Beyond Wheels: the Future of High-Speed Rail in Canada

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April 17, 2009

1 Executive Summary

High-speed magnetic levitation, or maglev, train systems are beginning to appear in commercial service. In 2004, Shanghai opened a 30-km line operating at 430km/h. Construction costs for that line were less than the cost of a 12-km stretch of Highway 401 access road to be built near Windsor.

Maglev trains offer substantial advantages over conventional high-speed trains, such as the ICE and TGV trains of Europe, and even greater advantages over medium-speed trains, such as the fossil-fueled Bombardier JetTrain. Compared to ICE or TGV trains, maglev trains are are faster (430km/h *vs.* 300km/h), are substantially quieter, pollute less (due to their lower energy consumption), have one-third the maintenance and operations costs (due to their non-contact technology and absence of moving parts), and have similar capital costs.

Any high-speed train line, regardless of its technology, can not achieve its rated speed except on a purpose-built line, with no grade crossings; medium-speed trains will have the same requirement. Because the capital cost of new lines dominates the total cost of a train system, it makes no sense for Canada to construct anything except maglev lines running at 400-500km/h.

Finally, research into magnetism being conducted in Canada and the United States has the promise of dramatically decreasing the line costs, and

perhaps operating costs, of maglev-based trains.

2 Rationale and Disclaimer

Recent press (*e.g.*, [Bre09]) regarding the role of high-speed rail in Canada prompted the writing of this article, which gives an overview of how conventional high-speed train technology compares with magnetic-levitation (*maglev*) ground transport systems and why 21^{st}-century Canada should opt for maglev over conventional high-speed rail systems.

This article expresses opinions held by the author, who is not a transportation engineer, nor connected with any transport-related firms, but a computer scientist and a high-speed land transportation aficionado; our research, being non-funded, has necessarily been limited.

Most of the claims presented in this article are based on information provided by the designers and manufacturers of maglev technology, so should be read with that in mind. Also, due to time constraints, information presented here is only a sample of that available in the open literature and on the intern et.

3 Introduction

Conventional high-speed rail transport systems, such as the German ICE trains and the TGV of France, are based on the early 1960's Japanese Shinkansen technology. These systems, which have cruising speeds of about 300km/h (Siemens ICE 3), are approaching the upper limit of what can be achieved with wheel-based technology. The fossil-fueled Bombardier JetTrain, a derivative of the Amtrak Acela trains, often touted as a possible Canadian "high-speed" rail technology, is actually only a medium-speed train, because its maximum sustained speed of 240km/h is about half of that of maglev trains, and about 2/3 of that of modern European trains. The JetTrain does have the redeeming feature of being able to run on standard track, but high-speed operation (or, in its case, medium-speed operation) is not possible without complete rebuilding of entire lines, including removal of all grade crossings, at similar costs to building a proper high-speed line.

The advent of magnetic levitation, or *maglev*, trains marks the first fundamental change in rail technology since the inception of the steam engine.

Maglev trains, unlike conventional ones, do not have wheels - they float above their guideway, supported by magnetic fields, and propelled by linear induction motors. They have no moving parts to wear out or break.

A 30-km, German-designed, Transrapid maglev system has been operating between Shanghai and Hangzhou since January 2004. The UK appears about to build UK Ultraspeed, an 800-km, Transrapid-based intercity system, linking the Chunnel, London, Manchester, Edinburgh and Glasgow. Other countries, including the Netherlands, United States, Germany, India, and the Gulf Region, are also looking to maglev for new ground transport technology.

Although maglev systems are in their technological infancy, they already exceed the capabilities of conventional, wheeled trainsets, in terms of quieter operation, dramatically lower energy consumption, higher maximum velocity, significantly faster acceleration and braking, ability to climb much steeper grades, tighter turning radius, and reduced wear and tear on the roadbed. The remainder of this paper discusses these, and other, factors in somewhat more detail.

