Toward a clean train policy: diesel versus electric

By West Toronto Chapter, Professional Engineers Ontario

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EXECUTIVE SUMMARY

This paper assesses diesel versus electric train operations and their implications for the human and natural environments. It concludes that rail electrification can deliver significant emission reductions, health benefits and long-term economic and operational advantages compared with existing train service.

The authors argue that modernizing Ontario's rail industry would propel the provincial economy to become both innovative and sustainable. They add that the enduring benefits of rail electrification present an enormous opportunity to develop a transit-oriented society that preserves our environmental equilibrium.

The paper also considers the economic trade-offs in an undertaking of such magnitude. Finally, the authors invite policy-makers to consider appropriate solutions that incorporate sustainable infrastructure and meet the province's overall environmental goals.

Modernizing Ontario's rail industry could propel the provincial economy to become both innovative and sustainable. The enduring benefits of rail electrification present an enormous opportunity to develop a transit-oriented society that preserves our environmental equilibrium. However, these benefits may be derailed by public concern about affordability.

Recently, the West Toronto Chapter of Professional Engineers Ontario (PEO) established a subcommittee to provide a neutral assessment of Metrolinx's proposed Georgetown South Service Expansion and Union-Pearson Rail Link. This subcommittee studied the reports and data, participated in public open houses and met with Metrolinx executives.

The paper's objective is to provide an assessment of diesel versus electric train technology operation and their potential implications for the human and natural environment. Our conclusion: rail electrification can deliver significant emissions reduction, health benefits and long-term economic and operational advantages over existing trains. We also discuss the trade-offs that should be considered in an undertaking of such magnitude. Finally, the paper invites policy-makers to consider appropriate solutions that incorporate sustainable infrastructure.

BACKGROUND

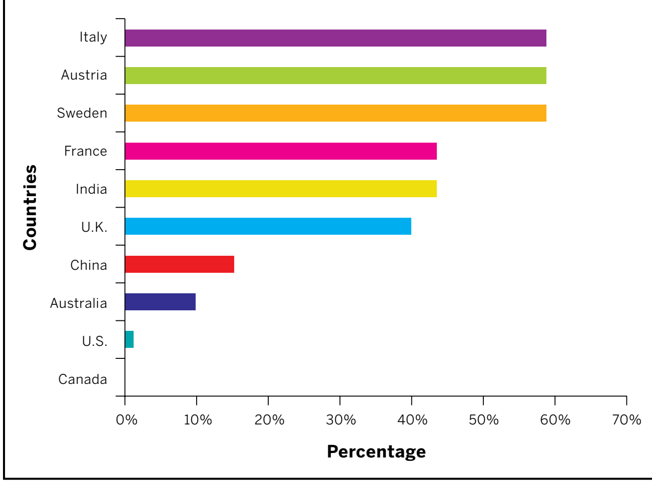
The superiority of electric traction over steam and other hybrid-diesel locomotives is undeniable. Rapid growth in urban areas at the beginning of the 20th century, fuelled by the continuing industrial revolution, created an increasing demand for public transit. Short-range, steam-powered rapid transit systems were replaced by faster and efficient electric systems that absorbed the rising demand (Duffy, 2003).

Electric trains operate with quick acceleration, which is ideal for urban metro transit systems. Similarly, long-range electrified commuter rail service has the advantages of air-quality benefits, high-speed capability and additional carrying capacity compared with diesel trains. Despite these inherent advantages, the North American rail industry, especially in the United States, has not shown any enthusiasm for mass rail electrification despite the postwar suburban explosion that continues to this day.

According to Richard Freeman and Hal Cooper (2005), the "bank-oil, cartel-automotive" alliance successfully led the resistance to electrification. In the 1950s, it lobbied for the U.S. National Interstate and Defense Highways Act (1956), which encouraged the petroleum-consuming system that still dominates the nation's transportation industry. Much of the electrified rail that did exist was dismantled and replaced by diesel-powered hybrid locomotives that now comprise 99 per cent of the North American rail fleet.

In contrast, both developed and developing nations in Asia and Europe followed the electrification track, especially after the mid-1970s energy crisis. As a result, a developing nation like India has revolutionized its rail industry, achieving 42 per cent rail corridor electrification, while the electrification rate in North America is less than one per cent (See Figure 1).

