filters; Environmental Protection Agency (EPA) standards have steadily tightened over the years, resulting in less (though still elevated) levels of pollution from buses. However, the MBTA specifically skirted these rules by pressing the newest diesel locomotives into service prematurely so that they would be grandfathered until the older Tier 3 laws rather than the newer Tier 4 regulations.*

23 *Jon Chesto, "Relief could be coming for Back Bay Station commuters weary of diesel fumes." The Boston Globe, April 4, 2016. https://www.bostonglobe.com/business/2016/04/04/relief-could-coming-for-back-bay-station-commuters-weary-diesel-fumes/Zd96LvNx5ZGd9hnzg7Zb2K/story.html*

24 *Andrew L. Hughes, "Diesel Exhaust and Chicago Union Station - Part 2 - Initial Air Quality Testing Results." Hughes Law Offices: Diesel Injury Law, July 25, 2018. https://www.dieselinjurylaw.com/blog/diesel-exhaust-and-chicago-union-station-part-2-initial-air-quality-testing-results*

25 *Adriana Jacobsen, "Air Quality vs. Carbon Emissions per Household from Private Vehicles." Accessed via Twitter, October 1, 2020. https://twitter.com/adrianaclimbs/status/1311714757083303937*

The Importance of Maximum Electrification

When undertaking electrification projects, there is occasionally discussion of only deploying EMUs and electric infrastructure on the busiest lines, and continuing to run diesel push-pull rolling stock elsewhere. The three commuter rail systems serving the suburbs and satellite cities of New York City - Metro-North Railroad (MNRR), the Long Island Rail Road (LIRR), and New Jersey Transit - all operate this way. While there are cases where this is sometimes practical, in the case of the MBTA Commuter Rail and indeed all of the Northeast's commuter rail networks, wiring some lines but not others is less prudent than it sounds. Even the lowest-ridership MBTA lines, like Greenbush, have enough traffic that the immediate financial return on investment is healthy, mid-single digits.

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Moreover, full electrification offers the advantage of a uniform fleet without special carve-outs for unmodernized branches, which complicate maintenance and add to operating costs. For instance, the LIRR's operating and maintenance costs are high due to peak-focused schedules and antiquated staffing levels, but they're especially high on the diesel tails, since their rolling stock and crew have extensive deadheading. We recognize that full electrification of the system will take some time, but conceding some sections to be permanently operated by diesel locomotives will only waste operating costs on maintaining equipment that is more costly to operate and more prone to failure. Further, an all-electric system would require less complex ventilation at Downtown stations or if air rights were sold.

The only viable way to achieve Governor Baker's goal of zero emissions by 2050 is to transition to a fully electrified Regional Rail system. Anything short of that is both environmentally and economically unsound.

What about...?

Diesel multiple units

DMUs are an attractive option for very low-traffic branch lines, typically with 2- and 3-car trains, carrying fewer riders than the MBTA commuter rail's lines. Their performance, while better than that of diesel locomotives, is only about halfway toward that of EMUs; DMUs also have about twice the lifecycle cost. Worse, the use of diesel traction is polluting in enclosed stations like Back Bay, and is not compatible with future tunnels like the North-South Rail Link.

Electric locomotives

Electric locomotives are more reliable than diesels, but less so than EMUs. They are also expensive, about $5 million per unit for recent European orders. They are heavier and consume more energy, raising operating costs. They do not accelerate any faster than diesel locomotives at low speeds, sometimes even more slowly, and are midway between diesels and EMUs in medium-speed acceleration, both of which increase the stop penalty.

Battery-powered trains

Battery-powered trains are an immature technology, deployed in small quantities on low-traffic lines. They are also expensive: one example in Germany has a range of 120 km (75 miles, significantly less than a Boston-to-Worcester roundtrip), takes half an hour to charge, and costs 100 million euros for 11 three-car trains, about $4.8 million per US-length car, double the cost of EMUs.[26] The use case is for lines where the cost of the equipment is less important because traffic is very low: an hourly 3-car train offers a marginal return on investment. When traffic is low, a half-hour charge time is not onerous either, but on a busy suburban commuter line, time is money and longer turnarounds require more trains and train station expansion. It's telling that Norway, which is experimenting with battery technology and is the world leader in battery-electric car adoption, is nonetheless still wiring urban commuter lines with less peak traffic than Boston.

Hydrogen fuel cell trains

Like battery-powered trains, hydrogen fuel cell-powered trains are not mature technology. A few examples exist, but they are uncommon and designed for low-intensity branch lines, with the performance of a DMU. The largest order so far is for 27 trains, each about as long as a two-car American EMU, for €500 million[27], or about $600 million, about four times as expensive as an EMU. In the realm of cars, too, hydrogen remains at best experimental, to the point that Volkswagen just had to admonish German politicians and say battery-electrics are the future[28]. Until costs come down, no regional railroad should consider buying fuel cell trains.