4 Energy Consumption

Today's first-generation maglev trains, when operating at 300 km/h, consume about 40% less power then conventional trainsets.[UKUa] Tests performed by the German federal government show that the energy consumption of the Transrapid maglev system is 34Wh/seat-km[1] at 300km/h, compared to 51Wh/seat-km for modern ICE trainsets, showing that maglev technology is far more eco-friendly and less expensive to operate than conventional high-speed trains. Figure 1 shows that, in addition, maglev trainsets can operate at the same energy levels as conventional high-speed trains, but at 100km/h higher velocity:

5 Maximum Velocity

At present, the Shanghai Transrapid TR-08 system has a cruising speed of 431km/h, with a maximum velocity of approximately 500km/h. Higher

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[1] This is a measure of energy consumption per passenger per kilometer.

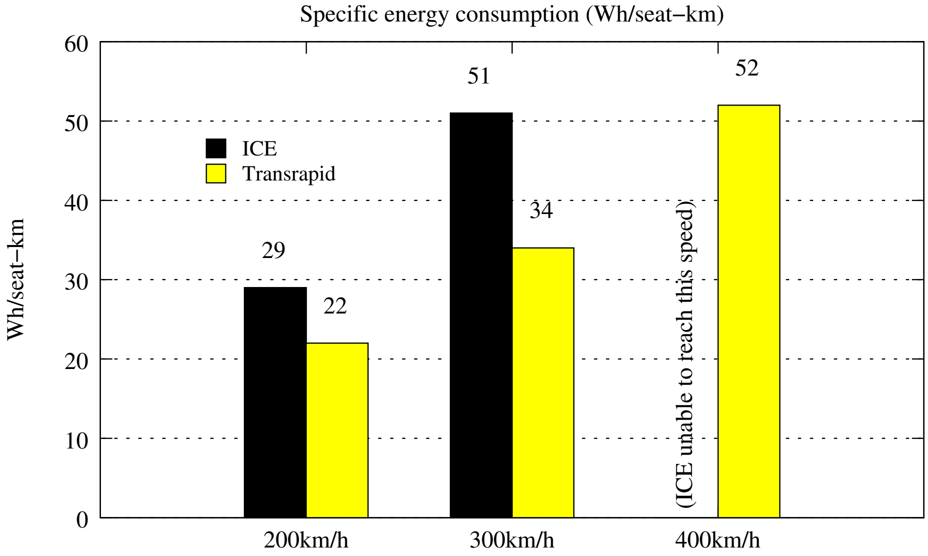

Figure 1: Energy Consumption: ICE versus maglev

speeds are possible, but at the cost of increased energy consumption, due to air drag. All transport technologies suffer from this air drag problem.

6 Acceleration and Braking

Maglev trainsets accelerate and brake much faster than conventional, wheeled trains. The Transrapid TR-08 trainset operating in Shanghai reaches a velocity of 300km/h within 5 km of departure from the station, just two minutes later. By contrast, an ICE train takes about nine minutes, and 28 km, to reach the same speed, which is also the ICE's cruising speed. The maglev continues to accelerate, reaching its own cruising speed of 430km/h in just over three minutes from departure.[UKUa]

Rapid acceleration and braking offers maglev a significant advantage over wheeled trains: a maglev system can make more station stops without materially affecting its arrival time at destinations nearly as much as conventional trainsets.

In the author's experience of riding the TR-08 trainset at the Transrapid test site in Emsland, Germany, we observed acceleration and braking to be extremely smooth, even though the train reached speeds of over 410km/h. Passengers do not experience discomfort from this acceleration, nor from the train's high speed. We found the comfort level, at 400km/h, to be equal or better than that of a TGV traveling at 300km/h, and far better than any North American train.