Figure 1: Percentage of rail electrification by country



Source: 1999-2007 World Bank Rail Database

Canada has explored the modernization of rail technology since the mid-1970s. Several Ontario studies over the past few decades have assessed various electrification technologies with system expansion alternatives. The GO Rail System study (CPCS et al., 1992) concluded that electrification of its 104-kilometre Lakeshore line from Oshawa to Hamilton could achieve a large number of environmental benefits and service improvements at a modest cost. However, the proposal was rejected as being too expensive.

Metrolinx, the provincial transit authority, recently commissioned the "GO Transit Lakeshore Express Rail Benefits Case" (Steer Davies Gleave, 2009), which concluded that electrification is the only viable option for handling the forecast demand on this corridor. In addition, Metrolinx launched another study (May 2009) on the possible electrification of the entire GO Transit rail system, which is expected to be finished by the end of 2010. Despite these initiatives, there appears to be no fundamental policy shift among decision-makers to realize rail electrification's potential. As Les Benjamin (1981) indicates, the barriers to electrification in Canada appear to be psychological rather than technical or financial.

Regardless of past failures, there is a renewed interest in rail electrification as planners focus increasingly on achieving a sustainable society. Ontario's recent Green Energy and Green Economy Act (2009) is expected to grow renewable energy sources and produce a surplus of "green electricity," an ideal foundation for rail electrification. In addition to the benefits of stimulating the local and regional economies through employment opportunities and other development expansion along corridors, rail electrification would promote intercity and regional transportation among Ontario's designated "Places to Grow" urban centres.

WHY ELECTRIC?

As with any engineering problem, all transportation design decisions must undergo a trade-off analysis. The solution creating the greatest benefit to the public for each dollar spent should be adopted. The following discussion examines the various considerations of rail technology and transit projects to shape a sustainable transportation policy. The factors examined include the following:

- Emissions from transit operations and the fuel life cycle of their energy systems.
- Health and safety implications.
- Technical and economic feasibility.
- Social and overall perceptions.

EMISSIONS AND FUEL LIFE CYCLE

Transportation is the largest single human-produced source of outdoor air pollution in developed nations. The industry accounted for 57 per cent of world energy consumption in 2003 (Smith, 2008), with the bulk of its energy coming from burning petroleum products. Among these products, diesel technology carries the stigma of being a "dirty" fuel. Unlike with the gasoline engine, the primary residue of diesel consumption is not a gas but charred particles that are airborne through the exhaust pipe. Diesel exhaust's principal air pollutants are nitrogen oxides and microscopically fine particles, often referred to as "particulate matter" or soot.

Apart from the negative impact of burning petroleum, the transportation industry is also held responsible for one-third of the globe's greenhouse gas emissions (Haywood, 2006). From an environmental perspective, the electric train is superior to its diesel counterpart because of its lower carbon dioxide and greenhouse gas emissions, as long as the electricity is produced from clean and renewable energy sources (Network Rail, 2009). Therefore, it is important to emphasize a careful energy choice when deciding how to best power future transportation infrastructure.

In Canada, transportation is one of the largest sources of air pollution and greenhouse gases, particularly in urban areas. Large, heavy-duty diesel engine vehicles are significant contributors to emissions of particulate matter, nitrogen oxides, carbon monoxide and hydrocarbons, all of which produce poor air-quality conditions. Therefore, a clear and definite mandatory pollution mitigation policy that improves air quality to an acceptable level would set the stage for a rail electrification plan for transit service providers, such as Metrolinx.

Exposure to diesel exhaust is part of our everyday lives, especially during commuting by diesel buses and trains. Several studies by the U.S. non-profit Clean Air Task Force (Schneider and Hill, 2007) estimate that although commuters spend only six per cent of the day commuting to and from work, more than half of their exposure to these particles occurs during that time. Indeed, diesel particle levels are four to eight times higher inside commuter cars, buses and trains than in the ambient outdoor air. In some cases, the ultra-fine particulate matter levels during commutes are so high as to be comparable to driving with a smoker.

Emissions attributable to electric rail transport are highly variable and depend on the electricity source used to power the train. Policymakers need to take into account the greenhouse gases at every stage of energy production, transportation and end use (U.S. Energy Policy Act, 1992). One imperative fuel life-cycle study (Messa, 2006) concludes that emissions from multiple diesel units and electric rail modes depend on the cleanliness of the electricity generation. In contrast, Puchalsky's research (2006) shows that electric light rail consistently performs better environmentally than bus rapid transit despite recent advances in bus technology.