Freight

Freight trains run under wire all the time, even if they themselves are powered by diesel engines. There are freight trains on the electrified Northeast Corridor; this includes some running double-stacked containers, and in any event, there is presently no double-stacked freight on the MBTA network. Some freight railroads complain about electrification, such as Union Pacific in California, but they're perfectly capable of coexisting with electric passenger trains on the Northeast Corridor and on Metra Electric in Chicago. Thankfully, with the exception of a short tail on the Fitchburg Line where we recommend track separation, the MBTA owns its railroads and freight operators are tenants. Freight railroads must not be the tail wagging the dog in Massachusetts, either by obstructing electrification or demanding expensive and unnecessary concessions.

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26 *See "Alstom signs battery-electric multiple-unit contract." Railway Gazette, February 5, 2020. https://www.railwaygazette.com/traction-and-rolling-stock/alstom-signs-battery-electric-multiple-unit-contract/55711.article.*

27 *See "'World's largest fleet of fuel cell trains' ordered." Railway Gazette, May 21, 2019 https://www.railwaygazette.com/traction-and-rolling-stock/worlds-largest-fleet-of-fuel-cell-trains-ordered/48563.article.*

28 *Herbert Diess, Twitter, May 18, 2021. https://twitter.com/Herbert_Diess/status/1394546760056459274*

Weather

Electric wires work reliably in winter, running without a problem in such places as Switzerland, Sweden, Norway, and northern Japan. In Korea, the portion of the high-speed rail system requiring heating is not the catenary but the switches.[29] In the summer, older American variable-tension catenary tends to sag, a recurring problem on the Northeast Corridor, but the constant-tension catenary (where wire is stretched by a mechanical series of weights and pulleys to maintain a constant tension, a low-tech solution to a high-tech problem) used in the rest of the world as well as on newer Northeast Corridor electrification works reliably.

Substations

Electrification involves two major expenses, the wire and the substations. The costs are split about evenly between the two in the projects above for which we have seen such a breakdown; the 2005 budget estimation for the Green Line Extension, likewise, had similar costs for wire ($4.464 million) and substations ($6 million). In the study for the causes of higher British costs, it was not the substations that generated extra costs, but rather bridge clearances for catenary.

29 *See Choi Jin-Seok (Ed.), "KOTI Knowledge Report: Korea's Best Practices in the Transport Sector, Issue 12: Korea's High-speed Rail Construction and Technology Advances." The Korea Transport Institute, 2014. https://centers.ibs.re.kr/html/living_en/transport/KSP%2012%20Korea%E2%80%99s%20High-speed%20Rail%20Construction%20and%20Technology%20Advances.pdf, p. 65.*

Conclusion

Electrification of the MBTA rail network is the most viable and cost-effective way to meet the goals of reduced emissions, increased reliability, and faster service. No other measure or combination of measures comes close. Despite claims to the contrary, there is ample evidence that this program can be delivered cost effectively; fear over electrification stems from a handful of high-profile failures to contain costs. Electrification is not a bespoke project, but an off-the-shelf implementation which has been replicated across the globe.

As Eastern Massachusetts embarks upon the necessary project of transforming its commuter rail network into a modern Regional Rail system, it will be in the unique position of pioneering this model of service planning and this level of infrastructure investment amongst American agencies.

> ***Electrification of the MBTA rail network is the most viable and cost-effective way to meet the goals of reduced emissions, increased reliability, and faster service.***

To that end, it is incumbent upon MassDOT, the MBTA and the State Legislature to insist that international best practices be adhered to here, as in Israel. The Office of Rail Transformation must be given the directive of drawing upon the expertise of engineers and managers who have worked on these cost effective electrification projects. It is not sufficient to simply hire international consulting firms; the staff hired must have direct experience in the best projects, and must be hired in-house, for wiring as well as rolling stock purchase[30]. Nothing short of that will guarantee success.

This principle is relevant not just for Regional Rail itself, but for both related and unrelated transit improvement and expansion projects. In order to do the hard and necessary work of providing the transit that Metro Boston requires to thrive, our planning processes need to imitate the ones that deliver the best results around the world.

30 *Stadler's bilevel KISS order for Caltrain cost at a premium of about 40% over the costs of the same train in Europe, for reasons that Stadler attributes to overuse of consultants rather than in-house experts by Caltrain as well as micromanagement. See: Martin Ritter, "High-Quality Railway Vehicles: North American Market." Stadler, October 19, 2017. https://slideplayer.com/slide/13671652/, slide 31.*

Comparison Matrix

Project Location	Current Status	Miles (to be) Wired	Cost/ Mile (USD)	Time from Proposal to Completion	Challenges	Lessons	Recommended?
Israel	Delayed, nearing completion	262	2.2m	12 years	Bidder lawsuit, scheduling	Experienced contractor, technical scoring	Yes
Denmark	Design	510	3.6m	13 years	Budget uncertainty	Concurrent signal upgrades	Yes
Norway	Under construction	125	2.5m	8 years	Low traffic density	Wiring suburban lines, keeping batteries to rural experiments	Yes
Auckland	Completed	50	2.2m	8 years	Fleet and yard expansion, restricted clearances	Use of imported standard rolling stock, electrification to be followed by urban rail tunnel	Yes
Britain	Under construction	*[31]	4.5m	10 years	Restricted clearances	Prioritization of regional over intercity lines	Yes
Toronto	Under construction	281	7m+	17 years	Cost control		No
SF Bay Area	Delayed	50	14m+	18+ years	Poor planning & standards, poor contracting, bespoke signals		No

31 *The RIA Electrification Cost Challenge Report compares many different British projects with line-by-line costs, differing by a factor of 3. Britain reports cost per single-track km, rather than by route-km or route-mile as we do here and as sources for other countries do; the report compares British projects of different levels of complexity, and the moderate complexity of Boston corresponds to a cost of about £1m/single-track-km, which is $4.5m/double-track-mile.*

What is Regional Rail?

