HOW ENERGY CONSTRAINTS COULD ENSURE A MAJOR ROLE FOR TETHERED VEHICLES IN CANADA'S NEXT TRANSPORT REVOLUTION

Richard Gilbert*
Centre for Sustainable Transportation
15 Borden Street, Toronto, Ontario M5S 2M8
Tel: 416 923 8839; Fax 416 923 6531
E-mail: richardgilbert1@csi.com

Mee-lan Wong
Faculty of Environmental Studies, York University
Toronto, Ontario M3J 1P3
Tel: 416 736 5252; Fax: 416 736 5679
Email: mlwong@yorku.ca

Introduction

After several false alarms, the prospect of major constraints on the availability of transport fuels is becoming more firmly entrenched. A consensus may be beginning to emerge that world *production* of oil, which now fuels 95 per cent of transport,[1] could peak during the next two decades (see Figure 1).[2] The production peak would echo the peak in worldwide oil *discovery*, which occurred in the early 1960s (see Figure 2).

Meanwhile, potential demand for transport fuels could continue to rise, driven chiefly by growth in economic and transport activity in China and other industrializing countries,[3] resulting in sharply elevated prices.

* Corresponding author

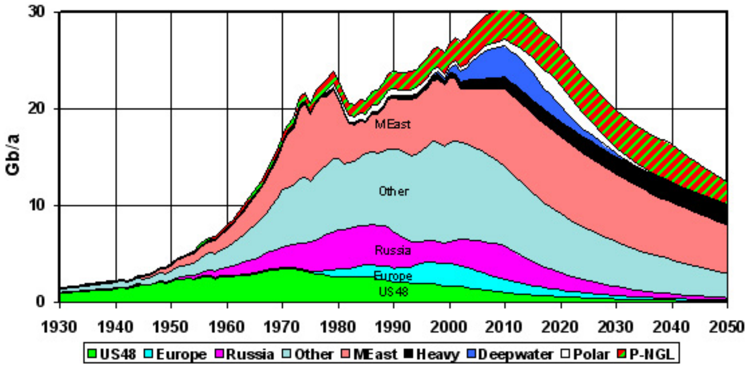

Figure 1. World production by region of regular oil and natural gas liquids, actual and estimated, billions of barrels per year, 1930-2050.[4]

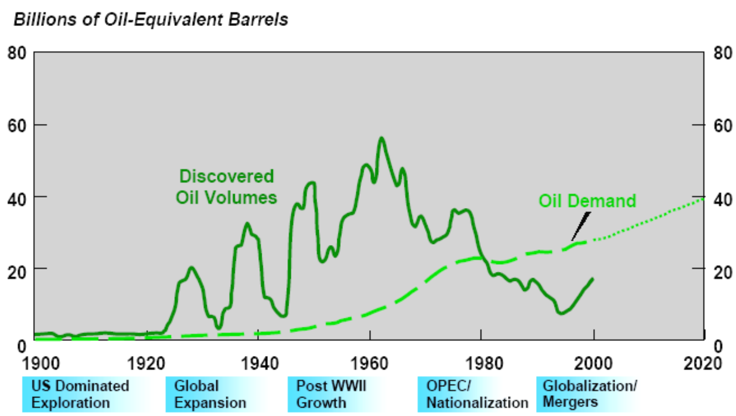

Figure 2. World discovery of and demand for oil, 1900-2000, and projected potential demand until 2020.[5]

The most promising alternative transport fuel is said to be hydrogen, whether for use in fuel cells or combustion engines.[6] However, North American production of natural gas—the source of about 95 per cent of hydrogen produced in the U.S.[7]—appears to have already peaked,[8] resulting in large increases in wholesale and retail prices.[9] There is much natural gas in the Middle East, Russia, and elsewhere,[10] but major constraints on moving it between continents.[11]

Canada's vast size and extensive international trade make us more dependent on transportation than most affluent countries.[12] Without adequate preparation, Canada could suffer inordinately from greatly elevated fuel prices, whether for conventional transport fuels based on crude oil or for fuels required by emerging technologies, including hydrogen for fuel cells.

Accordingly, addressing potential constraints on the availability of transport fuels could well become a national policy priority, perhaps similar in importance to that of meeting the transport challenges posed by Canada's Kyoto commitment.