7 Ascent, Descent, and Curve Performance

The Transrapid system can operate on a 10% gradient, whereas ICE trains are generally limited to a gradient of 4%.[UKUa] As a result, the routing of maglev line guideways is much simpler, and less expensive, than routing of conventional high-speed rail lines.

A related point is that of turning radius: the Transrapid maglev system can operate in half the turning radius of TGV trains: 1.6 km at 300km/h *vs.* 3.2 km for the TGV. This is advantageous, as it simplifies route planning, reduces land use requirements, and permits operation at higher velocities.

8 Cost

The costs associated with any large transportation system are difficult to assess, due to differing patterns of use - freight *vs.* passenger, distance traveled, frequency of service, passenger counts, etc. In the case of maglev, the problem of cost assessment is more difficult, since only one commercial line has been completed to date. However, we have a few data points available, taken from Transrapid, Maglev2000, and the UK Ultraspeed project. The latter have conducted an in-depth study of construction and operation costs.[UKUa] We present our cost review in three parts: Capital costs, for line construction; maintenance and operating costs, once the line has been built and is in normal operation; and capital cost reductions.

8.1 Capital Cost

All transportation infrastructures are expensive, whether they be airports, roads, or train lines. Ellis-Don construction claims, among their other "successes", that the Terminal 4 parking garage at Pearson Airport cost $220 million and that terminal renovations cost $300 million and $200 million, totalling $720 million.[Ell] A new, 12-km access road to Ontario's Highway

401 is slated to cost, before construction even starts, $1.6 billion, or $133 million/km.[O'R] This is far higher than any high-speed train line ever built or proposed, with the obvious exception of The Chunnel Tunnel.

The major cost of any rail system is the line itself, and the first line built with a given technology always costs more than follow-on lines. This is true of the Shanghai maglev line. The 30-km Shanghai Transrapid line, the first commercial maglev system in regular operation today, cost USD $1.2 billion to construct, or USD $40 million/km.[Tra07] Note that this cost, including foreign exchange rates, is less than the cost of the 12-km stretch of access mentioned above. The Transrapid update on the project claims that the high costs were due to the line being the first commercial maglev line ever built, a "challenging" construction schedule, steep learning curves for the Chinese engineers on the project, costs of importing all primary maglev components (vehicles, propulsion, control) from Germany, an entirely elevated, double-track guideway, construction in an urban environment that is also a medium-level earthquake zone, and poor soil conditions (river delta). The update claims that line extensions are to built at a capital cost of USD $24 million/km, due to technology transfer to China offering higher local content, "optimized guideway infrastructure", a more experienced local workforce, and a longer route that will allow investment costs to be amortized over larger quantities of material. These costs are claimed to be similar to that of constructing new conventional high-speed rail lines.

The UK Ultraspeed study predicts double-track *total*[2] costs, including all non-maglev components, of about GBP 20-25,000,000/km, exclusive of land acquisition costs; they compare this cost to the predicted cost of the London-Chunnel conventional high-speed line: between GBP 46-48,000,000/km, inclusive of land acquisition costs.[UKUa] We do not know why this estimate is so much higher than the proven cost of the Shanghai maglev line, since they use the same Transrapid technology.

Right-of-way acquisition costs should be lower with maglev than with conventional high-speed trains: maglev lines can share their right of way with freeways and, due to their ability to operate on elevated guideways, run down freeway medians, right into the heart of cities. Elevated operation also means that maglev lines in farmland need not divide pastures and the like - cattle can graze under the guideways; this capability presumably also

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[2] Presumably, this includes stations, landscaping, all trainsets, maintenance and storage yards, and the like.

reduces the rent payable for such land use.

Maglev technology is in its infancy, so there are great opportunities for improved suspension and traction technology; construction of new lines will be able to exploit economies of scale and new construction methods to reduce capital and operating costs. Conventional high-speed rail technology, being mature, is unlikely to obtain the same levels of cost savings as maglev technology, which is still in its infancy.

