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Infrastructure and the Economy: Future directions for Ontario

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1.0 Introduction

Economic history has shown that changes in infrastructure systems have often underlain phases of significant economic growth. Railroads in the 19th century, highway systems of the 1960s, and the internet infrastructure of the late 20th century are prime examples. More generally, changes in infrastructure are recognized to correspond with the 50 to 60 year technology cycles, as popularized by Schumpeter (Berry, 1991).

The innovation that gives rise to new infrastructure systems is often a response to severe stress. This has particularly been the case for innovation in urban infrastructure, where threats from fire, disease, pollution and congestion underlay developments of urban water, sewer and transportation infrastructure (Hall, 1998). In other cases, infrastructure was developed in response to military needs or matters of national defence at times of war. Changes in infrastructure are often driven by desperate circumstances.

For the early decades of the 21st century, it seems likely that changes in infrastructure will be driven by stresses related to energy supply (Tessaleno et al. 2008, Cuddihy et al. 2005). One concern is that extraction of oil from easily accessible reserves may have, or may soon, reach peak capacity, causing energy prices to escalate rapidly. Another issue is the apparent link between global climate change and emissions of greenhouse gases (GHGs), predominantly from the combustion of fossil fuels. As alternative forms of energy supply are sought, a potential outcome may well be a greater integration of energy systems. Energy supply systems for transportation, heating and electricity use are largely independent today, but may become more interrelated in the future, e.g., through the large scale adaptation of plug-in electric vehicles or heating by ground source heat pumps.

A further factor that may shape future infrastructure systems is the continued growth of an information economy, which has substantial emphasis on quality of life in cities as a prerequisite for attracting knowledge workers. This issue is inherently tied to the energy supply issues, since more efficient use of cleaner energy and better management of congestion contribute to making cities more liveable Addressing a wide range of environmental issues linked to energy supply is part of achieving the *quality of place* that is a key factor in attracting talented workers (Florida, 2000).

The objective of this paper is to assess the economic implications of potential changes to future infrastructure systems, through a case study of the Canadian province of Ontario. Three different futures for Ontario infrastructure are considered for the year 2021:

I) Current Plans:

Transportation continues to be primarily by automobiles and trucks fuelled by gasoline and diesel, likely with increasing prices. Electricity generation by coal is phased out, and replaced by natural gas, nuclear and renewable generating facilities, plus conservation.

II) Electricity Nexus:

Ontario substantially increases its nuclear power generating capacity, or other renewable sources. Ontario cities continue to develop with auto-dominated urban form, but emissions are eliminated by switching to plug-in hybrid electric vehicles.

III) Infrastructure for the Creative Age:

The focus is on creating infrastructure to achieve quality of place, to attract talented workers. Physical expansion of Ontario cities slows, but the connectivity of the cities increases through construction of a network of high-speed electric trains. New growth occurs through intensification in cities around transit corridors. Use of automobiles (plug-in electric) is balanced by growth in light-rail, streetcar and cycling networks. Activity nodes are greened and pedestrianized.

Following a review of Ontario's current economy in section 2, each of the three possible infrastructure futures is described in section 3. We calculate the energy and infrastructure requirements under each of the scenarios, for an Ontario population that is forecasted to grow from 12.9 million in 2008 to between 14.1 and 15.4 million people by 2021 (Statistics Canada, 2005, 2008). In section 4 we assess the economic implications of the three scenarios, in terms of five levels of economic impacts (Table 1).

2.0 The Ontario Economy and Infrastructure

The province of Ontario has the largest and most diverse economy in Canada. In 2007, Ontario had 6,593,800 jobs (Table 2). The manufacturing sector still employs 14.4% of the workforce, with automobile assembly, parts and related industries particularly prominent. Long term decline in manufacturing has been offset by the services-producing sector, which accounts for 76.5% of employment. The finance, insurance, real estate and leasing (FIRE) sector provides 7.2% of the jobs in Ontario, many of them in Toronto, which is Canada's financial capital. The diversity of the economy is strengthened through sectors such as agriculture in southern Ontario and natural resources, primarily mining and forestry in northern Ontario, which employ 96,100 and 34,800 respectively. Such diversity not only makes the economy more resilient, but fundamentally increases its potential for innovation. In 2007, the unemployment rate was 6.4% and the total gross domestic product of the province was $582.019 billion.

Ontario's trade is dominated by the auto sector, which accounted for $91.97 billion of exports in 2004. This is counterbalanced by $54.20 billion of imports in the same sector, leaving net exports of $37.77 billion (Table 3). The next highest sectors in terms of net exports are: wholesaling margins; professional and related services; FIRE; and the fruit and vegetable sector. It is also pertinent to subsequent discussion to note that Ontario's main net import sector is mineral fuels. The net import of oil, coal, and natural gas cost the province $17.86 billion in 2004.

The province's economy is supported by substantial transportation and energy infrastructure. Ontario has 16,525 kilometres of provincial highway, amongst a 72,350 km network of paved roads. The province's electricity generating capacity was 31,214 megawatts (MW), as of August 2007, comprised of hydroelectric (7,788 MW), nuclear (11,419 MW), coal (6,434 MW), gas/oil (5,103 MW), wind (395 MW) and biomass (75 MW) generating facilities (OPA, ElectrON). The delivery system consists of close to 300 transmission stations and 30,000 km of transmission circuits.

Recent investments in infrastructure have, however, been relatively modest. Ontario's expenditure account for 2007, including local government, shows just $8.83 billion of spending on transportation and communications, compared to $42.6 billion on health care, $33.9 billion on education, and $18.8 billion on social services (Table 4). Fifty years earlier, during a period of major infrastructure investment, spending on highways alone accounted for 25.5% of ordinary provincial expenditures and 38.4% of the capital account (Ontario Treasury Department, 1957). Last year's $8.83 billion spending on transportation and communications was just over 6% of total expenditures.

The province's accounts for 2007 also show that revenues from gasoline and motive fuel taxes ($3.083 billion) and motor vehicle licences ($1.114 billion) contributed approximately half of the $8.83 billion spent on transportation and communications (Table 4). The use of gasoline and other fuel taxes to maintain transportation infrastructure may need to be revisited under a changing energy paradigm. The UK, for example, has plans to introduce road tolling for its entire motorway network.