Among effective responses to potential energy constraints could be much wider use of tethered vehicles—i.e., electrically powered vehicles fuelled via rail or wire—including trains, streetcars, trolley buses, and even trolley trucks.

Tethered vehicles have three relevant advantages: (i) they can have remarkably low energy intensities; (ii) their primary fuels can include a wide range of renewable and non-renewable sources; and (iii) for the most part they involve familiar, tried, tested, and available technology.

They also have two major disadvantages: (i) they are confined to routes with appropriate infrastructure (i.e. rails and/or wires); and (ii) they rely on continuously available, centrally provided power.

The balance of this paper will discuss the advantages and disadvantages of tethered vehicles and show how they could and perhaps should be used more widely in Canada and thus become a significant feature of Canada's next transport revolution.

Energy use by tethered and other vehicles

The superior performance of tethered passenger vehicles with respect to energy use is illustrated in Table 1. In each of the three categories of vehicle, tethered vehicles show lower *operational* energy use.

Vehicle type	Fuel	Occupancy (pers./veh.)	Energy use (mJ/pkm)
Personal vehicles:			
SUVs, vans, etc.[13]	Gasoline	1.70	3.27
Large cars[13]	Gasoline	1.65	2.55
Small cars[13]	Gasoline	1.65	2.02
Motorcycles[13]	Gasoline	1.10	1.46
Fuel-cell car[14]	Gasoline	1.65	0.92
Hybrid electric car[15]	Hydrogen	1.65	0.90
Very small car[16]	Diesel	1.30	0.89
Personal Rapid Transit[17]	Electricity	1.65	0.49
Public transport between cities:			
Intercity rail (U.S.)[18]	Diesel		2.20
School bus[13]	Diesel	19.5	1.02
Intercity bus[13]	Diesel	16.8	0.90
Intercity rail (U.S.)[18]	Electricity		0.64
Public transport within cities:			
Transit bus (U.S.)[19]	Diesel	9.3	2.73
Trolleybus (U.S.)[19]	Electricity	14.6	0.88
Light rail (streetcar, U.S.)[19]	Electricity	26.5	0.76
Heavy rail (subway, U.S.)[19]	Electricity		0.58

Table 1. Energy use in megajoules per passenger-kilometre by various modes. Tethered modes are shown in colour.[20]

Overall (primary) energy use can be much greater than operational (secondary) energy use, according to how the energy is supplied. For example, electricity produced by a combined-cycle gas turbine generator requires expenditure of about 90% more primary energy in the form of generator fuel as is available in the secondary energy in the electricity.[21] Similarly, if hydrogen for a fuel cell is produced by electrolysis, the energy content of the electricity used is about 60% higher than the energy content of the hydrogen produced.[22]

With such conversion losses, it is important to consider the primary energy use; this is a better indicator of the energy burden. However, when the secondary energy—which provides the motive power—can be produced with little intermediate conversion, considerations of primary energy use are less important. Examples are gasoline produced from conventional oil and electricity from wind turbines.

Tethered vehicles also provide superior performance in freight transport. There are no electric freight trains in North America. The comparison in Table 2 is for Finland. Not shown are tethered versions of trucks, known as 'trolley trucks', which like trolleybuses are powered through an overhead wire. They are used extensively in mining and other off-road operations (see Figure 3). Data on energy use by trolley and regular trucks are not available; the difference is difference between the two is likely comparable to that shown in Table 2 for diesel and electric trains.

Vehicle type	Fuel	Energy use (mJ/tkm)
Truck	Diesel	0.45
Train	Diesel	0.20
Train	Electric	0.06

Table 2. Energy use by freight transport in Finland, in megajoules per tonne-kilometre.[23]

The particular features of electric motors that make them more efficient than comparable internal-combustion engines are: (i) higher torque at low speeds, thus requiring less fuel use and a smaller engine; (ii) smaller engines mean less weight to carry, also meaning less fuel use; and (iii) electric drive systems can have regenerative braking—motive energy is captured when decelerating rather than lost as friction heat—again resulting in energy savings.

Figure 3. Trolley truck operating at the Quebec Cartier iron ore mine, Lac Jeannine, 1970s.[24]

The low energy intensities of tethered vehicles, for passengers and freight, suggest that extensive use of them should be considered as part of the preparation for an era of energy constraints.