Future U.S. Tier 4 emission standards and other recent advances in diesel engine technology will make diesel fuel almost "clean" by removing soot and converting tailpipe emissions into harmless gases. However, diesel emission is, in fact, dirty when compared to the "life-cycle emission" of electric trains, a significant policy gap that leads to misinterpretation of air pollution standards.

HEALTH AND SAFETY

Air pollution takes a great toll on human health and the environment. Numerous studies have shown that exposure to air pollution can increase the risk of lung and heart disease. According to the Ontario Medical Association, poor air quality results in an estimated premature 5,800 deaths and more than 16,000 hospitalizations annually in Ontario (OMA, 2005).

Diesel exhaust is one of the most dangerous pollutants because of its carcinogenic compounds and the toxicity of its fine particles. Diesel exhaust includes more than 40 hazardous substances listed by the U.S. Environmental Protection Agency. Fifteen of these substances are also named by the International Agency for Research on Cancer (IARC) as probable or possible human carcinogens. In the United States, particulate matter spewed by diesel engines is said to be responsible for 125,000 cancer cases annually (STAPPA and ALAPCO, 2000).

Apart from the overall health risk of diesel exhaust, its fine particles, generally referred to as diesel particulate matter (DPM), are toxic in two areas. First, elevated "fine particulate" air pollution is associated with significant increases in lung-cancer mortality (Pope et al., 2002). A landmark study of air toxics (SCAQMD, 2000) quantified the risk and concluded that DPM contributed about 70 per cent of the cancer risk from airborne pollution.

Second, deadly effects of even smaller, ultra-fine particles (UFP) have become a subject of scientific investigation. A recent Australian government epidemiological study (Morawska et al., 2004) found that UFP matter appears to affect health outcomes such as respiratory and cardiovascular morbidity. Another UFP study reveals (Araujo et al., 2008) that the major contributors of nano-size pollutants from vehicles can lead to plaque buildup in the arteries. It found that the pollutants abundant in urban areas, although less than 0.18 micrometres in size, cause four times more artery buildup than particles four times larger.

The most vulnerable victims of diesel exhaust are children whose lungs are still developing, individuals with airway obstruction and the elderly who may have other serious health problems. As a result, such susceptible populations may experience the impact at lower particulate matter levels than the general population, and the severity of effects may be greater (Morawska et al., 2004).

One study focused on children suggests that young people with asthma who live near roadways with high amounts of diesel truck traffic have more asthma attacks and use more asthma medication (Kleinman, 2000). Therefore, health regulation bodies need to create a policy that protects the most vulnerable. Electrification is a viable potential solution as it would lower both DPM and UFP counts.

Electric trains have another health benefit: they are quieter. A GO Transit study found the noise from electric locomotives to be five to 10 decibels lower than from diesel (CPCS, 1992). Like emission standards, health regulation bodies need to create a Canada-wide "noise reduction" policy to protect residents living close to transportation corridors.

TECHNICAL AND ECONOMIC FEASIBILITY

The following section examines the operational impact of electrifying the rail system, highlights the technical constraints and concerns and reviews the cost debate associated with increased rail infrastructure spending.

Operational and passenger impact

Electrified railways can handle far more station stops without increased travel times because electric trains typically accelerate and decelerate faster than heavier diesel trains. A comprehensive cost-benefit study of railway electrification projects across Portugal and Spain in the 1980s (Stohler, 1989) concluded that electric operation of passenger and freight trains results in shorter travel times, reduced running costs and greater service reliability.

Metrolinx's 2009 benefits case analysis for GO Transit's Lakeshore line also concluded that electrification could reduce the travel time between Hamilton and Union Station by up to 17 per cent (Steer Davies Gleave, 2009). Faster acceleration coupled with upgraded signalling systems allows for improved headway, which accommodates increased ridership and customer satisfaction due to decreased travel time. As well, higher system capacity generates increased revenues to recover upfront infrastructure costs.

Overall rail electrification operational benefits that could increase passenger satisfaction are the following:

- Faster acceleration time due to light weight, especially on steep grades, reducing journey times.
- Improved station ambience because electric trains do not need open-air stations as opposed to diesel, which need fumes to escape.
- An electrified system produces full-system reliability compared to diesel.
- Due to onboard propulsion, a separate power car is not required in an electric train, providing additional seating capacity.