MBTA Commuter Rail operates as a mid-20th century service with a mid-20th century business model. It reflects out of date biases about where people and jobs are located, and about how people desire to get from one place to another. Many people no longer work on a strictly 9 am to 5 pm weekday schedule, and many more want convenient and frequent train schedules that respond to the needs of their daily lives.

> *"The current Commuter Rail paradigm costs way too much money for way too little ridership."*
>
> *— MBTA FMCB Chairman Joe Aiello, 11/20/17*

Our current approach to Commuter Rail, as a business model, fails to offer its rider/customers the service they want and need. As a result it contributes to the region's worsening traffic congestion, keeps Gateway Cities isolated during most of the day, and exacerbates income inequality since the inadequate service compels many to drive – for lower income people, the high cost of owning, maintaining and driving an automobile can have a crippling effect on their ability to make ends meet.

Public transit must be frequent all day, not just at rush hour. A Regional Rail system would have trains running at least every half hour all day in the suburbs and at least every fifteen minutes in Boston and other Inner Core communities.

Regional Rail requires both frequent all day service, accessible platforms and smarter equipment to provide the service. That means high-level platforms at stations to simplify and speed up boarding and alighting. It also means electrification of the system, enabling use of Electric Multiple Units to replace the current push/pull diesel fleet. EMUs will be more reliable and less expensive to maintain, will provide riders with speedier trips, and will provide better service without polluting the air around them.

A highly functioning Regional Rail system includes five critical components:

» **Systemwide electrification** and the purchase of high-performance electric trains.

» **High platforms**, providing universal access and speeding up boarding for everyone.

» **Strategic infrastructure investments** to relieve bottlenecks and speed restrictions.

» **Frequent service all day** at least every 15 minutes in and around Boston and to key destinations, and at least every half-hour systemwide.

» **Free transfers** between regional trains, subways, and buses, and fare equalization with the subway in the subway's service area.

And one useful component that will complete cross-region mobility:

» With a modern electric Regional Rail system in place, the **North-South Rail Link** (NSRL) is the next step to drastically enhance regional mobility. NSRL allows trips between any two stations through a one-seat ride or single, seamless transfer, providing the flexibility and connectivity to which many riders and potential riders would be drawn.

MORE INFORMATION AND REPORTS AVAILABLE AT:
HTTP://REGIONALRAIL.NET

REGIONAL RAIL FOR METROPOLITAN BOSTON	WINTER '18
REGIONAL RAIL PROOF OF CONCEPT	FALL '19
REGIONAL RAIL PHASE 1	SUMMER '20
PROVIDENCE/STOUGHTON LINE	SPRING '20
FAIRMOUNT LINE	FALL '20
NEWBURYPORT/ROCKPORT LINE	WINTER '21
OLD COLONY LINES	SPRING '21
HAVERHILL LINE	FALL '21
REGIONAL RAIL ELECTRIFICATION	FALL '21

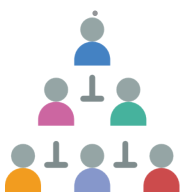
Regional Rail has 5 transformative benefits:

Almost all commuter rail stops have poor accessibility.
32 are entirely inaccessible. High-level platforms provide step free access to all riders, including those with mobility constraints, parents with strollers, and riders with heavy equipment or suitcases.

Regional Rail improvements facilitate economic growth and provide a wider customer base for local businesses.
Frequent, reliable rail can increase development near stations. Regional Rail provides a green, economical way to access our rich cultural resources and recreational amenities.

Modern electric trains create zero local emissions, reduce noise pollution, and increase reliability, making rail more attractive relative to car trips.
Electrification can thus help reduce respiratory ailments in environmental justice communities, and is critical for meeting the Commonwealth's 2050 zero net emissions goals.

Regional Rail opens up new housing markets, and makes transit-oriented development more attractive.
Workers who commute some or all days of the week can use the train for other longer trips, and walk or bike to local destinations. Frequent, reliable, and affordable rail service opens up new employment opportunities, particularly in Gateway Cities, which are well positioned to become employment centers in their own right.



Frequent, reliable, and affordable rail service opens up new employment opportunities.
Regional Rail both reduces the "spatial-skills mismatch" that holds back employment, and provides access to vocational opportunities to boost workers' skills. Regional Rail itself will provide up to 250,000 direct and indirect jobs during construction.

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