NO LITTLE PLAN:

Electrifying GO Transit

Greg Gormick

clean train coalition
TRANSIT FOR A HEALTHY CITY

Transport Action Ontario

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NO LITTLE PLAN: ELECTRIFYING GO TRANSIT

BY

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PART 1 of 4: FOREMATTER and CHAPTER 1

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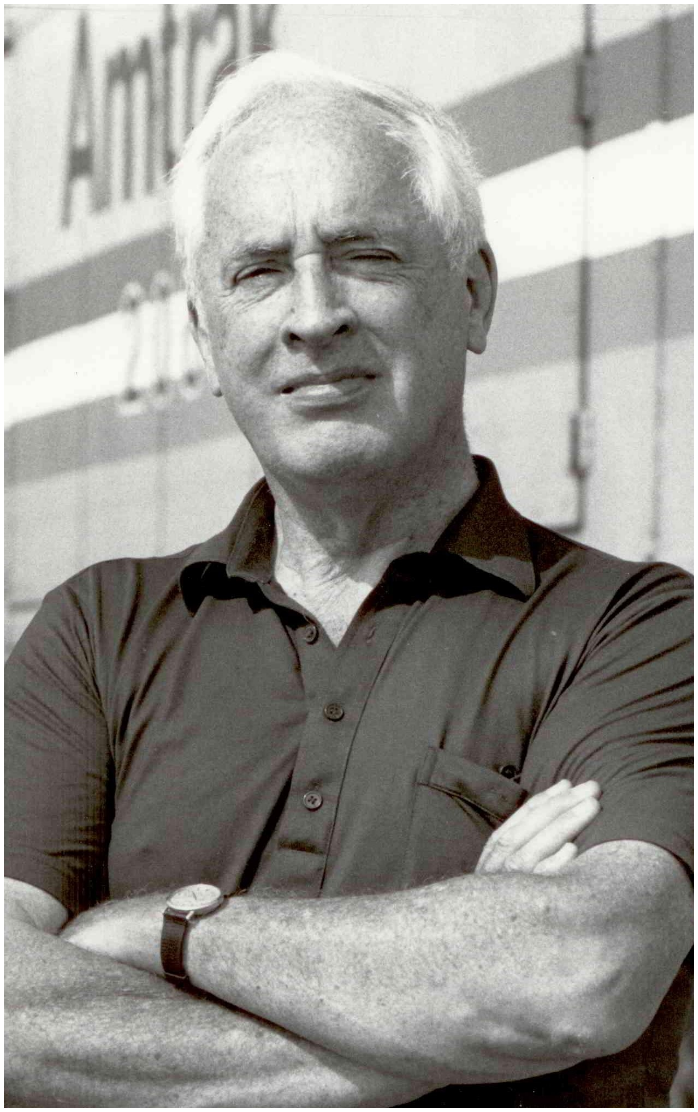
Dedication



This report is dedicated
to the memory of the late John Bruce McCullum,
President of Transport 2000 Ontario (now Transport Action Ontario)
from 1988 to 1992.

Visionary, ecologist, and sustainable transportation advocate.

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Foreword

As readers of this report will find, the electrification of GO Transit has a long history. Following the innovative establishment of GO's commuter rail service in 1967, electrification was studied seven times, most recently with the Metrolinx GO Electrification Study that was released on January 19, 2011.

All these studies identified many positive attributes to electrification. However, not one centimetre of electrified commuter rail infrastructure has to date been built. The situation today remains perplexing and frustrating. Despite identifying many positive features, the most recent Metrolinx study recommends what can only be described as a leisurely implementation of electrification on two corridors only.

As readers will also find, the GO Electrification Study and the Air Rail Link plan both contain assumptions and omissions that must be challenged. In our minds, the worst issue is the difference between the 2021 reference case used in the Electrification Study and the 2031 vision in the Metrolinx Regional Transportation Plan, better known as *The Big Move*. It includes high-frequency, day-long express rail service, similar to that provided by the impressive urban rail systems in European cities like Paris and Berlin. This can only be accomplished with electrification. But the study doesn't quantify the benefits, alternatives and costs to attain this vision, sticking only to the 2021 scenario of modest service increases. It also under-emphasizes the very likely ability of electrification to reduce the required scope of Union Station's capacity increase and the magnitude of the planned Yonge subway capacity expansion.

We commissioned this report, *No Little Plan: Electrifying GO Transit*, to prod the Government of Ontario to look at the longer term – the period from 2031 onward – and commit promptly to an accelerated, expanded electrification plan. Written by Greg Gormick, an experienced and visionary transportation commentator who has written extensively about the transformational potential of electrification, this report identifies the key next steps to maintain momentum. His exploration of worldwide electrification experience demonstrates the lengthy implementation plan can definitely be shortened.

The need for a European urban rail approach is even more intriguing as a result of recent events in the City of Toronto. With the cancellation of planned LRT lines and the reduced coverage provided by proposed subways, a "surface subway" concept using electrified GO integrated with other transit lines is an important cost-effective option to consider.

We urge decision makers to read this report carefully and start down the implementation path now. We are greatly concerned that another opportunity to transform GO and our region-wide public transit network – and thereby improve the economic, social and environmental health of the Greater Toronto and Hamilton Area – is once again slipping through our fingers.

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President
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May 16, 2011

Executive Summary

Introduction

GO Transit was launched by the Government of Ontario in 1967 as North America's first new commuter rail service in decades. It was an immediate success. Today, it is difficult to imagine what the Greater Toronto and Hamilton Area (GTHA) would be without the GO system. And GO's success has inspired other cities. There are now 10 commuter rail systems in other North American cities that are carbon copies of GO.

But GO and the region are at a crossroads. GO is slated to play a key role in altering the commuting habits and land development patterns in the GTHA. Vastly expanded GO service with more trains on more lines and quicker schedules are among the cornerstones of the Metrolinx Regional Transportation Plan (RTP), better known as *The Big Move*. To do this, the current provincial government is going to have to commit to a decision as bold as the launch of GO in 1967. There is compelling evidence to suggest that the only way to achieve the provincial goals is to progressively and aggressively convert GO to clean, quiet and cost-effective electric operation. This is the course that other large and medium-sized urban regions have followed worldwide.

This report has been commissioned to encourage the Government of Ontario to commit fully to an accelerated electrification plan now, thus avoiding the ongoing penalties on the region's economy, environment, public health and long-term sustainability.

1.0 Rail Electrification's History of Excellence

Rail electrification in North America is not new technology. The first application on a main line railway was in 1895 in Baltimore. The first example of "taking wealth from the air" by exploiting development rights over electrified lines was achieved above New York's Park Avenue in 1906. The first use of self-propelled electric multiple unit (EMU) cars for fast, frequent commuter rail service was implemented in New York at the same time. The first electrification of a major intercity network was undertaken by the Pennsylvania Railroad (PRR) from New York to Washington and Harrisburg, Pennsylvania, in 1928.

All these installations proved four advantages of electrification: lower emissions and noise, tunnel operation without massive ventilation systems, its superiority in conquering steep grades and its ability to squeeze more capacity from the same track and station infrastructure.