Ontario's total secondary energy use was 2778.5 petajoules (1 PJ = 10^{15} Joules) in 2005 (Table 5). The largest user of secondary energy was the industrial sector with 863.8 PJ, mainly in the form of natural gas and other fuels (such as heavy fuel oils, coal, coke, LPG and other gases). The transportation sector was a close second using 853.8 PJ, primarily from gasoline and diesel fuel oils. The residential and commercial sectors consumed 558.8 PJ and 454 PJ respectively, essentially for various forms of heating and electricity supply to buildings. Overall, the largest contributing source was natural gas (866 PJ) while, energy supplied by electricity and motor gasoline were of similar magnitude at 517.3 PJ and 555 PJ respectively.

Energy supplied by the combustion of fossil fuels accounted for 84.6% of the province's 201.6 tonnes of carbon dioxide equivalent (t eCO_2) GHG emissions in 2005 (Table 6). The contributions from electricity generation, natural gas and motor gasoline were relatively close at 17.6%, 21.2% and 19.2% respectively. Combustion of diesel fuels, largely by trucks, accounted for a further 10.3% of emissions. The GHG emissions, especially from electricity generation, are expected to decrease in the next decade under Ontario's Action Plan on Climate Change. In the long-run, i.e., by 2050, the province aims to reduce GHG emissions to 80% below 1990 levels.

3.0 Three Possible Futures

Scenario 1: Current Plans

In this first scenario, we consider Ontario in 2021 under current infrastructure plans. We include relatively new plans for the province's electricity infrastructure and transit in the Greater Toronto and Hamilton Area (GTHA), both of which should reduce reliance on fossil fuels. In considering the province's transportation in general, however, the scenario is essentially business as usual.

The Ontario Ministry of Finance projects that the province's population will be approximately 14,937,500 by 2021. Between 2001 and 2006, the population of Ontario increased on average, by 6.8%. The highest growth was observed in the Toronto economic region (11.25%) followed by the Kitchener-Waterloo-Barrie economic region (8.39%), while at the same time, the population of the Northeast and Northwest economic regions has decreased. Based on 2006 base populations for the Ontario economic regions, collected by Statistics Canada, the Ontario Ministry of Finance developed projections, per economic region, for 2011, 2016, 2021, 2026, and 2031 (Ontario Ministry of Finance, 2008). These projections almost follow the historical trends with the fastest growth projected to Toronto and the slowest to Windsor-Sarnia with a continuous decline in the populations of the Northeast and Northwest. Half of the Provinces projected population for 2021 will be living in the Toronto economic region (Figure 1).

The historical growth in the population of Ontario has also been associated with a growth in vehicle sales, vehicle kilometres travelled, and gasoline consumption. Since 1993, gasoline consumption increased at a slightly faster rate than population with a sharp increase between the years 2000 and 2003. Based on the Ontario net sales of gasoline for road transport, collected by Statistics Canada, gasoline consumption declined between 2004 and 2006. This decline coincided with the sharp increase in gasoline prices observed since 2003 (Figure 2).

Under this scenario, we consider the population projection conducted by the Ministry of Finance and project the gasoline consumption for road transport in 2021 using the population growth rate as a reference. Figure 3 presents high, medium and low projections for the evolution in gasoline consumption. We hypothesize that despite an expected increase in gasoline prices, gasoline consumption will continue to grow. At a minimum, it will grow at a rate of 3% every 5 years, and reach around 16.6 billion litres in 2021; this growth rate is almost half the projected growth rate in the population of Ontario. At a maximum, we expect gasoline consumption to increase at a rate of 10% every 5 years, similar to the growth observed between 2000 and 2003, and thus reaching a total around 20.3 billion litres in 2021. Under the medium (reference) projection, we assume a growth in gasoline consumption occurring at the same rate as population growth, around 6.5% every 5years, thus leading to a total around 18.4 billion litres in 2021. This would entail an increase in Ontario's gasoline GHG emissions from 38.7 Mt eCO_2 in 2005, to about 46.8 Mt eCO_2.

Under scenario 1, we include current infrastructure plans developed by Ontario provincial agencies for the forthcoming decades. In particular, the Ontario Power Authority's Integrated Power Systems Plan, and Metrolinx's Regional Transportation Plan for the GTHA, contain measures that aim to reduce the Province's use of fossil fuels. Both of these plans assist within Ontario's action plan to reduce GHG emissions to 15% below 1990 levels by 2020 – a target reduction of 27 Mt eCO_2 relative to 1990, or 99 Mt eCO_2 relative to projected trends.

The Integrated Power Systems Plan is a 20 year plan for power generation, transmission and conservation, which is expected to cost of the order $59.4 to $60.2 billion (in 2007 dollars). The plan entails several components. Energy conservation strategies aim to reduce demands by 4,950 MW by 2025. Renewable energy resources are to increase from 8,336 MW in 2008 to 16,164 MW by 2025. Coal-fired generation is to be phased out, with natural gas generation restricted to peaking, high value or high efficiency uses. To make up remaining base load, long-term nuclear capacity of 10,249 MW is planned for, requiring refurbishment of existing, ageing facilities and construction of new nuclear capacity of between 1,400 MW and 3,400 MW. With implementation, at an average cost of $3 billion per year, the plan is expected to reduce GHG emissions from the electricity sector from 33.1 Mt eCO2 to approximately 5.6 Mt eCO_2 by 2027. (i.e., the integrated power systems plan addresses 28% of the targeted 99 Mt eCO_2 reduction in GHG emissions for 2020).

The draft Regional Transportation Plan for the GTHA currently describes 56 projects to be implemented over the next 25 years (Metrolinx, 2008a). These include a range of express rail, regional rail, subway, light rail transit, bus rapid transit, and highway extensions, with estimated capital costs of the order $48 billion (not all of which is secured). If successful at encouraging modal shifts and reducing vehicular travel demands, the transportation plan is expected to reduce GHG emissions by about 1.6 Mt eCO_2. This is a small reduction in GHG emissions (only 1.6% of the 99 Mt eCO_2 target); the main justification for the GTHA transit plan is to overcome the large economic and social costs of congestion.