Even if maglev capital costs remain unchanged from when the Shanghai line was built, the 500 km line between Montreal and Toronto could be built for the same price as 17 Pearson Airport parking garages plus renovations, or for 55 parking garages, or for about 100 km of Highway 401 access road.

8.2 Maintenance and Operating Costs

There appears to be general consensus that maglev technology has substantially lower maintenance costs than conventional train systems, largely due to maglev's non-contact mode of operation and almost-total absence of moving parts. Conventional train lines require constant maintenance on their vehicles, roadbeds and rails, because of the enormous loads placed on the few points where a car's wheel contacts the rail. A report comparing the JetTrain and maglev trains notes that the JetTrain technology would require the following sorts of on-going maintenance:

> . . . routine maintenance of rolling stock, track inspection and periodic ballast, cross tie and rail replacement. For continued safe high-speed operation, rails must be constantly maintained for reduced wear and precision alignment.[Sch02]

In maglev systems, there is no contact between any part of the train and its guideway. Furthermore, maglev levitation systems distribute the vehicle's weight over its entire length, so there are not any point loads, and stress and dynamic guideway loads are reduced. This effectively eliminates misalignment, and also reduces wear and tear on the guideway. In general, moving mechanical parts no longer exist in maglev trains - everything is electronic. Hence, the above-cited maintenance activities are largely redundant, leaving only vehicle maintenance and periodic guideway inspection.

Maglev trains obtain their power through non-contact inductive coupling, so there are no power-pickup shoes or catenaries to wear out, unlike conventional electric trains. However, it may be that that Bombardier PRIMOVE

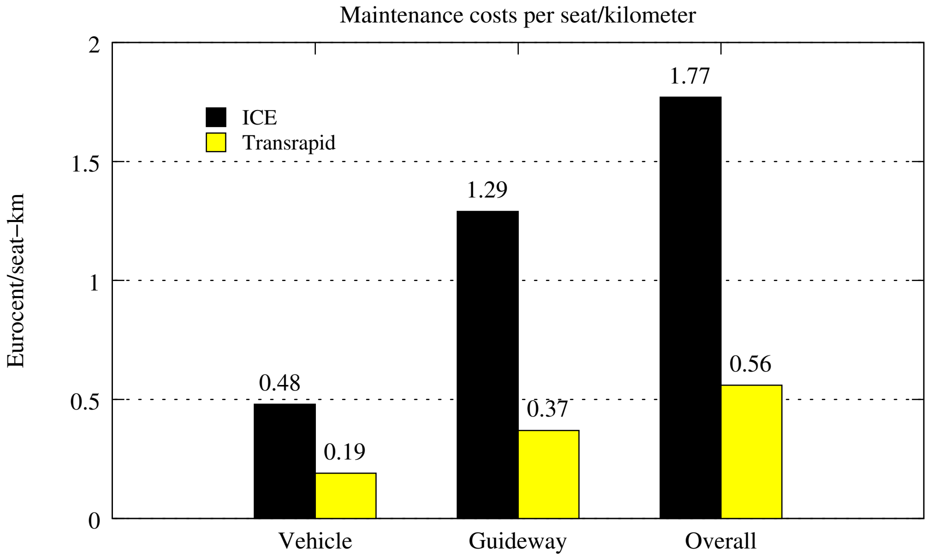

Figure 2: Maintenance Costs: ICE versus maglev

and MITRAC technologies, designed to eliminate the need for catenaries in low-speed urban and light rail systems, could be adapted to use on conventional high-speed trains.[Bom]

Maglev2000 a U.S.-based technology firm, with a maglev design tuned to North-American transportation patterns, has conducted a cost-benefit analysis of maglev travel, including both freight and passenger modes.[Magb] According to them, the cost of maglev passenger transportation is about 1/3 the cost of air travel. Neither of their cost estimates include government subsidies, airports, guideway costs, etc. They assume that the maglev line is bimodal – used for both freight and passenger service – and claim that the amortization period for maglev lines is dramatically reduced, from 30 years to three, if guideways are constructed to support bimodal operation.