After World War Two, rail electrification continued in Europe, but stalled in North America. The main reason was the perfection of diesel-electric locomotives, which use onboard diesel engines to power electric traction motors. This had some of the benefits of the electric locomotive and lower upfront capital costs compared to electrification. In the 1950s and '60s, some aging electric lines were scrapped, especially short tunnel operations, such as CN's St. Clair River Tunnel electrification at Sarnia, Ontario. These were replaced by diesel operations with new ventilation systems to clear the tunnels of fumes.

But one major railway maintained its commitment to electric traction. On the PRR, studies concluded diesels still couldn't compete with electric operation. The result was renewal of the fleet with new EMUs for commuter service and high-horsepower electric locomotives for freight.

In the early 1970s, as a result of the OPEC oil crisis, several North American railways re-examined electrification, including Canadian Pacific. But once the OPEC crisis passed, oil prices stabilized and the rail industry returned to its pro-diesel stance.

Today, North America has re-awakened to electrification's potential. Part of this renewed interest revolves around the spate of high-speed rail projects now proposed in the U.S. Also, faced with automobile-fed urban sprawl, rising energy costs, uncertain future oil supplies and continued environmental degradation, there is a growing public call for the expanded rail electrification. There are currently 19 commuter rail electrification projects and proposals under way in North America.

2.0 GO Electrification Studies: 1980-2001

The benefits and the means of electrifying GO have been studied on numerous occasions in the past. Each of the previous studies contains data still relevant to the issue today.

The first series of studies was carried out in 1980-1982 and concluded, *"The province should prepare for future change by completing current planning studies and carrying our detailed design of financial implementation studies needed to validate and implement electrification of the Lakeshore portion of the GO Transit commuter rail network."*

A detailed implementation plan followed. However, the plan was derailed by the Province's insistence that GO use the unproven, made-in-Ontario Advanced Light Rail Transit (ALRT) technology. By the time it was determined that the cost of ALRT was excessive, the momentum for electrification had been lost.

In 1992, another comprehensive study clearly spelled out the virtues of electric traction. Electric multiple units (EMUs) vis-à-vis electric locomotives received serious study. It was concluded it was not possible to convert GO's non-powered bi-levels to self- propelled EMU operation, as there was little under-floor space for traction equipment. It was suggested that new motorized driving cars could be paired up one-for-one with the existing bi-levels. The study team recommended the preferred traction power system to be +/-25,000 volts AC (now known as 2x25 kV). The report also dealt extensively with emissions and noise, demonstrating that electrification would result in significant reductions in both types of pollutants.

Exhaustive though it was, nothing came of the 1992 study, even though the government of Premier Bob Rae was philosophically supportive. The global economy had receded and there were no provincial funds available to move forward.

The GO electrification issue slumbered until 2001, when an opportunity arose to purchase surplus electric locomotives from Mexico. A study confirmed the incremental capital and operating costs for electrification from 2004 to 2021 would be less than $100 million. This did not account for the significant health, environmental and ridership benefits. Although GO electrification had never been more affordable, the government of Premier Mike Harris did not act.

3.0 Enter Metrolinx

Metrolinx is the provincial government agency established in 2003 to plan and coordinate transportation within the Greater Toronto and Hamilton Area (GTHA). A takeover of provincially-owned GO Transit was later added to its mandate.

In 2007, prior to release of the Metrolinx Regional Transportation Plan, *The Big Move*, the Premier released his Move2020 plan, an $11.5 billion commitment to 52 priority transit projects in the GTHA, including *"increasing speed and reducing emissions by electrifying the GO Lakeshore line and expanding capacity on all GO lines".*

The government's endorsement of electrification escalated in 2008 with its acceptance of *The Big Move*. Express rail, defined as *"high speed trains, typically electric, serving primarily long-distance regional trips with two-way all-day service"*, was a cornerstone of the plan. *The Big Move* proposed express rail on GO's Lakeshore and Brampton lines within 15 years and on the Milton and Richmond Hill lines within 25 years. Additional express rail service was identified for beyond the 25- year planning horizon.

The inspiration for this program was provided by the electrified, high-frequency urban rail systems of Western Europe, such as the Paris RER and the German S-Bahnen, which are much like high-capacity surface subway systems serving suburban and inner-urban passengers.

Metrolinx then commissioned a follow-up study for the Lakeshore. Electrification of the full line was pegged at $4 billion, including contingency. This large price tag seemed to discourage Metrolinx and electrification started to fade away once again.

Electrification was revived soon thereafter as a result of the Air Rail Link (ARL) project. Conceived as a diesel multiple unit (DMU) service, it would operate up to 150 trains between Union Station and Pearson International Airport daily. Added to the expansion plans of GO and VIA Rail, this would result in more than 400 diesel trains passing through well-developed neighbourhoods daily. In 2005, the Weston Community Coalition addressed the issue and then spearheaded the 2009 formation of the Clean Train Coalition (CTC). Composed of residents' associations along the line, the CTC dedicated itself to presenting citizen concerns and advocating improvements, including electrification. The urgency increased when the diesel-powered ARL was attached to Toronto's bid for the Pan Am Games, to be held July 10-26, 2015.

In May, 2009, under pressure from the CTC, local politicians and MPPs, the McGuinty government announced it would undertake a $4 million "comprehensive review" of GO electrification.

4.0 The Metrolinx GO Electrification Study

The 1,705-page GO Electrification Study Final Report was released January 19, 2011. Observers were pleasantly surprised that a phased electrification plan was recommended for the ARL/Georgetown and Lakeshore corridors, with the former as the first priority. The two-route plan was approved unanimously by the Metrolinx directors one week later and, within minutes of the board's decision, Minister of Transportation Kathleen Wynne announced the initiation of the Environmental Assessment process.

The decision was based on a combination of journey time savings, operating and maintenance cost savings, anticipated future ridership growth and electrification's contribution to the long term goals of *The Big Move.*

The estimated cost was $1.6-1.8 billion. It was recommended that the implementation be phased in over 21-24 years. This time line struck many as extremely slow when compared with the implementation schedules of other railways around the world.

CORRIDOR SEGMENT	COMPLETION
Union Station-PIA and Willowbrook (EA and Design)	2011-2015
Union Station-PIA and Willowbrook (Construction)	2018-2020
Airport Spur Junction-Brampton Mount Pleasant	2020-2022
Union Station-Oshawa	2024-2026
Willowbrook-Oakville	2026-2028
Oakville-Hamilton James Street	2028-2030
Oshawa-Bowmanville	2030-2032
Brampton Mount Pleasant-Kitchener	2032-2035

Perhaps the most useful revelation in the report concerned the cost of GO electrification. The estimated cost to electrify the full GO system was $3.7-4.2 billion, much lower than previous estimates.

Although the report was generally positive, there were a number of contradictions, false assumptions and omissions that still need to be challenged:

1. The Reference Case selected was GO's 2021 benchmark consisting of a limited amount of service expansion using diesel-hauled bi-level trains of 10-12 cars, except for the ARL which assumed single-level diesel-motorized units. The result is that electrification was assessed against a case that falls far short of what was envisioned in *The Big Move*, which contemplated high-frequency, all-day service in both directions on all routes. This results in a report that views electrification as far less of a system development tool that it should be.