Scenario 2: Electricity Nexus

One of the greatest achievements of – and also one of the most overwhelming threats to –modern society is certainly the abandon with which we have been able to use energy. Whether for running innumerable electrical devices, cooking food, space warming (or cooling), or running cars, modern society uses a staggering amount of energy, entirely dwarfing any pre-industrial utilization. Moreover, since no source of energy is totally benign from an environmental perspective, the accumulations from this scale of activity are changing the atmosphere, excavating mountains, transforming the landscape, and, more recently, changing the way we think about ourselves and our world. One of the premises of this paper is that the magnitude and diversity of these energy challenges represents one of the largest threats – but also greatest opportunities – to Ontario. The key to appreciate these issues, and particularly the opportunities, is to understand a little more of the trade-off between the infrastructure associated with electricity and vehicular requirements.

At the focal point of these considerations is the potential of a new generation of cars. These new vehicles can supplement, or entirely replace, their use of liquid fuels (gasoline and diesel), with stored electrical energy, usually in the form of rechargeable batteries. Such plug-in hybrid and electrical vehicles currently constitute only a small percentage of sales, but many predict a significant increase in their market penetration over the next 10-15 years. The arguments backing up this prediction are in themselves compelling, but have broad implications that have not yet been fully appreciated.

The basic facts in favour of a shift from liquid fuel to electricity for transportation are these. First, the purchase price of energy in the form of electricity in jurisdictions like Ontario is usually less than gasoline. For example, if gasoline can be bought for about a dollar a litre, and a litre of gasoline has an energy equivalent of just less than 10 kWh, the same amount of electrical energy would cost about 60 to 70 cents. Of even greater significance is the efficiency of use: when gasoline is burned in an internal combustion engine, perhaps 15% of this energy (on average) is translated into motion; equivalent values for an electric motor, even allowing for some loss of energy during the process of electrical storage, are more commonly around 80-90%, with further increases expected. Thus, profoundly, a dollar investment of electricity into motion would move an equivalent car five to ten times farther with electricity than with gasoline.

Given the importance and novelty of this area, it is not surprising that considerable attention has been given in the literature to questions of moving vehicles by conventional internal combustion engines, versus using some portion of grid-based electrical supply. Bradley and Frank (2009) review the sustainability implications of plug-in hybrid electric vehicles, including a detailed tabulation of the measured performance of research as well as manufacturer vehicles. Focusing on Canada, Steenhof and McInnis (2008) conduct a scenario analysis to compare different vehicle technologies and the current status of electric vehicles and other alternative fuelled vehicles. Assuming a standard driving cycle, Campanari et al. (2008) summarize a well-to-wheel energy analysis of both battery electric vehicles and fuel cell electric vehicles.

Although it is based on a less technical study, a recent popular press article is used here to support some preliminary calculations. The selection of this particular benchmark is made since it represents exactly the conditions of the current study, with its focus on standard trips in the Toronto area. Moreover, and reassuringly, the numbers it reports are consistent with the more academic studies quoted above. Thus, significantly, in an article published in the Toronto Star (June 6th), Tyler Hamilton test-drove a 2004 Toyota Prius retrofitted with a lithium-ion battery pack to allow it to be plugged in. For city driving, the recorded fuel economy was better than two litres per 100 kilometres; over six days of usage, a total of only 22.5 kWh of electricity was used, typically valued at about $2-4, depending on the source.

As impressive as such calculations are, it would be unfair not to mention some of the challenges. Current storage batteries are expensive, heavy, take considerable energy to manufacture, and yet still have limited life. Certainly, with the intensive interest this topic is receiving, considerable gains can be expected in all these measures, but the technical challenges are considerable. Another (often forgotten) factor in this comparison is favouring the tax structure – gasoline taxes are much higher (often about 40%) than those electrical rates, with the traditional argument being that this is a logical way of offsetting the considerable cost of the public infrastructure in the way of road ways, interchanges, bridges and related infrastructure. If a considerable shift occurs away from liquid fuels, how will publicly held transportation routes be paid for in as fair a way?

Yet, in as much as there are and will be complications, it is likely that the proportion of the energy required for transportation that is supplied by the electrical system will steadily increase, and by 2021 will begin to be considerable.

A consensus for predictions might have plug-in-hybrids representing 10-20% of new sales by 2021. Certainly, if there are technical advances, the growth in market share might be faster.

Yet, here too, we need to be fair and adopt a more holistic view: if transportation energy decreases, along with the desirable consequences of a reduction in air pollution, GHG production, and other related benefits, a considerable extra energy load must then be carried by the electrical system. What is conservative for one system may be challenging to the other. If, for argument's sake, we assume optimistically that a full 25% of personal vehicle energy could be transferred by 2021 to the electrical grid. What would this mean for electrical infrastructure?

Let's assume a "middle-of-the-road" projection of gasoline usage for 2021 as 18 billion litres. What portion of this can be transferred to the grid? Certainly, estimates vary and many factors will influence the number chosen (see also Ros et al. 2009). If we provisionally assume that 25% or 4.5 billion litres of load is transferred to the grid, this would represent a total yearly demand of roughly 45 billion kWh, which translates into an additional electrical production requirement of 1,700 MW on an average basis, assuming (as is reasonable) about 4 times the effective efficiency from an electrical source. But allowing for line losses, and particularly peak load requirements, as the car might well be charged mostly at night, the installed shift might be for 5,000 MW of additional night time production capacity, at least half of which might well be obtained by load levelling of other generators (particularly nuclear and any remaining coal fired plants).

The estimated 2,500 MW of extra generating capacity that we would require might cost in the range of $5 to $7.5 billion, assuming a mix of nuclear and wind power. This calculation is based on capital costs for constructing nuclear and wind generating capacity of 2,907 $/kW and 1,938 $/kW from the OPA's Integrated Power Systems Plan. Spread over a ten year construction period, the capital costs would be between 0.5 and 0.75 $billion/year.

Clearly these numbers are not impossible. The increase in production would create further challenges in terms of grid improvements and investments, and in terms of generating capacity. The political leadership, technical and financial planning required to see this through would be, even to understate the obvious, truly impressive. It is interesting to note that for a US study Bradley and Frank (2009, pg. 124) also reported that "A number of studies have shown that the electrical power requirements of PHEVs can be met by the grid for even a very large infiltration of PHEVs." (PHEV = plug-in hybrid electric vehicle.)

However, the benefits of the shift are also enormously attractive. Electrical production has many opportunities for GHG mitigation, from clean production to various forms of secondary cycles, or carbon capture technologies. The reduction in air pollution within cities would be noticeable and at times dramatic.