Engineering considerations

Despite its clear necessity, a project to electrify passenger trains in Ontario would be a notable and challenging undertaking. There are inherent risks in proceeding with an engineering project that has no national precedent. Strategies for design and commissioning that have worked in other countries need to be adapted for Ontario's climate and terrain.

When designing a railway electrification system, the following factors play a crucial role (Bhargava, 1999):

- Electrical utility costs—these costs can increase significantly due to power quality requirements.
- Civil engineering costs for overhead clearance of electric wires.

The low-frequency, low-voltage electric train systems in Sweden and Germany in particular are likely to supply relevant lessons for Ontario.

Electric trains have a high power-to-weight ratio compared with diesel vehicles, which carry their own power sources on board. On average, fuel costs tend to be lower for electric vehicles, but if electricity is produced from conventionally expensive energy sources, then the overall operational cost could be higher. This was the case in India (Indian Ministry of Railways, 1999), where overall growth in energy demand coupled with growth in the electric rail system led to increased reliance on "dirty" power sources such as coal.

For its part, Ontario has had the foresight to generate more than half of its electric power needs through clean nuclear energy. As the dependence on coal is reduced and sustainable energy sources are implemented nationwide, we can expect the environmental costs of our energy demands to be further reduced.

Use of regenerative braking in electric trains further reduces energy demands, noise levels and wear on mechanical brakes because kinetic energy is recovered and converted to electrical energy without friction. While regenerative braking is possible on diesel-powered trains, electrified trains typically have better regenerative braking performance because energy can be recovered from more powered axles.

With electric propulsion, further energy savings can be achieved by implementing coasting as the driving strategy (Hull, 2009). It is highly recommended that regeneration and coasting be considered for dense areas where trains stop frequently. This would optimize energy efficiency and reduce noise.

High-density corridors provide even more justification for railway electrification. The electrified lines in the United Kingdom (Network Rail, 2009) tend to serve the busiest parts of the network. Electric trains tend to be operated in longer formations than diesel trains, reflecting the demand in the markets they serve. Research demonstrates that higher ridership demand justifies electrification in GO Transit's Georgetown corridor, even if there is only half of the projected 2031 ridership growth.

Given capricious fuel prices and Canada's dependency on oil and gas for transportation of people and goods, the country faces grave economic consequences if it continues to be dependent on petroleum products. Thus, in calculating the costs associated with the growth in demand, the volatility of uncontrollable market factors must be accounted for. For

Metrolinx commissioned a study, which is expected to be ready by year's end, on the possible electrification of the entire GO Transit rail system, left. Right, a pair of high-speed electric engines in Taiwan

example, when oil prices increase, a greater number of people abandon their cars and turn to public transport.

Economic considerations

Diesel systems have been used in North America and worldwide because of their relatively low initial costs and commissioning time. These relative short-term benefits are offset by long-term re-occurring costs such as the required daily inspection of the fuel tank coolant and electrical connections close to the moving parts. Diesel trains also need additional space for fuel storage and before they can be used, they require more time and fuel to warm up. Recurring maintenance and volatile fuel prices combine to ensure that operational costs of a diesel system are always consequential to the profitability of the transit system.

For an electrified system, in contrast, the initial installation costs are higher and commissioning time is longer. The GO Transit Lakeshore Express Rail Benefits Case (Steer Davies Gleave, 2009) estimated that the capital costs for system-wide electrification of the Lakeshore corridor would amount to $6 billion in constant dollars. High upfront capital costs for electrification are offset by reduced daily maintenance activities that typically consist of remote monitoring of the power utility and overhead wires. Given that electricity costs tend to be more stable than oil prices, the operation of an electrified system can be profitable in a foreseeable time after the infrastructure costs have been incurred.

Several studies, including a comprehensive U.K. report (Network Rail, 2009), outlined the following benefits of electrification in relation to long-term costs:

- 50 per cent reduction in rolling stock operating costs.
- 15 per cent reduction in infrastructure operating costs such as track maintenance due to light-weight trains.
- three per cent increase in rolling stock availability.
- 22 per cent reduction in vehicle leasing costs.