Tethered vehicles can use a variety of primary energy sources

Just about as important for sustainability as tethered vehicles' low energy intensity is their versatility in the use of primary energy sources. Any means of generating electricity for the grid is a primary source of energy for tethered vehicle operations. In this way, wind, sun (thermal and photoelectric), tide, falling water, nuclear fission, and combustion of fossil fuels and biofuels can all be energy sources for tethered vehicles.

As we move towards an energy future whose only certainty may be reduced reliance on fossil fuels, the ability to power transport by a wide variety of sources will be advantageous. Moreover, electricity is the most convenient energy currency of many sustainable primary sources, including wind, sun (photoelectric), tide, and falling water.

Tethered vehicle technology is readily available (but there are opportunities for improvement)

Tethered electric vehicles have been in practical use for at least 120 years.[25] There were streetcars on Canadian streets before there were automobiles.[26] There has been continuous development of the technology as adoption of these modes has spread throughout the world, and as technical requirements have been enhanced (e.g., for high-speed trains).

Building on this well-established technology, there are many opportunities for further enhancement, especially in the matter of personal rapid transit (PRT, noted in Table 1). Because PRT could provide a convenient, affordable alternative to automobile use in low-density areas, it offers the opportunity to address what may be the most intractable of transport challenges.

Another major challenge concerns road freight transport, the fastest growing source of energy use and greenhouse gas emissions. It's possible to conceive of technological development that would allow any truck, and even any road vehicle, to draw motive power from overhead wires, replacing some of it during braking.

Tethered vehicles are restricted to powered routes

The most serious disadvantage of tethered vehicles is their infrastructure requirements. At a minimum, they require wires above existing roads, and the means to power them. According to the type of vehicle, they could also require new rails or other guideways.

A similar challenge confronted automobiles 100 years ago. They were mostly confined to summer travel on roads within urban areas. In 1910, the only paved highway in Canada was a 16-kilometre stretch from Montreal to Ste.-Rose. Present levels of route flexibility took many years to develop. Indeed, an automobile was not driven across Canada until 1946, and the Trans-Canada Highway was not completed until the 1960s.[27] Today's automobiles and trucks may be even more confined to laid-out roads than those of a century ago, but the road system is extensive, reaching to most parts of southern Canada.

Widespread adoption of tethered vehicles for the next transport revolution could well involve continued use of the present road system, with the addition of powered overhead wires that can be shared by all. However, vehicles run more efficiently on rails or tracks than on roads, and energy constraints may favour trains and other vehicles confined to special-purpose rights-of-way.

Tethered vehicles require continuously available, centrally provided power

Toronto's streetcars and subway trains stopped during the blackout on August 14, 2003, but cars and trucks kept on rolling, at least for a time. Then they were stopped in traffic jams caused by non-functioning traffic signals and by line-ups at non-functioning gas stations.

It is nevertheless true that cars and trucks have some additional resilience compared with tethered systems because they carry their own fuel. However, both depend ultimately on heavily centralized systems of energy distribution.

Greater dependence on tethered transport systems would stimulate designs for greater resilience involving more distributed production and greater redundancy. These would in any case be likely features of a more sustainable system of energy supply.

Preparing for the next transport revolution

If we had a perfect political system, able to assess and respond to long-term risks and opportunities, we might well be busy now laying down the infrastructure for an easy transition to predominantly tethered transport over the next few decades. Present political systems are more able to respond to emergencies. Thus, it could be a decade or two before the transition begins in earnest, too late for the transition to be painless.

If the next transport revolution will indeed be about tethered vehicles, what could be done today? Here are some suggestions:

- Confirm whether or not energy constraints will be severe and whether or not tethered vehicle systems offer the best opportunities for continued movement of people and goods.
- Plan a transition from what we have now to what we need to have in terms of energy supply, transport infrastructure, and vehicles.
- Conduct needed research, e.g., into PRT, trolley trucks, and overhead wire systems that can accommodate a range of users.
- Direct investments appropriately, e.g., towards light-rail transport rather than bus rapid transport and towards electric rather than diesel trains, because in each case the former will be more compatible with the next transport revolution.

End Notes

[1] According to Page 411 of International Energy Agency, *World Energy Outlook 2002* (IEA, Paris, France, 2002), 95.5% of the energy used for motorized transport worldwide in 2000 came from oil, i.e., 1,696 out of 1,775 million tonnes of oil equivalent.

[2] Part of the evidence of emerging consensus on the notion of a peak in world oil production during the period 2010-2030 is the authorship of the first *Nature* paper mentioned in Note 4 below, which comprises an academic and two industry specialists.