Interesting though, at the moment, we are mired not in vision but in conventional thinking. The current OPA plan views conservation primarily in the context of saving electrical power, with replacement, maintenance and gradual reduction of the electrical system being the operative thinking. The collision course that can be expected is that if, as we suspect here, electrical vehicle energy use will increase significantly, thus dramatically shifting the role, requirement and challenges from petroleum, to improving and investing in the electrical system. However, if the overall goal is the noble one of reducing the overall impact of our energy-related activities – rather than a too narrow and traditional view that considers transportation and electricity as non-overlapping domains – it is time for Ontario to step forward and recognize the benefits available through a more comprehensive vision of infrastructure planning.

Scenario 3: Infrastructure for the Creative Age

The third scenario considers fundamental changes to the transportation and land-use planning of Ontario's expanding urban regions, by envisioning a possible future for the Greater Golden Horseshoe (GGH). The GGH is the economic heartland of the Province of Ontario, home to more than 70% of its population, and the portion of the province that is most adversely affected by congestion, pollution, urban sprawl and other transportation-related issues. Infrastructure investment in the GGH is essential, not only for the continuing development of the GGH, but for the economic and environmental health of the province as a whole. Good data on person travel within the GGH is also available from the Transportation Tomorrow Survey (TTS), which collects travel information for the entire region every 5 years. Thus, the GGH provides an excellent "case study" within which to explore issues in transportation infrastructure investment within the Province.

The trends towards growth in population, auto-ownership, and travel observed in the Province of Ontario are strongly manifested in the GTHA and the GGH. In the GTHA only, the total daily trips have increased by nearly 41 percent between 1986 and 2006. This increase has followed the growth in the GTHA population (nearly 47 percent between 1986 and 2006), which has occurred at a much faster rate than the growth in the rest of the Province. Tables 7(a) and (b) illustrate the distribution of daily trips between the City of Toronto, the rest of the GTHA, and the GGH (excluding the GTHA) in 2001 and 2006. These tables show that between 2001 and 2006, daily trips between the GTHA (excluding Toronto) and the rest of the GGH, have increased by 5 percent; however, more than 97 percent of these trips are conducted by car. Trips between Toronto and the rest of the GTHA benefit from a lower share of the auto mode (decreased from around 85% in 2001 to around 82% in 2006); this share is still, however, far from ideal.

Increasing gasoline prices and concerns over GHG emissions currently constitute major drivers for more sustainable transportation alternatives to replace single occupancy vehicle travel. While vehicle technology improvements and a higher market share of electric vehicles can partially reverse the current trends, the region is in dire need for investments in local and regional transit systems. The new draft Regional Transportation Plan (RTP) for the GTHA prepared by Metrolinx represents a bold vision for significantly improving transit service throughout the GTHA. This vision, however, needs to be extended to include the rest of the GGH, as well as to connect the GTHA/GGH with the rest of Ontario. The only environmentally sustainable form of transportation that can address this need is some form of (electrified) high-speed rail.

The concept of high-speed rail and its impact on the Province of Ontario has been debated for years. This issue has been revisited numerous times in the context of the Quebec-City / Windsor corridor, always seeming appealing yet in need of substantial public funding. While discussion of the financial feasibility of high-speed rail in the GGH is beyond the scope of this paper, we believe that it is hard to envision this region in 2021, without any “high-order” transit or “express service” linking the major regions. Such a system should also extend beyond the GGH, by linking it with the cities of London, Kingston, Buffalo (New York) and beyond.

A proposed vision for such a network is presented in Figure 4. Although obviously very preliminary and conceptual in nature, this figure illustrates potential corridors that could provide high-order, high-speed rail connectivity between major GGH centres, and between the GGH as a whole and the rest of Ontario, Canada and North America. A wide range of train technologies are available for this purpose, and average speeds can range from 130 km/h to more than 250 km/h while top speeds can exceed 400 km/h. At an average speed of 150 Km/h, the travel time between Waterloo and Toronto, with stops at Wellington-Guelph and Peel, is around 50 minutes; at an average speed of 200 km/h, the travel time is reduced to approximately 38 minutes. Clearly this estimate is largely approximate and does not take into account train acceleration and deceleration rates as well as top speeds achieved between stops. However, this illustrates the importance of high-speed to improve the connectivity between the GGH regions. For comparative purposes, the journey from Waterloo to Toronto is at least 1 hour 45 minutes by car during the morning peak period.

Such a high-speed rail system would replace and extend existing VIA Rail services, providing high frequency, reliable express connections throughout the GGH and beyond. It would be overlaid on and interfaced with local and regional transit services. In particular, each high-speed rail station would be a “mobility hub” with integrated connections with local transit (bus, light rail, bus rapid transit, etc.) and commuter rail systems that would provide local connectivity to trip origins and destinations throughout the region. Figure 4 also illustrates the need for direct connectivity between centres other than downtown Toronto, both to promote growth within and interaction among these other centres and to provide efficient, attractive service between these centres that will be competitive with direct auto travel.

Using 2006 TTS data, Figure 5 illustrates the flows on selected corridors based on Figure 4. While these trip flows might be expected to increase by around 20 percent by 2021, the selected corridors show that even currently, trip flows justify improvement of the current infrastructure. Indeed while the current share of VIA rail services in the region is far from ideal, the current ridership experience does not extrapolate well into the high-speed rail scenario envisioned. While it is beyond the scope of this paper to forecast the potential ridership should high-speed rail be implemented in Ontario; there is reason to believe that the availability of a fast and reliable train service with convenient schedules will attract an increased number of riders.

The cost of constructing a high-speed rail system for the GGH will only be roughly approximated at this point, based on studies from outside Ontario. Levinson et al (1997) reported costs (in 1994 US dollars) for segments of a high-speed-rail system in California to range from 6.2 million $/km to 29.5 million $/km; and costs for the French TGV to range from 2.05 million $/km to 5.06 million $/km. The higher costs occur in areas that are more urbanized or more mountainous. Using the Californian values, converting to 2008 Canadian dollars, assuming an exchange rate of 0.8 $US/$Can., we might expect the costs to vary between 7.3 million $/km and 35 million $/km. Figure 4 shows four potential rail segments in the GGH: Niagara Falls – Peterborough (265 km); Toronto – Orillia (130 km); Mississauga – Guelph - Waterloo (95 km); and Waterloo – Hamilton (70 km). To construct all 560 km would likely cost between $4 billion and $20 billion based on the above calculation. A tighter estimate would require further study including route location, costs of purchasing land, and estimation of numbers of stations, tunnels or bridges required. Moreover, the above estimate does not include the costs of local feeder transit systems that would be necessary.