Photo: (left) GO Transit/Brian Main

MODERNIZATION STRATEGY

If the Ontario government committed to railway electrification by funding the capital cost of track installations as well as for the necessary additional electric supply, upgraded signals, station upgrades and catenaries installation, there would be a market opportunity for private companies to enter the operation stage. The operational costs to be borne by the private companies under this scenario would include vehicle leasing (including train propulsion electricity costs), engine maintenance and fare collection.

In order to create greater incentives for private companies to enter this marketplace, the province could make available low-interest loans for the purchase or leasing of electric trains. Fair and equitable track lease rates would further encourage private companies to enter the field and compete for the ridership on the basis of service quality.

According to the Metrolinx 2009 GO Transit Lakeshore Express Rail Benefits Case, electrification generates more direct and regional employment than the diesel option. As well, faster, more frequent electric service would result in a dramatic increase in land development potential. Due to the resulting increased spending, the government can anticipate significant track-leasing revenues from the private operator and an increase in sales and employment tax revenues from a mobilized and employed population. To date, these benefits have not been quantified.

OTHER ASPECTS OF TRAIN OPERATION TECHNOLOGY

Today, the dynamics of the rail industry includes environmental and health issues as well as the need to establish a sustainable society. Achieving a modern railway infrastructure will require direct supplementary expenditures that are generally seen as a major barrier. However, long-term operational and economic benefits should be taken into account while considering the additional capital cost for new rail infrastructures. Given that transit infrastructure is the backbone of the Canadian transportation industry, we therefore propose the following:

- Different levels of government and transit authorities must develop a common emission mitigation strategy that takes into account the adverse effects of diesel train technology. In particular, the impact of fine and ultrafine particulate matters, an elevated exposure experienced by transit commuters and outdated criteria for other toxic airborne compounds must be considered.
- When allocating funds for railway infrastructure spending, governments should use well-accepted techniques to reduce commissioning costs and propose a system that leads to lower maintenance costs and provides greater reliability.
- Different levels of government and transit authorities should move toward decreasing the long-term cost of railway operations.
- Governments must increase railway ridership by improving travel times, passenger comfort and level of availability.
- Governments must construct the framework for market conditions that promote sustainable industries such as electrified rail that will lead to the growth of regional economies with better-quality jobs and improved standards of living.

As for the cost of electrification, the British Transport Commission's seminal 1955 report (U.K. Department of Transport, 2009) famously stated: "It is not so much a question of whether the nation can afford to undertake the new investment in its railway system here proposed, as whether it can afford not to do so and thereby continue to carry the economic burden of a public transport system that lags far behind the standard of efficiency technically possible."

Believing that engineers should support a more efficient and modern scientific rail system, we recommend that public funding be used only for those transportation projects that promote the use of clean renewable energy.

REFERENCES

Araujo, Jesus A., et al. "Ambient Particulate Pollutants in the Ultrafine Range Promote Early Atherosclerosis and Systemic Oxidative Stress." *Circular Research*, Volume 102, Issue 5, March 14, 2008. Available at http://circres.ahajournals.org/cgi/content/full/102/5/589.

Benjamin, Les, and Darrell Richards. "Electrification Is the Way to Move Canada in the 1980s." *Canadian Public Policy*, Volume 7, Issue 3, 1981. Available at www.jstor.org/pss/3549646.

Bhargava, Bharat. "Railway Electrification Systems and Configurations." IEEE Power Engineering Society Summer Meeting, July 1999.

Cooper, H. B. H., and C. A. Webb. "Energy Considerations for Railroad Electrification in the United States." *Transportation Research Record*, Volume 802, 1981.

CPCS Ltd. in Association with Hatch Associates Ltd. (CPCS). "Commuter Rail Services—Electrification Study." March 1992. Available at www.metrolinx.com/electrification/archive/L1901.pdf.

Duffy, Michael C., *Electric Railways: 1880–1990*. London: The Institution of Engineering and Technology, 2003.

Freeman, Richard, and Hal Cooper. "Why Electrified Rail Is Superior." *21st Century Science & Technology*, Volume 18, Number 2, 2005. Available at www.21stcenturysciencetech.com/Articles%202005/SuperiorRail.pdf.

Haywood, John B. "Fueling Our Transportation Future." *Scientific American*. September 2006. Available at www.scientificamerican.com/article.cfm?id=fueling-our-transportation-future-2006.