Transrapid claims that the total maintenance cost per Available Seat Kilometer (ASK), including guideways, vehicles, and infrastructure, is about 1/3 that of an ICE rail system, as shown in Figure 2:[Tra]

8.3 Capital Cost Reduction

Even though maglev lines are going to be much less expensive than roads such as the Highway 401 access road described earlier in this section, the costs are still daunting, and it makes sense to look for ways to reduce guideway construction costs, since they comprise the lion's share of the project cost. Clearly, economies of scale will appear in constructing any long-haul Canadian maglev line that do not exist in shorter lines. Nonetheless, any reduction in guideway costs is desirable, and improved suspension or traction technologies are the areas where substantial cost savings could be obtained.

Maglev2000 claims significantly lower-cost guideway construction costs, of about USD \$6,000,000/km, for a two-guideway system.[Magb] Apparently, they achieve this much lower cost by exploiting super-conducting magnets in the vehicles, which allows them to use inexpensive technology in the guideway, and also reduces the width of the right-of-way, which may reduce land acquisition costs.

Recent research on the suspension technology front is promising: Richard F. Post and other researchers at the Lawrence Livermore National Laboratory, working with General Atomics and several Pittsburgh engineering firms, have designed and prototyped *Inductrack I*, a passive suspension technology that uses permanent magnets mounted as Halbach arrays; it does not require cryogenically cooled super-conducting coils, as does the Japanese Yamanashi design.[RFP05]

On the traction power front, Ed Cook, also at LLNL, has developed a *modular pulsed LSM drive*[3] system that "promises much higher efficiency" than conventional LSM drive systems. We do not have specific information on the potential cost reductions available from either of these two advances, but they sound extremely promising.

Finally, research work at several Canadian universities on the fundamental theories of magnetics and high-temperature superconductivity promise to reduce, perhaps significantly, the capital costs of maglev lines, by means of improvements in suspension technology, power distribution, and traction power. We suspect that practical application of such technologies is likely at least ten years away, given current levels of research funding.

Our point here is that maglev lines are likely to become substantially cheaper to construct over the next few years. If we are careful in how we design and build maglev lines, we should be able to upgrade them to newer technologies whose power savings alone will pay for their deployment.

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[3] LSM: Linear Synchronous Motor

9 Convenience

Maglev transportation is convenient, in the sense of being door-to-door and extremely rapid. Maglev guideways can be elevated, without reducing maximum trainset speed. Hence, construction of elevated guideways as a way to reach stations in crowded city centers need not seriously disrupt the city and its infrastructure, unlike airports and conventional high-speed rail. Elevated guideways would allow maglev trains to glide silently and smoothly into downtown stations, such as Union Station in Toronto, a feat that is not possible for aircraft, without impacting existing land uses in urban areas.

In terms of travel time, a UK Ultraspeed presentation claims that a trip between Glasgow and Edinburgh would take 14 minutes with maglev, *vs.* 43 minutes by conventional rail, and 75 minutes by car.[UKUb]

To get a feel for the speed of maglev transport, assume a first-generation maglev train running at 430km/h, much like the present Shanghai line. Such a train would reduce the time to get from downtown Montreal to downtown Toronto from about five hours to just over one hour, making it faster and far more convenient than short-haul aircraft, unable to serve the downtown core, and which take between 2-4 hours door to door. The same speed train, were a Trans-Canada maglev line constructed, could go from Toronto to Vancouver in somewhat more than ten hours, not including time for station stops along the way.

10 Pollution

The UK Ultraspeed Factbook claims that maglev will produce only 20% of the emissions of short-haul aircraft. If a maglev system were powered by non-fossil-fuel means, such as wind or solar, its emissions would drop to zero. Furthermore, unlike aircraft, maglev transportation does not contribute to pollution of the upper atmosphere.