Such a high-speed, express regional rail service can only succeed as a viable, major alternative to the private automobile for longer-distance travel within the GGH if it is supported by a comprehensive transit system that provides high frequency, reliable connectivity throughout the region, connecting population, employment and other activity centres to one another and to the high-speed rail stations. This means that not only must the Metrolinx “regional” network within the GTHA be implemented but also that “local” transit systems throughout the GGH must be expanded and improved. The vast majority of long-distance trips made within the GGH are from origins and destinations that are not within walking distance of potential high-speed rail stations. People must be able to get to and from the rail stations in a cost-effective, convenient manner if such a rail system is to be useful. Thus, a hierarchy of interconnected, mutually supporting transit services, from local to regional to “super-regional”, is essential if an alternative transportation <u>system</u> is to be built that will provide a viable, attractive alternative to the private automobile. A direct model of this is any major German city, in which a seamless hierarchy of S-bahn (commuter rail), U-bahn (subway), tram (LRT) and bus services provide integrated connectivity across spatial scales from local to regional. Figure 6 provides a very abstract schematic of such a hierarchical network, extended to a large region such as the GGH.

Transit planning is particularly strongly linked to land-use questions, for at least two reasons. First, conventional transit is only viable within certain types of land-use/urban forms. In particular, certain minimum levels of trip-end densities are required before fixed-route transit services can be operated cost-effectively (Pusharev and Zupan, 1977, 1980). Second, transit is often viewed as part of "the solution" with respect to urban sustainability, yet this is surely a hopeless proposition without a direct tie (behaviourally and with respect to policy) between transit and land-use. Thus, effective investment in transit infrastructure and operations can only occur if supportive land use policies are in place.

As the Province of Ontario's Places to Grow initiative recognizes, building new transit infrastructure alone is not sufficient to realize economic and environmental sustainability within the Province. Urban form within the GGH must be fundamentally changed to a more transit-supportive, less energy-intensive form. Implementation of the Greenbelt, which creates a physical boundary against an unlimited expansion of the GTHA, represents a major step forward in this regard, but much more must be done to create real mobility hubs throughout the region and to both densify and concentrate population, employment and other activities in a manner that facilitates and justifies viable transit services. This must be done in a way that respects personal housing preferences and market forces, but it is as essential as the actual building of new rail lines to the eventual success of these rail lines.

The discussion of changing urban form often focuses on increasing residential densities. While some residential densification is inevitable and desirable, especially in regional centres and around mobility hubs, what is far more critical is the concentration of employment and other activity centres as much as possible in locations that can be well served by both local and regional transit. Access by private (hopefully electric/hybrid) cars to higher-order transit will presumably always remain a major complement to local transit services in lower density neighbourhoods (that will always remain difficult to cost-effectively serve with high-quality transit), but access/egress to/from non-home destinations must be accomplished either by local transit or by walking. Both possibilities require concentrated activity centres to be viable. Thus, the truly significant change in our use of land that must be achieved is a renewed concentration of employment (particularly office-based and retail/services) within transit- and pedestrian-oriented activity centres.

Finally, returning to Figure 4, the economic competitiveness of the GGH and the Province of Ontario depends directly on its connectivity to its trading partners and markets in the rest of Canada and the United States. Air and auto travel are the dominant forms of personal transportation connecting GGH people and businesses with Ottawa, Montreal, Chicago, New York and beyond. Construction of a very high-speed rail system between the GGH and these centres creates the potential for the evolution of a trans-provincial, trans-national “mega-region” that could well revolutionize Ontario’s role within the continental and global economic system as well as urban form and quality of life within the GGH.

In summary, this scenario envisions a future in which a significantly expanded, hierarchical transit network throughout the GGH provides the basis for a sustainable, high quality of life, economically productive future for the central core of the province. The planning, design, construction and operation of this network – and the associated reconfigured urban form – would provide direct economic stimulus for the Province, along with export potential of expertise and technology. More important, it would significantly reduce the Province’s dependence on fossil fuels and generation of greenhouse gases, maintain or enhance the quality of life within the region, and directly support the continuing development of a productive, creative Provincial economic system.

4.0 Economic Implications of Future Infrastructure

If we accept the premise of this paper, that changes to infrastructure will result from stresses over future energy supply, then it seems likely that these changes will be large in scale. Of course, substantial new oil reserves might be discovered, and new evidence might change scientists’ understanding of climate change. Yet, even if both of these were to occur, there may still be impetus on economic grounds alone for some regions to cut back on consumption of fossil fuels. For regions that have no natural supplies of fossil fuels, the costs of importing can be large. We already saw that fossil fuels was Ontario’s largest net import sector costing $17.9 billion in 2004, and likely a lot more in the subsequent three years as crude oil prices rose. Some economists, notably Jacobs, have argued that import replacement is key to growing and sustaining economies. If fossil fuels can be replaced in ways that increase productivity, or grow higher value-added industries, then there are clearly economic benefits. But the costs of developing infrastructure to break the dependence just on oil alone are large. For Ontario, we estimated $5-7.5 billion under scenario 2 and $4-20 billion under scenario 3. These scenarios involve changes that are perhaps on par with major infrastructure revolutions that occur on the 50-60 year Kondratiev cycle. In this section we attempt to assess the potential economic implications of such infrastructure changes on the Ontario economy.

The first obvious effect of infrastructure spending is that it boosts the economy through creation of construction jobs, but there are limits to such an argument. The number of construction and vehicle manufacturing jobs created by the GTHA regional transportation plan, for example, average about 6,150 per year (Metrolinx, 2008b). The first limit though is that spending is constrained to a large extent by government budgets. The necessary annual expenditures estimated under scenarios 2 and 3 combined could approach $2 billion, equivalent to 1.4% of the consolidated expenditures for Ontario in 2007-08

(Table 4). The second limitation is that large scale public spending on infrastructure has the potential to crowd out or compete for resources for construction by the private sector. This point is only valid, however, during a thriving economy. Indeed, a good time to make massive investments in new infrastructure projects is during a recession. History shows that many great infrastructure developments were *make work* projects during times of depression. Many of the construction projects under Roosevelt's New Deal of the 1930s are good examples. Similarly during the last significant recession in Ontario, in the early 1990s, many road construction projects were instigated under the Canada Infrastructure Works Program.