2. Tier 4 diesel motive power was assumed to be available and it was against this form of traction that electrification was compared. Tier 4 aims to significantly reduce particulate and nitrogen oxide emissions versus today's diesel engines. However, no manufacturer has yet produced a commercially viable Tier 4 diesel.

3. The equipment selected was electric locomotives rather than EMUs, largely because the study concluded EMUs would have higher total costs over the 30-year life cycle. However, many senior railroaders feel these costs were overstated, especially in view of the superior performance of EMUs. A bi-level EMU strategy should have been studied in detail. For example, the 1992 GO Electrification Study found the design of existing bi-levels could be adapted to create bi-level EMU power cars capable of hauling existing GO bi-level coaches.

4. Health, environmental, social and community benefits were undervalued. The study claimed these benefits are small. To make this case stick, Metrolinx reported the benefits in the context of GO's anticipated emissions on a regional basis, not directly on the affected corridors. This contradicts the opinion of Toronto's Medical Officer of Health.

The beneficial economic impact of electrification is substantial. Using accepted industry multipliers, it is estimated electrification of the ARL/Georgetown and Lakeshore corridors would generate $5-7 billion in economic benefits. Electrification of the full GO system would generate $11-17 billion. Much of this activity would occur in Ontario.

It is difficult to fathom how electrification of two GO corridors could possibly require the 21-24 years proposed by Metrolinx. There are numerous techniques and technologies around the world to make it happen quicker and without unduly disrupting existing rail traffic. Metrolinx must be encouraged to study this issue in much greater detail and move in concert with other planned infrastructure investments.

The most controversial aspect of the report was the recommendation to proceed with the ARL as a diesel service to be completed in time for the two-week Pam Am Games in July, 2015, with future conversion of the units to EMUs. If the approved plan is followed, the ARL will be electrified by 2018-2020 and some further reduction in the level of diesel-powered GO service on the Georgetown Corridor will occur by 2020-2022. The complete elimination of diesel-based service on the line will not occur until 2032-2035.

It has become clear that the 2015 start-up of the ARL as a diesel-powered service is a "done deal". The contract with Japan's Sumitomo for 12 diesel multiple unit (DMU) rail cars was signed on March 29, 2011.

Still, many issues and concerns remain:

- There is doubt the passenger volumes and automobile trip replacements predicted for the ARL will materialize.
- With its low projected ridership, the diesel-powered ARL may actually increase fuel consumption and emissions vis-à-vis the automotive trips it will allegedly replace.
- The future conversion of the DMUs to EMUs is risky and highly unlikely.
- The ability of the Sumitomo DMUs to meet Tier 4 emission standards is unknown.
- The final price for the Sumitomo DMUs is surprisingly high when compared to the price paid by the Sonoma-Marin Area Rail Transit District.

- The addition of more station stops should be explored in the context of using the large investment in the ARL as a springboard for a high-frequency urban rail service.
- GO's questionable decision to spend $400 million to build a fourth track on the Weston Subdivision to protect for the construction of electrification infrastructure after ARL diesel service begins requires further investigation and justification.
- Delaying the ARL until electric service can be launched from the start ("do it once, do it right") would avoid this $400 million expenditure. Other green transportation alternatives can be put in place for the two-week Pan Am Games.

5.0 Conclusions and Recommendations

Despite initiation of the Environmental Assessment process, the fight for GO electrification has not yet been won. As with many other Ontario transit programs that were supposedly assured, there has been far too much talk and too little action.

If GO electrification is to be implemented as promised, there are measures that need to be taken soon:

- **Accelerated and Expanded Electrification Program**: The leisurely timelines must and can be accelerated. The scope of the lines to be converted can be increased.

- **International Peer Input**: This will advance the implementation in the most expeditious and cost-effective manner possible.

- **Freight Railway Consultation:** Most of the track for the approved plan is owned by freight railways. The involvement and approval of these railways is critical to successful implementation.

- **European Urban Rail Concept:** In *The Big Move*, a vision was presented that transformed GO into a higher speed, higher frequency urban rail service. Electrification is critical to such a plan, along with high-performance EMUs, full fare integration and numerous physical connections with other transit lines. Some have termed this a "surface subway" or "overground" system.

  The implementation of an urban rail strategy should be accelerated within the City of Toronto. With the cancellation of Toronto's Transit City LRT plan and the reduced coverage to be provided by the proposed subway alternatives, a fully-integrated GO rail system providing subway-like service on existing and re-aligned rights-of-way is an attractive option. A failure to embark on such a project will only condemn the GTHA to more gridlock, lost productivity, environmental degradation, excessive automobile dependency and a loss of global competitiveness.

- **Public Scrutiny and Oversight:** GO electrification only became an issue because of public scrutiny and advocacy. If electrification is to be implemented as promised by the current government, and even expanded, then the public will need to keep up the campaign. And if the government is sincere in its stated desire to involve citizens in this process, it should maintain and strengthen the stakeholder workshop process that was in place throughout the one-year GO Electrification Study. Few of the public recommendations made in those sessions were investigated, let alone incorporated into the final plan.

Introduction

"Make no little plans; they have no magic to stir men's blood and probably will themselves not be realized."

Daniel Burnham

In the late 1950s, the Government of Ontario faced a daunting challenge. The rapid growth of Toronto had placed tremendous pressure on the region's existing transportation system. Major choices about its future direction had to be made. As with many North American cities that boomed in those heady postwar years, most of the growth beyond the boundaries of the old, transit-dependent city was being fuelled by the automobile.

How would the province respond? There was pressure from many quarters to follow the example of U.S. cities such as Los Angeles, Houston, Atlanta and Detroit by recasting this urban region as one whose transportation destiny would be surrendered to the automobile. A few lonely voices argued for a response that leaned heavily on transit expansion and urban development policies designed to support it.

Both Premier Leslie Frost and his successor, Premier John Robarts, remained unconvinced that automobiles and highways alone should define the future of the Metropolitan Toronto Region. The cost and consequences of the land acquisitions for a highway-based transportation system would have been staggering. Cities that had done so, such as Los Angeles, were already drowning in the cars that merely continued to feed the sprawl and consumed all new highway capacity.

On May 19, 1965, Premier Robarts announced his bold plan. Ontario would create an 84-kilometre experimental commuter service over the upgraded Canadian National line from Pickering to Toronto Union Station and on to Oakville and Hamilton. It would be called GO Transit and it would be North America's first new commuter rail service in decades. The public hailed the premier's decision, even while many highway-minded civil servants and planners scoffed at it.

Launched on May 23, 1967, with Premier Robarts at the controls of the first train, GO was – to paraphrase the legendary Chicago architect and planner, Daniel Burnham – "no little plan." The impact of the initial Lakeshore Line on the communities it served was swift and dramatic. The two-year ridership targets were reached within six months. A visiting delegation of politicians, civil servants and planners from New Jersey declared GO to be "Toronto's transportation triumph: The right thing, done at the right time and in the right way."