The same document reports on studies conducted by the German federal government, showing that the maglev system, operating under a contemporary German electricity-generating mix, would produce 23g/seat-km of CO_2 at 300km/h and 33g at 400km/h, whereas an ICE would produce 30g at 300km/h. In comparison, an auto would produce 60g and a short-haul flight 190g.

Figure 3 shows the dramatic difference in CO_2 pollution created by a

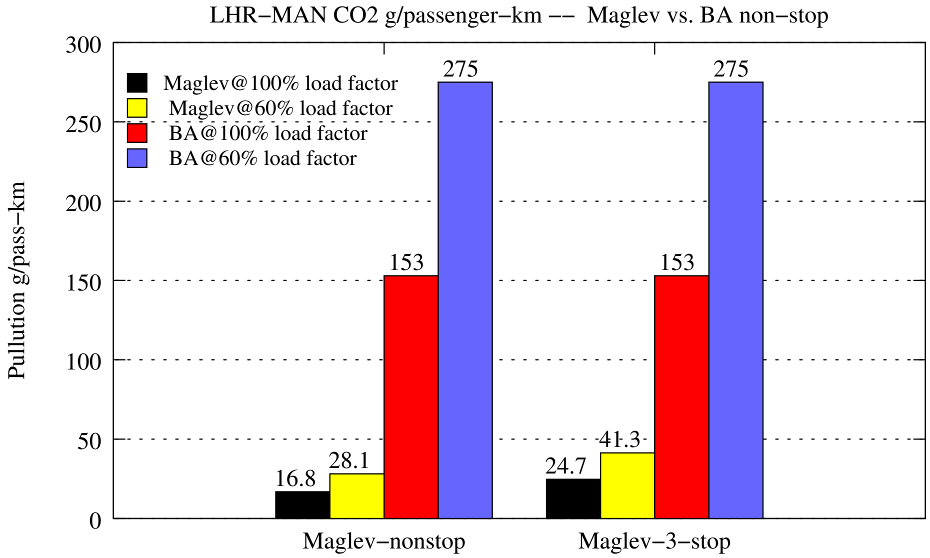

Figure 3: Pollution: Airliner versus maglev

British Airways aircraft operating non-stop between London Heathrow and Manchester and a maglev train on the same route, in both non-stop and 3-stop modes, under 60% and 100% load factors. Note that the aircraft creates between 6-10 times as much pollution as the maglev.

A study by HMG Transport Direct claims that the CO_2 pollution for a trip between Glasgow and Edinburgh would be 17.7kg/passenger for a large car, 5.18kg/passenger for a small car carrying two people, 4.10kg/passenger for conventional rail, and 1.99kg/passenger for a non-stop maglev trip.

All electric trains, both maglev and conventional, become "greener" as the electricity-generating mix that they run on becomes itself greener. This is not true for fossil-fuel-based trains, such as the fossil-fueled Acela and JetTrains. Maglev trains have an additional edge, in that they can use regenerative braking, and put the power generated from braking back into the electrical grid, reducing emissions even further.

11 Noise

Studies conducted by the German federal government show the maglev to be substantially quieter than conventional rail systems, even when the maglev