The purpose of such spending is to stimulate the economy – and this is aided by multiplier effects, which we count as a second form of economic impact in Table 1. Multiplier effects include not only increased demand in the sectors producing construction materials, but also wider effects throughout the economy at large; for example, output will increase in the retail sector due to increased spending by construction workers. But of course, multiplier effects occur with any form of government spending, or for that matter private spending, in an economy. Moreover, multiplier effects are typically a short-term phenomena. Perhaps the more important question to ask is: What are the long-term economic impacts of large scale infrastructure investments?

The first potential long-term effect of infrastructure investment is increased productivity. Connections between infrastructure and the productivity of economies are well recognized. Transportation infrastructure impacts economic growth by increasing the size of markets. Transportation provides accessibility between consumers, producers, workers and suppliers, leading to increases in productivity, typically through economies of scale. Some researchers have established empirical models relating infrastructure to economic growth, although their explanatory power is limited (Aschauer, 1989; Ford and Poret 1996; Gillen, 1996). With many different types and scales of markets, different varieties of products and services, and various complementary and competing transportation modes, deciphering the economic impacts of transportation is complex (Batten and Karlsson, 1996). Nevertheless, there is at least some basic understanding of the structure of the causal relationships between infrastructure investment and economic development (Banister and Berechman 2000; Kennedy and Miller, 2001).

Scenarios 2 and 3 have potentially different impacts on Ontario's productivity, due to their fundamentally different approaches to handling traffic congestion. Metrolinx (2008b) estimate that the cost of congestion to the GTHA economy was $2.7 billion in 2006. This was comprised of increased costs of transportation for businesses, and adverse impacts on labour markets. The congestion costs for motorists – comprised of time costs, operating costs, accidents and vehicle emissions, was a further $3.3 billion. Scenario 2 does not address the costs of congestion to households and industry in Ontario, as it only changes the type of vehicle driven. Scenario 3 has the potential to increase the productivity of the

GGH region by decreasing highway congestion, and increasing the size of labour markets.

There is currently no way of estimating the increase in regional productivity that would result under scenario 3, although it would likely be substantial. A high-speed rail network uniting the cities of the GGH could dramatically increase the size of labour market catchment areas and potentially unlock inaccessible sites for development. This could lead to reorganization of production and distribution activities and stimulate inward investment. These are mechanism by which all types of transportation investments can improve economic performance (SACTRA, 1999), but the increases in market size envisaged under scenario 3 cannot be achieved with automobiles, because they are not as fast as high-speed rail. Moreover, with the lowering of transportation times under scenario 3, further benefits such as linking of universities, enlargement of technology clusters, and faster circulation of ideas may result (Bettencourt et al., 2007).

Beyond its impacts on productivity, infrastructure has a deeper, more fundamental role in shaping economies. The whole ecology of a regional economy – the amounts of consumption, the demand for imports, and the types and numbers of certain jobs – can be linked to long-term infrastructure developments. Through its association with land use and urban form, infrastructure fundamentally influences consumption within an economy. For example, construction of road infrastructure and changes in building practices enabled cities to physically grow at substantial rates over the 20th century, providing greater space for households. In the United States, the average single detached house more than doubled in size from 1950 to 2000; the living area per family member increased by a factor of three, as did the mass of construction materials used. Auto dependency, larger lots and larger houses with more space to fill, all fuelled consumption in the 20th century, thereby creating many jobs. Economic growth entails simultaneous increases in output, income and the net of savings and consumption. *Lock-in* to highly consumptive urban form was arguably as important as changes to production technology in driving 20th century economic growth (Gifford, 1996; Kennedy, 2008).

The relationships between infrastructure, consumption and economic growth are perhaps best perceived during periods of fundamental change. Three particular examples are described in *The Wealth of Cities* (Kennedy, 2008). Rebuilding of London after the Great Fire of 1666 dramatically increased the prosperity of the city. The underlying cause was the new building code that spurred new industries in material manufacturing and created multi-functional buildings in which commercial activities thrived. Second, the widening of London's roads in the early 19th century, and addition of new roads and bridges, allowed the omnibus to support suburbanization, thereby growing the transportation and home construction sectors of the economy. The subsequent introduction of subways and trams supported significant societal change, growing new sectors in retailing, entertainment and tourism. Third, in the early 20th century, New York City constructed a massive urban highway system inventing the archetypal urban form that exists in many western cities today. Such auto-dependent urban form grew jobs in vehicle production, vehicle maintenance, and home construction, as well as in a myriad of related industries from insurance to resource extraction to box-store retail.

If the Metrolinx regional transportation plan for the GTHA, or a vision for the GGH along the lines of scenario 3 come to fruition, then expansion or creation of new economic sectors may result. The transportation plans aim to achieve higher levels of connectivity and accessibility, with movement of people by safer, healthier and less tiring means. The effect should be some combination of increased market sizes, increased leisure time (due to shorter commuting times) and a fitter population – all of which could help generate new forms of consumption.

Scenario 3 is described as infrastructure for the creative age, because development of high quality urban transportation is understood to make cities better able to attract human capital. While providing families with spacious, comfortable suburban homes, the negative social aspects of the contemporary auto-dominated city are well documented (Newman and Kenworthy, 1999). Kennedy (2002), for example, quantified the economic costs, health impacts of local air pollution, and accident rates associated with automobile use in the Greater Toronto Area. Designing cities for walking, cycling, transit use and more balanced use of automobiles, improves quality of life in cities. Most urban scholars agree that quality-of-place is a key ingredient for increasing urban competitiveness (Porter, 1990; Begg, 1999; Florida 2000; Department of Transport, 2004).

Perhaps an equally important outcome of the transit-based scenario 3 is the potential for it to enable Ontarians to save more. From 1984 to 2004, household savings rates in Canada fell from 17% to 2.7% of personal income. The concern with this is that households are investing less, and will own a decreasing share of future wealth. Statistics Canada found that the households that are failing to save are those that are over consuming on transportation (Chawla and Wannell, 2005). Moreover, in a GTHA context, Miller et al (2004) have shown, as urban economic theory predicts, that it is households in suburban regions, poorly served by transit, that spend most on transportation. By providing suburban auto-dependent neighbourhoods with a cheaper, but high quality, transportation alternative, scenario 3 should enable Ontario households to increase their rates of saving.