Hull, G. J., Dr C. Roberts and Dr S. Hillmansen. "Energy Efficiency of a Railway Power Network with Simulation." Presentation at the International Conference on Energy Technologies and Policy. Birmingham, United Kingdom, 2008. Available at www.universitas21.com/pastevent/EnergyConf08/Roberts.ppt.

Indian Railways Service of Mechanical Engineers. "Economies of Traction Diesel vs. Electric." 1999.

Kleinman, Michael T. "The Health Effects of Air Pollution on Children." Irvine, California: South Coast Air Quality Management District (SCAQMD). 2000. Available at www.aqmd.gov/forstudents/health_effects_on_children.pdf.

Messa, Christina A. "Comparison of Emissions from Light Rail Transit, Electric Commuter Rail, and Diesel Multiple Units." *Transportation Research Record*, Volume 1955, 2006.

Metrolinx. "Modelling Methodology and Results for the Regional Transportation Plan." Backgounder to the Metrolinx Regional Transportation Plan, December 2008. Available at www.metrolinx.com/Docs/big_move/RTP_Backgrounder_Modelling.pdf.

Morawska, Lidia, Michael R. Moore and Zoran D. Ristovski. "Health Impacts of Ultrafine Particles: Desktop Literature Review and Analysis." Australian Government Department of the Environment and Heritage, 2004. Available at www.environment.gov.au/atmosphere/airquality/publications/health-impacts/pubs/health-impacts.pdf.

Network Rail. "Network RUS: Electrification." October 2009. Available at www.networkrail.co.uk/browse%20documents/rus%20documents/route%20utilisation%20strategies/network/working%20group%204%20-%20electrification%20strategy/networkrus_electrification.pdf.

Ontario Medical Association (OMA). "The Illness Costs of Air Pollution: 2005–2026 Health & Economic Damage Estimates." 2005. Available at www.oma.org/health/smog/report/icap2005_report.pdf.

Pope III, C. Arden, et al. "Lung Cancer, Cardiopulmonary Mortality, and Long-term Exposure to Fine Particulate Air Pollution." *The Journal of the American Medical Association*, Volume 287, Issue 9, March 2002. Available at www.airimpacts.org/documents/local/thurston_JAMA.pdf.

Puchalsky, Christopher M. "Comparison of Emission from Light Rail Transit and Bus Rapid Transit." *Transportation Research Record*. Volume 1927, 2005.

Schneider, Conrad G., and L. Bruce Hill. *No Escape from Diesel Exhaust: How to Reduce Commuter Exposure. Boston: Clean Air Task Force*. 2007. Available at www.catf.us/publications/reports/No_Escape_from_Diesel_Exhaust.pdf.

South Coast Air Quality Management District (SCAQMD). "Multiple Air Toxics Exposure Study (MATES-II)." 2000. Available at http://www.aqmd.gov/matesiidf/es.pdf.

Smith, Roderick A. "Enabling Technologies for Demand Management: Transport." *Energy Policy*, Volume 36, Issue 12, 2008. Available at www.foresight.gov.uk/Energy/EnergyFinal/Smith%20paper%20-%20Section%204.pdf.

Smoorenburg, G. F. "Effects of Impulse Noise on Man." *Noise as a Public Health Problem, Volume 1*. Norman L. Carter and R. F. Soames Job, eds. Proceedings of the International Congress on Noise as a Public Health Problem, Sydney, November 1998.

State and Territorial Air Pollution Program Administrators and the Association of Local Air Pollution Control Officials (STAPPA and ALAPCO). "Cancer Risk from Diesel Particulate: National and Metropolitan Area Estimates for the United States." 2000. Available at www.4cleanair.org/comments/cancerriskreport.pdf.

Steer Davies Gleave. "GO Transit Lakeshore Express Rail Benefit Case." Interim Report. June 2009. Available at www.metrolinx.com/Docs/general/GO_Lakeshore_BCA_Report.pdf.

Stohler, Werner, and Peter Giger. "Cost-Benefit Analysis of the Electrification of the Beira Alta Line in Portugal." London: Institution of Electrical Engineers. 1989.

U.K. Department for Transport. "Britain's Transport Infrastructure: Rail Electrification." July 2009. Available at www.dft.gov.uk/pgr/rail/pi/rail-electrification.pdf.