The two Ontario premiers who believed in rail transit and committed their governments to build it: John Robarts (far left) and Leslie Frost (second from right), at the 1963 opening of the TTC's University subway.

Today, it is difficult to imagine what the Greater Toronto and Hamilton Area (GTHA) would be without the expanded GO rail system. Not only has it helped shape this region, it has inspired other cities to follow Toronto's example. There are now 10 GO carbon copy commuter rail systems operating in cities as diverse as Vancouver, Miami, Dallas, Albuquerque and Los Angeles. Others have emulated major aspects of GO.

But GO and the region are at a crossroads once again. They are facing a challenge as daunting today as that which confronted Premier Robarts back in 1965. In the years since he launched his visionary commuter rail system, there has been a failure to bolster and increase the public commitment to GO and the transit-oriented principles which compelled its creation. At best, successive governments have been stingy in their treatment and funding of GO. At worst, they have ignored and neglected it, underestimating its power to help shape this region's urban form and functioning. The publicly-funded highway system has continued to grow, fuelling the gridlock and urban sprawl that GO was designed to prevent.

Now, the opportunity has arisen to recommit to GO and fully embrace its ability to bring about decisive change to the commuting habits and land development patterns of the GTHA. One of the cornerstones of the 2008 plan wrought by the Government of Ontario's regional transportation agency, Metrolinx, is vastly expanded GO service. More trains, on more lines, operating on quicker schedules, seven days per week.

To do this, the current provincial government is going to have to commit to a decision as bold as that made by Premier Robarts 45 years ago. There is compelling evidence to suggest that the only way to make GO one of the healthiest, most efficient and sustainable arrows in the Province's regional transportation quiver is to progressively and aggressively convert it to clean, quiet and cost-effective electric operation. This is the course that other major city regions have chosen worldwide.

Make no mistake about it: this will be no little plan. It involves a steady and assured stream of capital funds if it is going to deliver its full benefits. But – measured by the performance of the great electric commuter rail systems around the world – that investment will repay itself many times over in health, environmental, social and economic benefits.

This report has been commissioned to encourage the Government of Ontario to commit fully to an accelerated electrification plan now. The growing pressures on the GTHA and its transportation system suggest that delaying it will only inflict ongoing penalties on this region's economy, its environment, the health of its citizens and the long-term economic sustainability of its regional transportation system.

The time for accelerated GO Transit electrification is now.

1.0 Rail Electrification's History of Excellence

"Electricity is the natural medium for the application of motive power. Its supply is unlimited. It is everywhere. It is to movement what the sun is to growth."

The Western Electrician, 1899

To appreciate the advantages of rail electrification, it is necessary to understand how and why it was developed. It is a saga of continuous development and evolution that has produced a form of high-productivity transportation that is risk-free, economically superior, environmentally sustainable and unchallenged by any other type of motive power.

The development of the railway was one of the world-changing events of the 19th century. The concept of low friction steel wheels rolling on steel rails altered the world's perception of time and distance. Steam trains made possible rapid, all-weather communication and commerce between cities and towns that had been at the mercy of uncertain and expensive water and wagon road transportation. Inside those cities and towns, horse-drawn streetcars were the first step towards affordable mass transportation for the growing urban population in countries transformed by the steam-powered Industrial Revolution.

As revolutionary as these early forms of transport were, they had limitations. Horsecar systems required large numbers of animals to power them and equally large workforces to tend them. Steam locomotives were dirty, noisy, labour intensive and limited by the capacity and efficiency of their fireboxes and boilers.

It is little wonder that numerous inventors tried to improve railroading as early as the 1830s by marrying it with another wonder of that century: electricity. Early attempts using battery power were unsuccessful. But by the last quarter of the 19th century, the advances in electrical technology resulted in numerous demonstrations of small, generator-powered electric rail vehicles in North America and Europe.

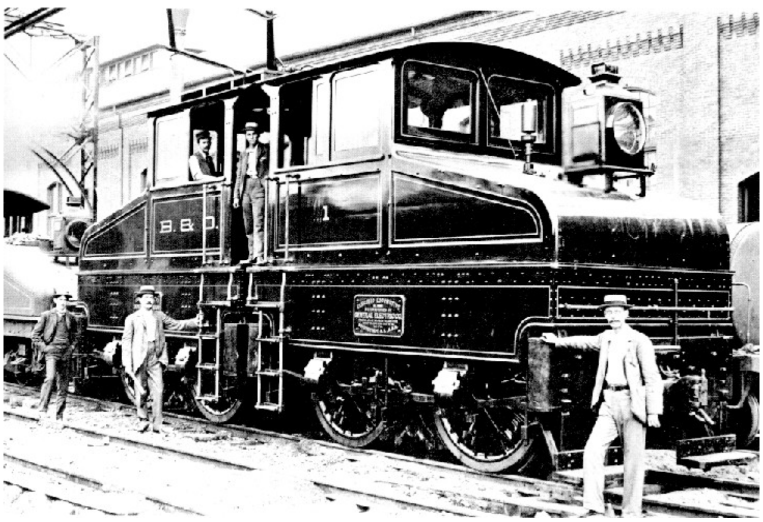
Inventors such as Werner von Siemens, Charles J. Van Depoele, Frank Sprague and others at Thomas Edison's Menlo Park labs were among those who built experimental electric trains using direct current (DC) transmitted by ground-level rails or overhead wires. The first was demonstrated in Berlin in 1879 by von Siemens. Another was constructed in 1883 at the predecessor of the Canadian National Exhibition.

"Our electric train is creating quite a stir," Werner von Siemens proudly wrote to his brother on June 12, 1879. His experimental electric train – generally regarded as the world's first successful design – was demonstrated to eager Berliners 132 years ago.

By the 1880s, commercial applications finally appeared, drawing heavily on the numerous advances that had been made in electrical generation, transmission and motor design. The first beneficiaries were the horse-drawn street railways, which were electrified with low voltage DC power supplied to the streetcars via wires strung over the tracks or in conduits buried between the running rails.

Next, it became possible to electrically power the larger and heavier rolling stock used on elevated rapid transit systems in cities such as New York and Chicago, which had been powered by steam engines that showered the streets with smoke, soot and hot cinders. Electrification also made possible underground or subway rapid transit systems. Attempted with limited success in London using complex condensing steam locomotives, subways were impractical until it became possible to power them electrically.

1.1 Harnessing 'White Coal'



Finally, in 1895, electricity was first applied to main line railroading. When the Baltimore & Ohio Railroad (B&O) built its 5.5-kilometre Baltimore Belt Line, it required a 2.3-kilometre tunnel under the city with a steep climb at its northern end. The city was opposed to any scheme that would vent smoke and cinders on to the streets from the tunnel. As well, the steep grade would have required a reduction in the train lengths or "double-heading" with two steam locomotives and crews. Electrification was the answer.

The B&O contracted with General Electric (GE) for the locomotives, power generation station and a rigid DC overhead power rail system. When the line opened on June 27, 1895, it was heralded as the dawn of a new era in transportation. Small and specialized as it was, the B&O's line demonstrated it was possible to move heavy intercity trains reliably with electricity. Because of its clean, quiet qualities compared to the coal-fired steam locomotives, electrification advocates called this new motive power source "white coal" and said a trip on an electric train was like riding "on a streak of chained lightning."