While auto-dependent urban form may have been a significant driver of global economic growth, there are examples of successful cities that took very different directions in their development of infrastructure. From the early 1970s, Curitiba in Brazil developed a highly efficient bus rapid transit system, which along with other green urban planning initiatives attracted new industries to the city. Freiberg, Germany, pedestrianized its city centre, and built a substantial streetcar network along with bicycle highways. Rather than using its skilled labour to support an automobile based economy, Freiberg became a centre for the German solar power industry. Singapore, also sought to balance automobile use by imposing high registration fees and providing an extensive, high quality subway system. By not developing a highly consumptive urban form, Singapore has become the prime example of an *investing city*, with household savings rates well above those of western nations (Abeysinghe and Choy, 2004). These three examples show that there could be attractive alternatives to highly consumptive urban form – more in line with the ideals of the creative city.

Finally, it should be recognized that either of scenarios 2 or 3 could grow the Ontario economy as key initiatives in a regional strategy. If hybrid electric cars are going to replace gasoline vehicles, then are there first mover advantages to early adoption? The automobile industry is still very important for the Ontario economy. What are the implications of being first, or last, to start manufacturing electric vehicles? Similarly, scenario 3 is part of a still unfolding vision of infrastructure for a new creative age. What are the implications of the Greater Golden Horseshoe being a leading global region in this age?

5.0 Conclusions and Key Issues

We have presented two new visions for Ontario's future infrastructure, with comparison to current plans, which may be necessary responses to stresses over energy supply (Table 8). One is a future in which plug-in hybrid electric vehicles begin to displace the conventional automobiles fuelled by gasoline. The other considers development of regional network of high-speed electric trains, supported by local transit systems and fundamental shifts in land-use planning. The two infrastructure scenarios are by no means mutually exclusive; indeed a mix of both may well be required to reduce Ontario's dependence on fossil fuels.

The costs suggested for the two new infrastructure scenarios are rough approximations, missing essential details, and in need of more careful study. We have only estimated the order of magnitude of infrastructure investments that will be required to transition to a low carbon economy. Under current provincial plans to rejuvenate the electricity grid, phasing out coal, and to provide an extensive new transportation system for the GTHA, Ontario is expected to spend on average about $5 billion per year. This is approximately 3.5% of Ontario's current consolidated expenditures. To put the main infrastructure components in place for the two new scenarios presented here (i.e., more power generation capacity and high speed rail for the GGH) will likely require up to another $2 billion per year. This rough estimate does not include increases to transmission capacity, purchasing of land, or the local transit investments necessary to make high speed rail work.

A key observation from our study is that electricity has great potential as a future energy source for transportation. If generated from sources other than fossil fuels, then electricity provides a low polluting means of propelling transportation vehicles. Moreover, with advances in plug-in hybrid electric vehicle technology, there is potential to exploit the greater efficiency of electric motors over conventional internal combustion engines. In order for electric vehicles to replace fossil fuel vehicles, however, it is necessary to provide more power generation capacity. Electricity has to be provided in excess of current demands thereby enabling other energy sectors to shrink.

A future in which current levels of automobile use are simply replicated by electric vehicles is, however, undesirable on economic grounds. Current levels of automobile use in Ontario are excessive. Levels of congestion are so high, e.g., currently costing the GTHA economy $2.7 billion per year (Metrolinx), that the Province plans substantial new investment in public transportation systems. The economic effects of designing highly automobile dependent cities is decreasing productivity and worrying decreases in household savings rates due to over consumption.

A more desirable future for Ontario would see her urban regions linked by a high-speed rail network. If appropriately supported by new local transit systems, such as proposed by Metrolinx for the GTHA, then higher levels of connectivity and safer, healthier movement of people will create a new economy. This vision of infrastructure for the creative age needs fundamental changes in land-use planning, with concentration of people and employment around mobility hubs. If transformation of land-use can be achieved – and this remains a key challenge – then reconstruction of the creative city can be expected to attract high levels of private sector investment. A high-speed rail network knitting Ontario's cities together could revolutionize the Province's role within the continental and global economic systems.

The construction of high-speed rail and transformation to plug-in electric vehicles will go a long way to helping Ontario meet its short-term GHG reduction targets. If implemented by 2020, the two scenarios would reduce GHG emissions by about 10-15 Mt e CO_2. Assuming that this is done in addition to the OPA's current Integrated Systems Plan, and the GTHA regional transportation plan, then over 40% of Ontario's GHG reduction target for 2020 would be achieved.

In order for Ontario to meet its long-term GHG reduction target (80% below 1990 levels by 2050) it will need to take an even more integrated view of energy use in the province. Here we have focussed on connections between transportation and electricity, but the fuel which contributes most to emissions is natural gas. Green building strategies and underground energy storage systems have perhaps evolved to the point that the use of natural gas for heating buildings could be substantially reduced. But, here again an integrated approach should be taken: should the displaced natural gas be used to generate electricity, or perhaps the rooftops of the buildings themselves?

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Appendix – Tables and Figures