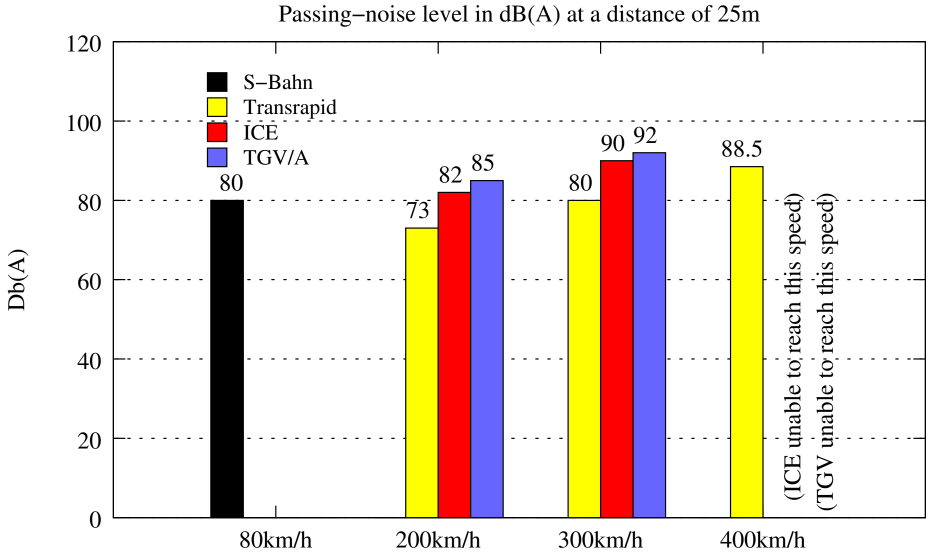

Figure 4: Passing-noise level in db(A) at 25m

system is operating at significantly higher speeds:

Figure 4 shows that one of today's maglev trains, operating at 400km/h, makes less noise than a ICE or TGV/A trainset operating at 300km/h, and only slightly more noise than an ICE or TGV/A operating at 200km/h. Moreover, an S-Bahn[4], operating at 80km/h, makes the same amount of noise as a maglev trainset operating at 300km/h – nearly four times as fast! A JetTrain at 200km/h would make twice as much noise as a maglev trainset.

A maglev line between Pearson Airport and downtown Toronto would resolve the complaints about the noise of a conventional rail line in that corridor, and would also serve as a very good pilot project for maglev trainsets in Canada.

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[4] Stadtschnellbahn: A class of German suburban and regional railways, similar to the GO Transit trains operating in the Toronto region, except electrified, so even quieter, and much less polluting, than GO trains.

12 Disadvantages

One claimed disadvantage of maglev is that it can not share right-of-way with conventional rail lines. This is only half true: Maglev2000 has a design that does allow sharing of the same trackage as conventional rail, albeit at lower maglev speeds (250km/h), but at low capital cost: "…a few million dollars per mile."[Maga]

Their design also permits mixed service, in the form of freight containers or truck trailers. Being able to haul freight, even if restricted to lighter loads than conventional rail lines or trucks, would help to amortize the construction cost of a maglev line, and would also reduce its operating costs.

Objections to maglev transport systems are likely to be raised by those who feel threatened by their advent. For example, operators of short-haul airlines, transport truck operators, and manufacturers of conventional high-speed trainsets may feel that their jobs are at stake. We must be cognizant of the fact that the health of the planet requires displacement of pollution-generating technologies with renewable ones, and take steps to assist those affected by technological change.

One potential problem is that of ice or snow on the guideway. We are not aware of any practical experience with such buildup, but it has to be dealt with, just as it must be done on roads, airport runways, and conventional train lines.

Recent increases in the cost of copper may impact the costs of building a line, but we do not claim competence to quantify such increases. New technologies, such as those proposed by Maglev2000 or LLNL, may avoid this problem by using aluminum or other, less expensive, conductors in their guideways. We have not examined this question in detail.

13 Cradle to Grave Cost

Some proponents of conventional high-speed rail systems tout the "low" costs of wheeled trainsets, ignoring the fact that even our current VIA trains are unable to operate at their rated speeds, due to the poor state of tracks, roadbeds, and signal systems. To make high-speed rail work requires complete rebuilding of tracks and signal systems, removal of level grade crossings, etc. We must examine all costs: land acquisition, line construction, trainset construction, stations, switches, yards, and ongoing maintenance for all of these, for the life of the line, before making any claims about the cost of a proposed system. Fuel costs and pollution abatement costs must be included, for global warming will not listen to lies.