Rail electrification – in lockstep with the entire electrical industry – advanced rapidly. Other North American and European railways studied its application for tunnels, heavy grades and dense urban operations, such as the Gare d'Orsay in Paris, which became the world's first fully-electrified underground railway complex when it opened in 1900. But it was a tragedy that gave electric railroading its biggest boost and led to three projects that decisively proved its applicability and reliability.

The New York Central Railroad (NYC) was the only line to directly serve Manhattan, which it did via a four-track route that required 3.2 kilometres of tunnels under Park Avenue to reach Grand Central Station at 42nd Street. On January 8, 1902, a commuter train in the tunnel was rear-ended by another whose crew couldn't see the smoke-obscured signals, killing 15 people. The New York State Legislature decreed that steam locomotives would be prohibited in Manhattan as of July 1, 1908.

Based on the success of the B&O operation and facing the legislated deadline, the NYC's managers embarked on a crash program of electrification and modernization. The old station was replaced by a new Grand Central Terminal consisting of 67 tracks on two levels below the city's streets. Using a DC third rail system similar to those applied to subway and elevated transit lines, the NYC electrification ultimately embraced three routes and 800 track-kilometres.

The first phase of this landmark project was inaugurated ahead of schedule in late 1906. All the work had been undertaken while the existing steam-powered commuter and intercity passenger and freight services kept rolling. At its peak, the NYC's electrified zone handled more than 800 trains daily, almost all of them funnelled through the four-track tunnel under Park Avenue. It continues today as the state-owned Metro-North Commuter Railroad, which carried more than 79 million passengers in 2009 – nearly 300,000 on a typical weekday.

1.2 Taking Wealth from the Air

One large benefit of the NYC electrification was the world's first air rights development project. Without the need to vent smoke from the steam locomotives, it was possible to build over a railway line. The project's chief designer described it as "taking wealth from the air." His visionary Park Avenue development plan – combined with the reduced rail operating costs – helped pay the $80 million cost of the electrification and the monumental Grand Central Terminal. Thanks to electrification, air rights development has occurred hundreds of times over in major cities around the world.

The reputation of electricity as a form of propulsion capable of meeting the heavy demands of urban railroading was solidified by the NYC project and boosted by its major competitor, the Pennsylvania Railroad (PRR). Its tracks from the west ended at the Hudson River, placing it at a competitive disadvantage.

The PRR's answer was a 21.5-kilometre line under the Hudson to its new 21-track Pennsylvania Station in Manhattan. An East River tunnel extended the electrification to a connection with its subsidiary Long Island Railroad (LIRR), North America's first commuter railway. The only way to operate this vast underground complex was electrically. The PRR chose a 600 volt DC third rail system, which it also applied to six LIRR commuter lines, all of which remained in service as they were electrified. Completed in 1910, the $113 million PRR New York Tunnel and Terminal Project dramatically improved passenger transportation in New York and spurred transit-oriented development on Long Island.

The third player in this electrification revolution was the New Haven Railroad (NH). To reach uptown Manhattan, the NH had trackage rights on the NYC's Grand Central line for its New England trains, including its Connecticut commuter service. To continue using that track, the NH adopted the NYC's third rail DC scheme. But east of the junction, 11,000 volt alternating current (AC) was supplied by an overhead wire catenary system to roof-mounted pantographs on the trains, which switched from one system to the other while running at speed.

The NH decision to use AC power came at the height of the "War of the Currents." Championed by GE, DC power had a tremendous effect on everyday life, bringing with it widespread electrification of street and household lighting, street railways and industry. It was hailed as the Second Industrial Revolution. But the subsequent perfection of AC by GE's rival, Westinghouse, offered advantages just as revolutionary. In railroading, too, AC power had a lasting impact.

AC can be transmitted at high voltages over long distances with little energy loss and fewer substations than DC. Catenary, which can also be used for DC current, is safer and less prone to weather disruption than a third rail, which can't handle higher-voltage AC current. AC reduced rail electrification costs, as was proved when the NH's first segment opened in 1907. It eventually encompassed 245 route-kilometres and 1,050 track-kilometres, including a new line to connect with the electrified PRR line into Penn Station.

The success of the three New York electrification projects sparked a wave of planning in North America and Europe. It was apparent that electrification had set a new gold standard for high-efficiency railroading.

1.3 The EMU: A Whole Train in One Car

Although there were technical differences, the three New York systems shared many principles and characteristics. The most visible was the motive power and rolling stock. All three used electric locomotives to haul the passenger and freight trains that originated or terminated outside the electrified zones behind steam engines. But for fast, frequent commuter service within those zones, the three railways selected self-propelled, subway-like electric multiple unit (EMU) cars.

Many first and second generation North American EMUs delivered reliable and cost-effective service for decades. Typifying this longevity were the Blueliners of the Philadephia-area commuter service of the Reading Company, which entered service in 1931 and weren't completely replaced until 1990. Photo from the Joe Testagrose Collection.

The key to this EMU concept was hardwired electrical control technology, which couldn't be duplicated with steam traction. It enabled any number of electric cars or locomotives to be coupled and controlled by one person from cabs at the front or rear of any train. This yielded one of the tremendous operating cost advantages of electrification, eliminating the need to power long and heavy steam trains with extra, individually-controlled locomotives operated by separate crews.

EMUs offer many advantages over locomotive-hauled operation, including:

- Even distribution of motors and brakes throughout a train, yielding uniform performance no matter how short or long the train, allowing for greater speed and density of service, and with fewer cars than required by locomotive haulage;
- A reduction of the heavy forces exerted downward into the track and bridges by locomotives, with the weight distributed evenly throughout an EMU train;
- Elimination of the need to move the locomotive from one end to the other or turn the entire train on special trackage, saving time, crew costs and infrastructure;
- Ease of maintenance, thanks to under-slung motors and other gear accessible from the sides or through trap doors in the car floors; and
- Substantial reductions in labour and energy costs.

Most importantly, the three New York projects validated electrification's superiority in solving four broad challenges facing railroaders worldwide.