[3] According to the June 2003 issue of the *BP Statistical Review of World Energy*, available at the URL below, China passed Japan in 2002 to become the world's second major user of oil after the U.S. Over the previous decade, use of oil in China had increased by 99%. Use of oil in Canada and the U.S. had increased respectively

by 17% and 16%. Use of oil in Japan had declined by 3%.
1. http://www.bp.com/subsection.do?categoryId=95&contentId=2006480. Accessed Feb. 8, 2004.

[4] Figure 1 was taken from the Web site of the Uppsala Hydrocarbon Depletion Group at the first URL below. The figure suggests that production of liquid hydrocarbons suitable for conversion into transport fuels will peak in about 2012. Some estimates point to earlier peaks, e.g., in 2005, as projected in Deffeyes KS, *Hubbert's Peak: The Impending World Oil Shortage.* Princeton University Press, 2001. Others point to later peaks, e.g., in 2018-2023, as projected in White N, Thompson M, Barwise T, Understanding the thermal evolution of deep-water continental margins, *Nature*, 426:6964, 324-333, 2003. Extreme among the projections of later production peaks are those of the U.S. Energy Information Administration (EIA), which suggests production will continue rising beyond 2025 (*International Energy Outlook 2003*, Washington DC, 2003, available at the second URL below) and those of the International Energy Agency (IEA), which suggests oil production will continue rising until 2030 (*Energy to 2050: Scenarios for a Sustainable Future*. IEA, Paris, France, 2003). Energy constraints will arise from potential demand running ahead of actual production of liquid hydrocarbons resulting in high prices, *not* from depletion of all available oil. Put another way: “The world is not about to run out of hydrocarbons, and perhaps it is not going to run out of oil from unconventional sources any time soon. What will be difficult to obtain is cheap petroleum, because what is left is an enormous amount of low-grade hydrocarbons, which are likely to be much more expensive financially, energetically, politically and especially environmentally.” (Hall C and four others, Hydrocarbons and the evolution of human culture. *Nature*, 426:6964, 318-322, 2003).
1. http://www.isv.uu.se/uhdsg/. Accessed Feb. 4, 2004.
2. ftp://ftp.eia.doe.gov/pub/pdf/international/0484(2003).pdf. Accessed Feb. 4, 2004.

[5] Figure 2 is from a presentation by Harry J. Longwell, Executive VP, Exxon Mobil Corporation at the Offshore Technology Confer-

ence, Houston, Texas, May 7, 2002, available at the URL below.
1. http://www.exxon.mobil.com/files/corporate/hjlslide3.pdf. Accessed Feb. 5, 2004.

[6] According to the International Energy Agency, “In the long term, perhaps the most promising path for virtually eliminating the direct use of petroleum fuels … is the hydrogen fuel cell. Once all vehicles operate on hydrogen fuels, they will be potentially renewably fuelled (if a renewable source of hydrogen is developed), and will produce water as their only emission.” (Pages 168-169 of *Towards a Sustainable Energy Future*, IEA, Paris, France, 2001). In January 2003, U.S. President George Bush announced the FreedomCAR and Fuel Initiative “to reverse America’s growing dependence on foreign oil by developing the technology needed for commercially viable hydrogen-powered fuel cells”, detailed at the URL below. Hydrogen can be used as fuel for internal combustion engines, but its use in fuel cells is said to offer “significantly greater potential” (see the second URL below).
1. http://www.eere.energy.gov/hydrogenfuel/. Accessed Feb. 8, 2004.
2. http://www.initiative-brennstoffzelle.de/en/ibz/live/nachrichten/detail/104.html. Accessed Feb. 8, 2004.

[7] According to Amory Lovins in *Twenty Hydrogen Myths* (Rocky Mountain Institute, 2003, available at the URL below), “U.S. hydrogen production is at least one-fifth and probably nearer one-third of the world total, is equivalent to ~1.8% of total U.S. energy consumption, and comes ~95% from natural gas at ~99% purity from steam reforming and associated cleanup processing.”
1. http://www.rmi.org/images/other/Energy/E03-05_20HydrogenMyths.pdf. Accessed Feb. 8, 2004.