We noted earlier that present-day construction costs for maglev lines are claimed to be about the same as for conventional high-speed lines. Trainset costs are probably similar, although maglev proponents claim that maglev's higher speed permits operation at identical service levels with a smaller fleet than that of conventional trains. Finally, as noted earlier, maintenance costs for maglev, because of the near-total elimination of moving parts, will be far lower than that of conventional trainsets. These substantially reduced costs give maglev a very clear financial edge, particularly at this time, when total system cost minimization is so important.

14 Economic Benefits

UK Ultraspeed claims that their lines will save 2 billion GBP/year, just in "value of time" figures for journey time savings. In these times of economic difficulty, the jobs provided by major construction projects, such as maglev lines connecting the large Canadian cities, should be apparent. Obviously, there are other benefits, such as faster delivery of perishable goods, greatly reduced pollution, and so on, but we did not investigate these in detail.

Although maglev trains do not, at present, have the same load-carrying capacities as rail, a ten-car maglev train can carry roughly 150 tons of freight, or roughly the same payload as a fully-loaded Boeing 747-400ERF. For high-value continential freight service, maglev could supplant much of the traffic currently carried by air, while dramatically reducing pollution and noise, with only slightly longer delivery times than by air. This modal change, of using maglev lines for freight and passenger use, would also greatly reduce the amortization period of the capital costs of those lines.

15 Conclusions

Maglev ground transport offers clear advantages over the conventional high-speed rail systems whose designs date from the 1950s: maglev offers extremely high-speed operation, dramatically reduced air pollution, much quieter operation, and significant energy use reduction, all of which are important from the standpoints of health, the environment, and the financial well-being of Canadians. These factors make it manifest that any new high-speed ground transport in Canada should be maglev-based.

The cost of an effective high-speed ground transport system is dominated by the costs of right-of-way and trackage, so it makes absolutely no sense to build conventional wheeled rail systems, when all the advantages of maglev are available at similar capital costs and reduced operating costs.

Canada was built on railroads; is it not time that Canada regains that former glory and, with it, a clean, healthy, and financially sound environment for our children and their children, by adopting high-speed maglev transportation?

One last word: if you want to know why maglev is the future, go ride the maglev line in Shanghai - they have already built the future.

References

[Bom] `http://bombardier.com/en/transportation/sustainability/technology/primove-catenary-free-operation\?docID=0901260d800486ab`.

[Bre09] Steve Brearton. Express delivery. `http://www.theglobeandmail.com/servlet/story/LAC.20090227.ROB3PG14/TPStory/\?query=maglev`, 2009.

[Ell] Ellisdon. `http://www.york.ca/Services/Transit/EllisDon+Corporation.htm\?ODA=1`.

[Maga] `http://www.maglev2000.com/apps/apps-09.html`.

[Magb] `http://www.maglev2000.com/today/today-02-a.html`.

[O'R] D. O'Reilly. Financing set for planned $1.6-billion ontario road. `http://enr.construction.com/news/transportation/archives/080509.asp`.

[RFP05] Toward more efficient transport: the inductrack maglev system. `gcep.stanford.edu/pdfs/ChEHeXOTnf3dHH5qjYRXMA/09_Post_10_11_trans.pdf`, 2005.

[Sch02] Jerry Schneider(?). Technology comparison: High speed ground transportation – transrapid superspeed maglev and bombardier jet-train, 2002.

[Tra] Transrapidcapability. `http://www.thyssenkrupp-transrapid.de`.

[Tra07] Transrapid shanghai maglev project update. `http://atg.ga.com/EMS/transportation/transrapid/reports.php`, 2007.

[UKUa] Factbook: Economic, policy & business case. `http://500kmh.com/pdfpublications.html`.

[UKUb] Presentation: from strategic business case to delivery. `http://500kmh.com/pdfpublications.html`.