1.4 Electrification's Advantages

1.4.1 Emissions and Noise Abatement

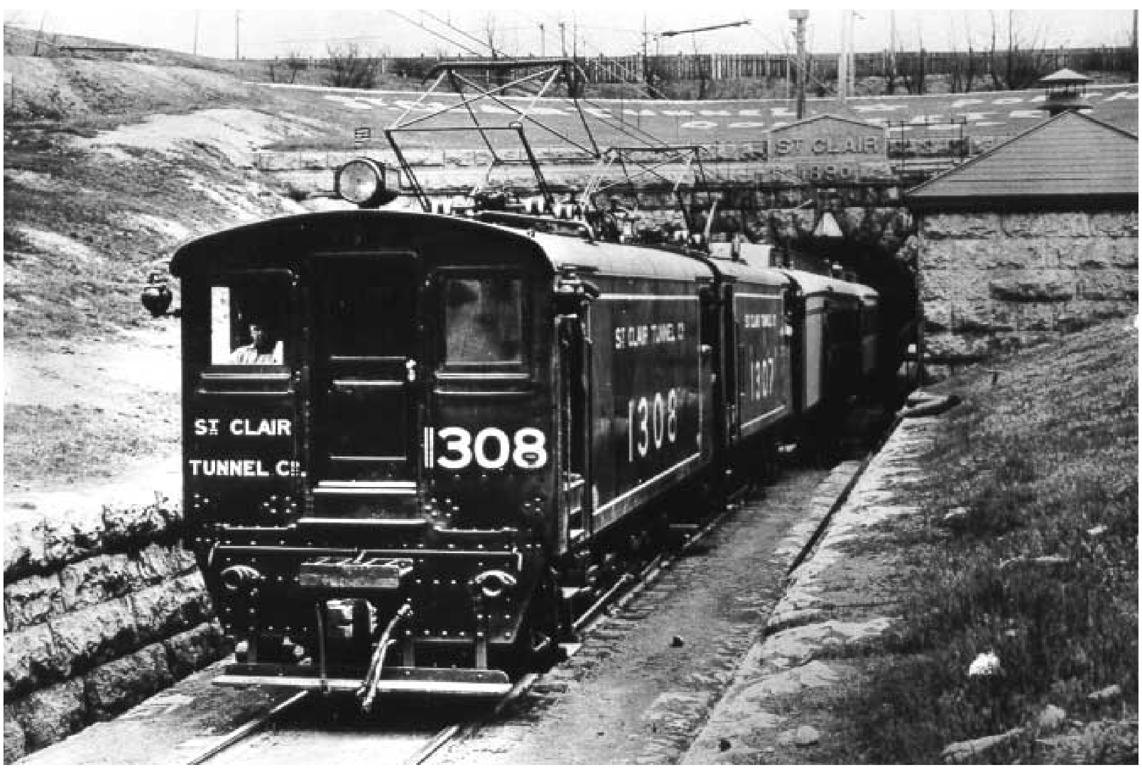
In urban areas, the emissions and noise from steam engines was, at best, a nuisance and, at worst, a health hazard. Electrified urban railways rid cities of online pollution and reduced noise considerably.

Critics point out that pollution is still created at offline generating stations, which in North America were generally coal-fired thermal plants during electrification's early years. However, even early grid-connected systems converted more of the energy in the coal into productive horsepower than was possible with multiple steam locomotives of varying degrees of combustion efficiency. As a result, electric rail lines consumed less coal per horsepower and produced less pollution.

Cleaner power generation methods, particularly hydro, reduced the carbon footprint of many electrified rail operations. It also freed them from dependence on a single energy source. This provides strategic policy benefits for those railways using renewable, non-fossil fuel sources. For example, shortages of imported coal forced a reduction in the steam-hauled services of the Swiss Federal Railways during the First World War. An aggressive postwar electrification program made Switzerland's railways independent of foreign energy by adopting domestic power sources for virtually all of its routes.

1.4.2 Tunnels

The drawbacks to operating steam locomotives in long tunnels are obvious. Where it was done, it often had life-threatening consequences for train crews and passengers alike, as was demonstrated by the NYC's Park Avenue Tunnel collision. Just as electrification resolved the problem on that line, so it did for other tunnel operations, as well as making long tunnels on several new lines feasible.



Grand Trunk's St. Clair River Tunnel electrification was the first in Canada, opening in 1908. It replaced a dangerous and inefficient steam operation between Sarnia, Ontario, and Port Huron, Michigan.

Three examples were found in Canada, two of them destined to become important components of the Canadian National Railways (CNR) after the Crown corporation was formed to rescue certain bankrupt private railways. The first was the Grand Trunk's St. Clair River Tunnel between Sarnia, Ontario, and Port Huron, Michigan, which was retrofitted as a DC catenary operation in 1908. The Canadian Northern line from downtown Montreal to the railway-planned suburbs to the north was opened in 1918 and its operation was only possible because of the DC catenary electrification of the five-kilometre Mount Royal Tunnel. As well, the New York Central's Detroit River Tunnel between Windsor, Ontario, and Detroit, Michigan, was opened in 1910 as a third rail DC electric operation.

Electrification was an even greater boon to the operation of Europe's long tunnels under the Alpine passes, including the Simplon (19.8 km), Gotthard (15 km), Lötschberg (14.6 km) and Arlberg (10.25 km). It later made possible the construction of even longer subterranean railway tunnels, such as Japan's Seikan (53.85 km) between the islands of Honshu and Hokkaido, the Chunnel (50.5 km) linking England and France, and the new Gotthard Base Tunnel (57 km), which will be the world's longest when it opens in late 2017.

1.4.3 Steep Grades

As the original B&O Baltimore Belt Line and several early European operations proved, electric locomotives are capable of conquering steep grades that would be difficult or even impossible for steam and other forms of motive power.

Electric locomotive and EMUs are able to deliver high and constant tractive effort through a wider speed range than steam or diesel locomotives. From a standing start through to high speeds, the electric output converted to actual pulling power is high and delivered continuously. Passengers on electric trains often comment on the smooth, rapid departures from stations and the seemingly effortless ascent of steep grades. The result is what railroaders often refer to as the "jack rabbit" acceleration qualities of electric trains.

Furthermore, electric motors have high short-term or overload capabilities. For short periods, electric traction systems can be overloaded to as much as twice their long-term continuous output rating. Unlike other forms of motive power, the electric is not limited by the capacity of an onboard power plant, such as a diesel engine or a steam boiler, but only by the high capacity of its traction system and the amount of electricity being fed to the trains from offline generating stations.

As a result, electrification was adopted by many railways serving mountainous territory, such as the Norfolk & Western and Virginian railroads in the Appalachian Mountains, and the Milwaukee Road's western transcontinental line, which crossed five mountain ranges on its route to Puget Sound.

The Milwaukee Road also introduced an innovation that remains a key advantage of electrification. Known as regenerative braking, it converts the train's traction motors into generators when braking or descending a grade, feeding electricity into the catenary to help power other trains and reducing wear on the air brake systems. Regenerative braking can recover more than 10 per cent of a train's power intake.

1.4.4 Capacity Expansion

The early New York City projects and others in Europe and the U.K. demonstrated electric trains make better use of track and station capacity than other forms of rail traction, thanks largely to their rapid acceleration and braking characteristics. This is especially true with EMUs, which make it possible for trains to easily reverse direction at their end terminals merely by having the engineer or motorman move from one end of the train to the other.

These capacity-building advantages grew with the development of automatic couplers. With the push of a button in the cab, EMUs can be quickly coupled or uncoupled. This reduces time and labour costs, and makes it easy to alter train lengths to meet fluctuations in demand. This helps to reduce the time that trains tie up tracks and platforms in end terminals with marshalling and switching movements.

These advantages were not lost on the Pennsylvania Railroad (PRR), which faced a major congestion problem at its Broad Street Station in Philadelphia at the same time it was gaining experience with its New York Penn Station project. Broad Street was handling more than 500 daily trains by 1913 and further expansion was impossible. Nor was the noise and pollution from this steam traffic appreciated by Philadelphians. The answer was electrification. Beginning in 1915, the PRR progressively electrified this dense commuter service with an 11,000 volt AC catenary system and improved EMUs.