[8] For an informed view that North American natural gas production may have already peaked, see the presentation by Matthew Simmons, *The Natural Gas Riddle: Why Are Prices So High? Is a Serious Crisis Underway?* at the mini-conference of the International Association for Energy Economics, Houston, Texas, December 11, 2004, available at the URL below.

1. http://www.simmonsco-intl.com/files/IAEE%20Mini%20Conf.pdf. Accessed Feb. 8, 2004.

[9] The Alberta Gas Reference Price increased more than 3.5-fold between February 1999 and February 2003, from $1.90 to $6.83 per gigajoule (see the URL below). Over the same period, the price Toronto consumers paid for natural gas rose by about 70%.
1. http://www.energy.gov.ab.ca/gmd/gas/monthlyref.asp. Accessed Feb. 8, 2004.

[10] According to the International Energy Agency (see the source detailed in Note 1), North America was responsible for 31% of world natural gas consumption in 2000 but had only 5% of proven natural gas reserves (pp. 110 and 114).

[11] Natural gas can be economically shipped between continents as liquefied natural gas (LNG) when the wholesale natural gas price is above about Can$4.40 per gigajoule. Three difficulties impede rapid expansion of LNG imports: (i) a shortage of vessels designed to carry LNG; (ii) a shortage of terminals designed to receive LNG; and (iii) movement of LNG is regarded as hazardous. On the last point consider the following from Powers B, *Assessment of Potential Risk Associated with Location of LNG Receiving Terminal Adjacent to Bajamar and Feasible Alternative Locations*, at the URL below: "The US Coast Guard requires a two-mile moving safety zone around each LNG tanker that enters Boston Harbor, and shuts down Boston's Logan Airport as the LNG tanker passes by. … These extraordinary precautions are taken out of concern for spectacular destructive potential of the fire and/or explosion that might result from a LNG tank rupture."
1. http://www.borderpowerplants.org/pdf_docs/lng_position_paper_june 2002_english.pdf. Accessed Feb. 8, 2004.

[12] Figure 17 (Page 29) of *Measuring the New Economy: Trade and Investment Dimensions* (Organization for Economic Cooperation and Development Document No. TD/TC/WP(2001)23/FINAL, October 2001) sets out 1999 data on trade and GDP for 25 OECD and east European countries, at the URL below. Among the listed countries, Ireland (125%), Hungary (110%), and The Netherlands

(86%) had trade as a higher share of GDP than Canada (72%).
1. http://www.olis.oecd.org/olis/2001doc.nsf/LinkTo/td-tc-wp(2001)23-final. Accessed Feb. 8, 2004.

[13] The data in this row are derived from the electronic version of *Energy Use Data Handbook* (Ottawa, Ontario, Natural Resources Canada, June 2003), available at the URL below.
1. http://oee.nrcan.gc.ca/neud/dpa/handbook_tables.cfm?Text=N&PrintView=N. Accessed Feb. 6, 2004.

[14] The fuel-cell-car data are for the 2004 Honda FCX subcompact, as posted by U.S. Department of Energy at the URL below.
1. http://www.fueleconomy.gov/feg/fcv_sbs.shtml. Accessed Feb. 6, 2004.

[15] The data for a hybrid gasoline-electric car are those for the 2004 Toyota Prius midsize car, as posted at the URL below.
1. http://www.fueleconomy.gov/feg/hybrid_sbs.shtml. Accessed Feb. 6, 2004.

[16] The data for the 'very small car' are those for Volkswagen's Lupo 3L, a two-seater-plus diesel car available only in Europe and described by the manufacturer as the "first 3L vehicle in production" (see Klaus-Peter Schindler, *The future of the Diesel engine in passenger cars*. Presentation at the 7th Diesel Engine Emissions Reduction Workshop, Portsmouth, Virginia, August 2001, at the first URL below). Manufacturer's energy-use data are given here, i.e., 2.99 litres/100 km, equivalent to 0.89 mJ/pkm for an occupancy of 1.30 (this author's estimate). In Slide 10 of the cited presentation, a rate of 0.75 mJ/pkm is given for "average rate of occupation" "in urban traffic under 75 km", which suggests an average occupancy of 1.54 or higher. Testing of the Lupo 3L by Transport Canada indicated highway fuel use of 3L/100 km and city fuel use of 3.8L/100 km (*Advanced Technology Vehicles Program, 2001-2002 Annual Report*, Road Safety and Motor Vehicle Regulation, Transport Canada, January 2003, at the second URL below).
1. http://www.osti.gov/fcvt/deer2001/schindler.pdf. Accessed Feb. 7, 2004.
2. http://www.tc.gc.ca/roadsafety/atvpgm/reports/annual/atvp0102.pdf. Accessed Feb. 7, 2004

[17] Personal Rapid Transit (PRT) is a generic term for concept systems comprising fully automated small vehicles carrying 1-6 passengers running on guideways at, above or below ground, providing direct origin-to-destination service. A useful review of these and other innovative technologies can be found at a Web site maintained by Jerry Schnieder of the University of Washington, at the URL below. The energy use shown in Table 1 represents the average of several developers' estimates.
1. http://faculty.washington.edu/jbs/itrans/. Accessed Feb. 7, 2004.

[18] There are no electrically powered intercity trains in Canada, and so U.S. data are provided for this type of vehicle. Amtrak's Northeast corridor is the only electrified part of the intercity rail system in the U.S. About 2.63 billion passenger-kilometres (pkm) were performed in this corridor in 2000 and about 6.34 billion pkm in the rest of the system (this author's estimates from various sources, notably Report No. GAO/RCED-96-144 by the U.S. General Accounting Office, *Northeast Rail Corridor: Information on Users, Funding Sources, and Expenditures*, 1996, at the first URL below, and Table 9.12 of Davis SC, Diegel SW, *Transportation Energy Data Book 23*, Oak Ridge Tennessee: Oak Ridge National Laboratory, 2003, at the second URL below). According to Table A.16 of the second source, 470,170,000 kilowatt-hours of electricity and 94,968,000 U.S. gallons of diesel fuel were used respectively to provide this service.
1. http://ntl.bts.gov/data/rc96144.pdf. Accessed Feb. 11, 2004.
2. http://www-cta.ornl.gov/data. Accessed Feb. 11, 2004.

[19] The data in this row are derived from data on U.S. systems provided by the American Public Transportation Association (APTA), available at the URL below. (Data on Canadian systems in the source cited in Note 13 are not provided by mode. However, in aggregate they seem roughly comparable to the APTA data.)
1. http://www.apta.com/research/stats/. Accessed Feb. 7, 2004.

[20] The sources for the estimates in Table 1 are in the corresponding end notes. The table shows *end* or secondary energy. As noted in the text, primary or full-cycle energy use can be much greater.

[21] For generator efficiency see, for example, Wei A, *Technologies for Next Generation Turbine Systems*. Presentation at the Turbine Power Systems Conference and Condition Monitoring Workshop, Galveston, Texas, February 2002, available at the URL below.
1. http://www.netl.doe.gov/publications/proceedings/02/turbines/wei.pdf. Accessed Feb. 7, 2004.

[22] For the efficiency of electrolysis, see Page 171 of Committee on Alternatives and Strategies for Future Hydrogen Production and Use, National Research Council, *The Hydrogen Economy: Opportunities, Costs, Barriers, and R&D Needs.* (Washington DC, National Academies Press, 2004), available at the URL below.
1. http://books.nap.edu/books/0309091632/html/index.html. Accessed Feb. 7, 2004.

[23] The freight transport data in Table 2 are from the source at the URL below. In Finland, electric freight trains appear to use less than one third of the operational energy per tonne-kilometre (tkm) used by comparable diesel freight trains, which in turn use less than half of the energy used by trucks. Note that the report energy use by Finnish trucks (0.45 mJ/tkm) is very much lower than the use estimated even for heavy Canadian trucks in the source detailed in Note 13 (2.41 mJ/tkm). However, the Finnish and Canadian sources present similar estimates of energy use diesel freight trains (respectively 0.20 and 0.25 mJ/tkm).
1. http://www.ecotraffic.se/pdf/et.pdf. Accessed Feb. 7, 2004.

[24] The trolley truck photo is at the URL below.
1. http://hutnyak.com/Trolley/trolleyphotos.html. Accessed Feb. 8, 2004.

[25] See, for example, the URL below.
1. http://mikes.railhistory.railfan.net/r066.html. Accessed Feb. 10, 2004.

[26] Filey M, Howard R, Weyerstrahs H, "*Passengers Must Not ride on Fenders*", Toronto, Ontario, Green Tree Publishing Co., 1974)

[27] Nichol J, *The All-Red Route* (Toronto, Ontario, McArthur and Co., 1999).