As PRR managers knew, electrification also yielded higher speeds out on the main lines. The average speed of the New York Central's commuter trains increased 50 per cent with electrification, thanks to the higher acceleration and braking rates it made possible. Furthermore, the speed capabilities of electric trains had already been explored extensively in Germany. On a test track near Berlin, an experimental electric car set a speed record of 210.2 km/hour in 1903.

1.5 The Pennsylvania Railroad: Mother Road of Electrification

It was for all of these reasons that the PRR committed itself to what would become the largest and most influential electrification of the pre-Second World War period. In 1928, the PRR began electrifying the entire intercity passenger, commuter and freight operation on its four-track "broad way" from New York to Washington, as well as its main line from Philadelphia to Harrisburg. This was reputed to be the world's busiest railway system and, with the $250 million electrification and improvement project, it would eventually be considered the world's finest.

The PRR electrified with the 11,000 volt AC catenary system and developed several new, high-powered locomotives, including 139 of the sleek GG1s, some of which ran daily at up to 160 km/hour for more than 50 years. As well, more than 400 EMUs were built for commuter service in New York, Philadelphia, Baltimore and Washington, D.C.

Under a rolling implementation plan, the PRR's electrification project faltered only when the Great Depression descended in September, 1929. Because of electrification's proven ability to quickly repay its capital costs from operating savings, the U.S. government rode to the rescue and the project was completed in 1938. A huge benefit was the creation of 45 million man-hours of employment during its construction.

The undisputed monarchs of pre-war electrification were the Pennsylvania Railroad's 139 sleek, swift and strong GG-1s, many of which remained in 160 km/hour service for nearly half-a-century. Photo from the Joe Testagrose Collection.

At its peak, the PRR electric operation covered nearly 1,100 route-kilometres and 3,200 track-kilometres. It was so successful that the PRR was able to repay the government loans earlier than expected from the operating savings. U.S. Secretary of the Interior Harold Ickes called these loans the best the government ever made, especially in light of the tremendous volume of traffic this intensive railway plant later handled during the Second World War. Had not wartime rationing and manufacturing priorities intervened, the electrification most likely would have been carried west 400 kilometres on the steeply-graded, four-track main line over the Allegheny Mountains from Harrisburg to Pittsburgh.

The company-published *Centennial History of the Pennsylvania Railroad* noted the conversion to electric operation occurred smoothly, even under the tremendous traffic that had to continue moving on the main lines and through the complex terminal facilities during construction. It also noted that electric traction is so fundamentally different from other forms of motive power "that a revision of operating practices and methods in many respects was necessary on the electrified lines" in order to ensure a trouble-free conversion that did not interfere with day-to-day operations. In the end, electrification "soon tended to show a performance even better than the engineers had envisaged."

Inspired by the success and the breadth of the PRR project, electrification flourished overseas in this period, too. As on the PRR, electrification overseas covered all aspects of operations: commuter, intercity passenger, freight and even yard switching.

Electrification's effect on commuter service was especially impressive. In the period between the world wars, substantial electric commuter services were developed in major cities in the U.K., Europe, Asia and Australasia. In each case, they not only reduced operating costs and improved service, but also resulted in a phenomenon evocatively known as the sparks effect, being found to have a public appeal that "sparked" higher-than-expected ridership and revenue.

1.6 Electrification in Perspective

But electrification was not a panacea. Its principal drawback was its initial capital cost. Right from the start, railroaders made it clear that electrification could only be justified by large volumes of revenue-producing traffic. In 1913, one of the deans of electrification said it cost almost as much to electrify an existing line as to build one from scratch. This partially resulted from the tendency to use electrification as an opportunity to make other upgrades, in essence building all-new railways on the old rights-of-way.

Therefore, a combination of operating constraints, traffic density and other conditions had to be present for a line to be a candidate for electrification. Light density lines were rarely converted unless they could be "wired" economically as part of larger projects. But where these favourable factors existed, electrification demonstrated its ability to revolutionize a rail service physically and financially by generating operating benefits and substantial cost savings. Electrification didn't cost, it paid, especially on dense suburban commuter rail networks. In general, electric trains:

- Increased service speed, which made increased train frequency possible;
- Increased capacity and often made physical expansion unnecessary;
- Increased reliability, being less vulnerable to severe weather than other forms of traction;
- Reduced maintenance costs, being comparatively simpler machines;
- Improved asset utilization by requiring less maintenance and no down time for fuelling, making diesels more available for revenue-producing service; and
- Reduced life cycle costs because of their robustness and longevity.

1.7 Post-War North America: Running Out of Juice

After the Second World War, rail electrification continued its rise throughout Europe, but it stalled in North America. The reason was simple: the diesel-electric locomotive. The diesel had been under development almost as long as the electric locomotive, but progress was slow. In the late 1920s, through the research efforts of General Motors (GM) and GE, the marriage of a lightweight diesel engine with the control and traction gear of electric trains yielded results.

Although a diesel can't deliver the same performance as an electric, it had some competitive advantages in postwar North America. First and foremost, diesels were fuelled by plentiful, relatively inexpensive oil. As well, by using a diesel engine to drive an onboard electrical generator, they offered some of the benefits of the electric locomotive and performance improvements over steam. The diesel's control systems used MU technology, reducing labour costs by enabling operation of two or more locomotives with one crew. It also provided higher availability than steam with reduced maintenance labour costs.

The diesel's key advantage was its lower upfront capital cost compared to electrification. It required only modification or replacement of existing steam maintenance facilities, not a whole electrical transmission system and revisions to other facilities, such as "immunization" of signal systems. It also reduced – but didn't eliminate – emissions problem.

It was no contest. In the post-war years, North America's for-profit railways were in financial trouble. All levels of government had undermined the self-sufficiency of the railways with large investments in other modes and without requiring users to pay their full costs directly. Highways, ports, waterways, aviation facilities and state-owned airlines bloomed with this public funding. As these modes diverted an increasing amount of traffic and revenue, the railways were weakened. None could contemplate a massive, long-term investment such as electrification at a time when their existence was being jeopardized.

The situation was completely different in Europe and it explains why electrification is one of the mainstays of railroading on that continent today.

1.8 Post-War Europe: Electrification's New Valhalla

At the end of the Second World War, much of the European rail network was in ruins, bombed by the Allies and sabotaged by retreating Axis troops. One of the first orders of business for the Allies was the resuscitation of the industries and the economy of Western Europe, which required reliable, high-volume transportation. Railways – not highways and aviation – were the answer. Often with U.S. Marshall Plan and United Nations recovery funds, the state-owned railways were rebuilt. Electrification had been applied to the busiest lines, so their rebuilding was a priority. Rail electrification was considered so strategic that the U.S.S.R. stripped the East German railways of their electric motive power, rolling stock, catenary, substations and related gear, shipping it east to be redeployed on the Soviet Railways.

The Second World War spurred unprecedented technical development in all industrial sectors, including electronics. The rebuilding of Western Europe's electrified rail systems wisely took full advantage of these advances. This produced rail electrification options more sophisticated than those in North America, where research focused on diesel motive power. Western Europe's lack of domestic oil and its abundance of coal and hydro-electric power also drove plans to expand electrification of the continent's main rail lines.

Working with visionary electrical manufacturing giants, the publicly-owned railways of Western Europe wrought a second revolution in electric railroading. One major advance was the development of AC systems of 15,000 and 25,000 volts at commercially-available frequencies of 50 or 60 cycles. This made it easier to draw current directly from utility companies without expensive rectification and conversion gear, as had previously been the case. As well, higher-voltage AC was more efficient, cost-effective and reliable than previous systems. It was used widely as electrification accelerated from the 1950s onward in Europe. As well, the Soviet Union, Australia, South Africa and India undertook large electrification projects, often with the 25,000 volt AC catenary system.

In a 1958 statement, the International Union of Railways said:

"For its outstanding characteristics – availability, suitability for high speeds, heavy loads and long non-stop runs, robust construction, low maintenance – the electric locomotive is the master card of the European railways in the modernization of the large systems...."

A Swedish State Railways night train to Narvik, Norway, pulled by an ABB Rc-series electric locomotive. These powerful, pint-sized European locomotives can lay claim to being the most successful electric motive power of all time. They have served in their native Sweden, Norway, Austria, the former Yugoslavia, Turkey and Iran, as well as on the U.S. Northeast Corridor. Photo by David Gubler.

Through all this, rail electrification in North America was at low ebb. The conversion of the main line railways from steam to diesel was complete by 1960. The diesels also doomed some of the short but aging electric operations of the past. This included numerous electric tunnel operations, where diesels were substituted, but only through the construction of massive ventilation systems required to clear the tunnels of diesel fumes after the passage of each train. CN's St. Clair River Tunnel was but one example, being dieselized in 1958.

On the PRR – the electric operation viewed as the pace-setter – studies in the 1950s concluded diesels couldn't compete. The result was renewal of the fleet with new EMUs for commuter service and high-horsepower locomotives for freight; the existing passenger motive power fleet soldiered on. The sturdy PRR electrification also made possible America's first higher-speed service with the 1969 launch of the 200-km/hour New York-Washington Metroliner EMU trains.

On the other electric commuter railways in New York, Philadelphia and Chicago, a limited amount of modernization and expansion occurred in the 1960s and '70s because diesels had still not proved themselves capable of bettering the performance of the electric trains and infrastructure, which were then more than 30 years old and still incredibly robust.

1.9 The 1973 Energy Crisis

The outlook for North American electrification changed dramatically in the early 1970s thanks to a world event that demonstrated one of the risks inherent in an oil-dependent transportation system. In October, 1973, the Organization of Petroleum Exporting Countries (OPEC) announced a 70 per cent rise in the price of oil and a drastic cut in exports. As oil prices rose and supplies dropped, the global economy was thrown into turmoil and the dangerous oil addiction of many nations – especially Canada and the U.S. – became apparent. Government policies were enacted to combat the situation, including the encouragement of alternate energy sources. The crisis was resolved in March, 1974, but the effects lasted for many years.

One result was that several North America railways re-examined electrification. Canadian Pacific (CP) was one that looked closely, going so far as to conduct winter tests in Sweden, Norway and Switzerland using state-of-the-art electric locomotives and erecting a catenary section in B.C.'s Selkirk Mountains to determine the effects of extreme winter weather. The test catenary withstood three major snow slides.
But the predicted North American electrification renaissance didn't happen. Once the OPEC crisis passed, oil prices stabilized and even declined in relative terms. The opportunity was lost and, with the exception of some electric commuter extensions, the rail industry returned to its pro-diesel stance.

Not so in Europe and emerging industrial nations, such as China and India, where the conversion from steam and diesel to electric increased. Several factors drove this movement, particularly public policies aimed at energy self-sufficiency. Another was the quest for speed. Testing of internal combustion designs – such as a preliminary gas turbine version of France's electric Train à Grande Vitesse – confirmed the superiority of electric operation for high-speed service. Electrification has triumphed in Europe; the remaining non-electric mileage is declining annually.

Electric racehorses at rest at the Gare du Nord in Paris. From left to the right, two of the Eurostars that provide service through the electrified Channel Tunnel, a Thalys trainset used on the Paris-Brussels/Cologne/Amsterdam routes and a first-generation SNCF Train à Grande Vitesse, one of the speedsters that launched the European high-speed electric rail revolution on the Paris-Lyon route in 1981. Photo by Mathieu Costecalde.

1.10 Electrification Today

Today, North American passenger railroading has once again awakened to electrification's potential. Part of this renewed interest revolves around the spate of high-speed rail projects now proposed in the U.S. The one notable electrification project of the post-OPEC oil embargo period was Amtrak's 1999 extension of the catenary east from New Haven to Boston for its Acela Express higher-speed service.

Now, faced with automotive-fed urban sprawl, rising energy costs, uncertain future oil supplies and continued environmental degradation, there is a growing chorus of voices calling for rail expansion – particularly electrified rail service – across North America.

An Amtrak Acela zips through the Ruggles commuter station on its way to Boston's South Station, oblivious to the weather. Built in Canada by Bombardier and combining advanced North American and European technologies, the Acelas are this continent's only high-speed trains, achieving a maximum speed of 240 km/hour on portions of Amtrak's electrified Northeast Corridor.

North American Commuter Rail Electrification Projects – 2011

PROJECT	ROUTE	ROUTE-KM.	STATUS
Montréal AMT Lakeshore Line	Lucien-L'Allier-Vaudreuil	38	Under study
Montréal AMT Delson Line	Montreal West-Candiac	21	Under study
Montréal AMT Blainville Line	East Junction-Saint-Jérôme	48	Under study
Connecticut DOT Danbury Branch	South Norwalk-Milford	61	Under study
Connecticut DOT Hartford Corridor	New Haven-Springfield	101	Under study
Long Island East Side Access	Sunnyside-Park Avenue Tunnel Junction	5	Under construction
Long Island Main Line Extension	Ronkonkoma-Yaphank	16	Under study
Long Island Port Jefferson Branch	Huntington-Port Jefferson	37	Under study
Long Island Montauk Branch	Babylon-Speonk	56	Under study
Long Island Central Branch	Babylon-Bethpage	10	Under study
SEPTA Schuylkill Valley Metro	Philadelphia-Reading	99	Under study
SEPTA Quakertown Extension	Lansdale-Shelly	30	Under study
SEPTA Wawa Extension	Elwyn-Wawa	5	In design
Denver RTD East Line	Union Station-Denver International Airport	37	Under construction
Denver RTD Gold Line	Union Station-Wheat Ridge	18	In design
Denver RTD Northwest Line	Pecos-South Westminster	5	In design
Caltrain Peninsula Commute Line	San Francisco-San Jose	83	In design
Mexico El Tren Suburbano Line 2	Martin Carera-Jardines de Morelos	19	In design
Mexico El Tren Suburbano Line 3	Chalco-La Paz	11	In design
TOTAL		**700**	