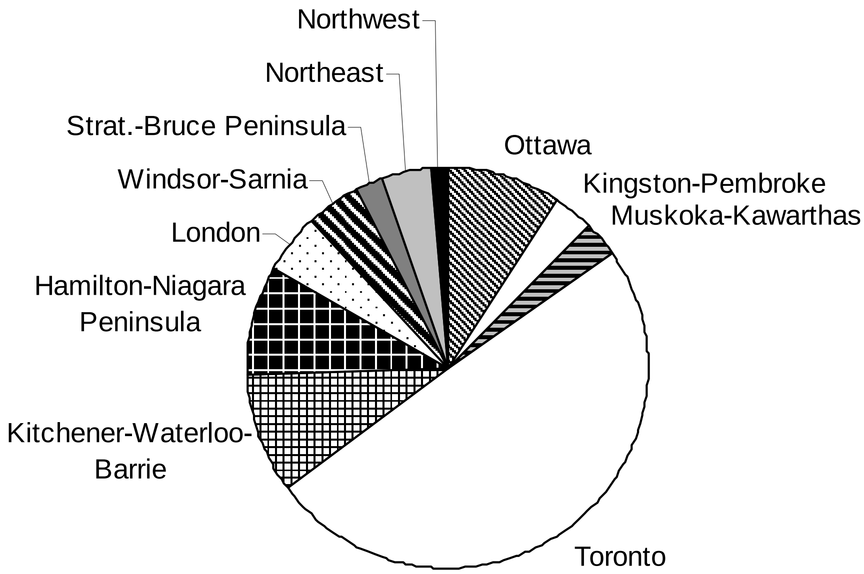

Figure 1. Distribution of 2021 Ontario population among its economic regions

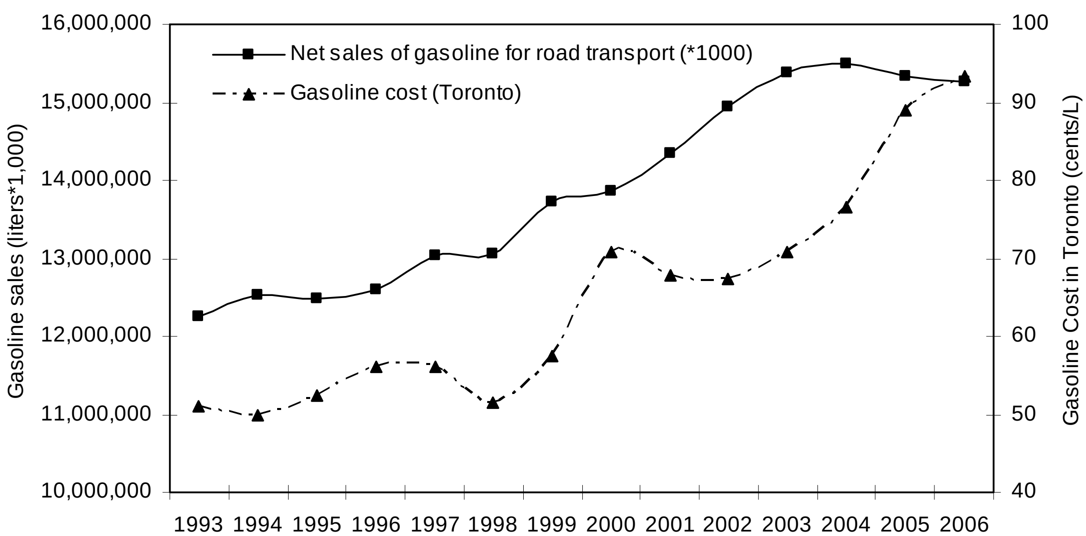

Figure 2. Net sales of gasoline in Ontario and gasoline price in Toronto between 1993 and 2006

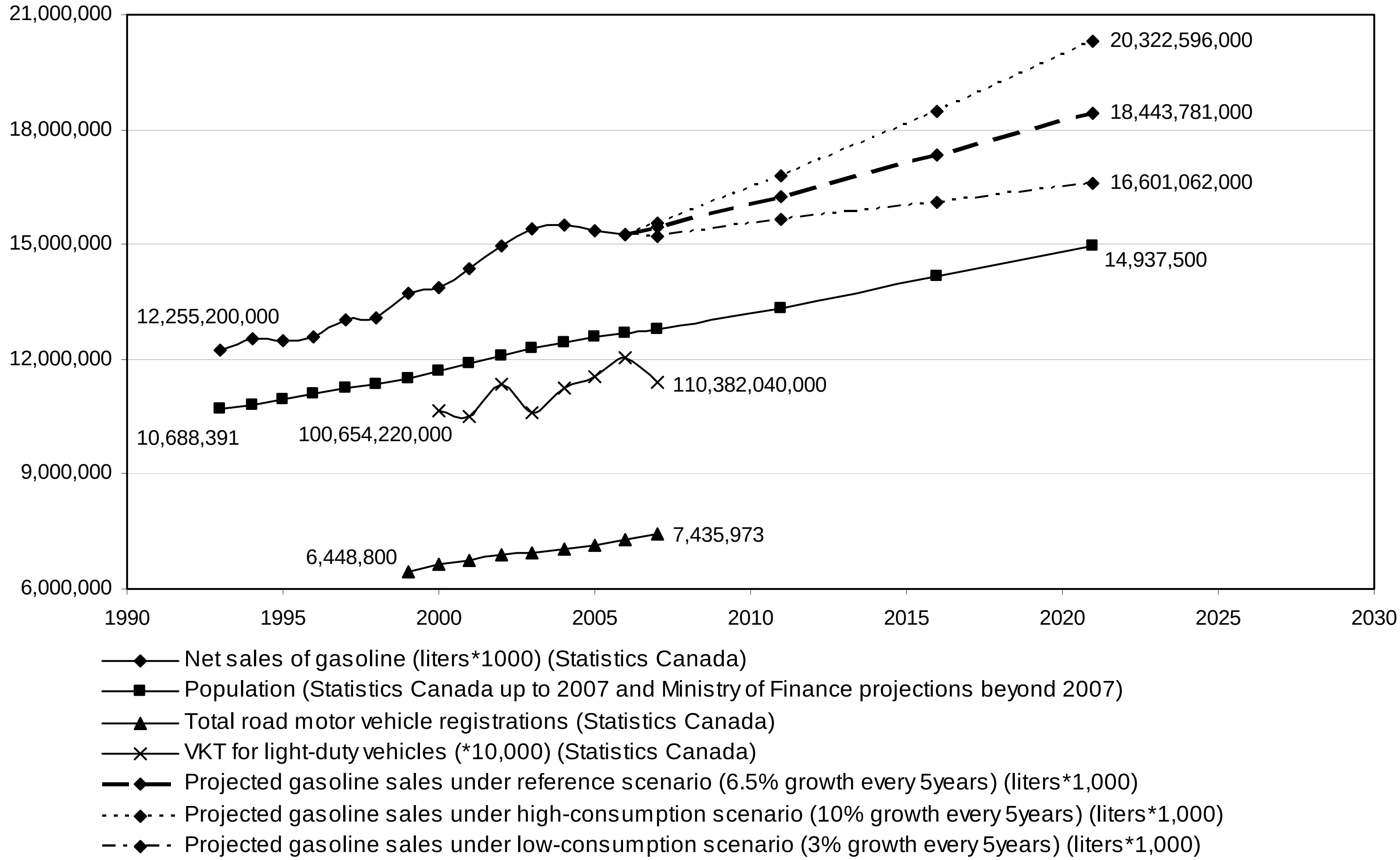

Figure 3 Projected gasoline consumption in 2021 and comparison with population projection (conducted by the Ministry of Finance) and historical trends in vehicle registrations and vehicle kilometres travelled

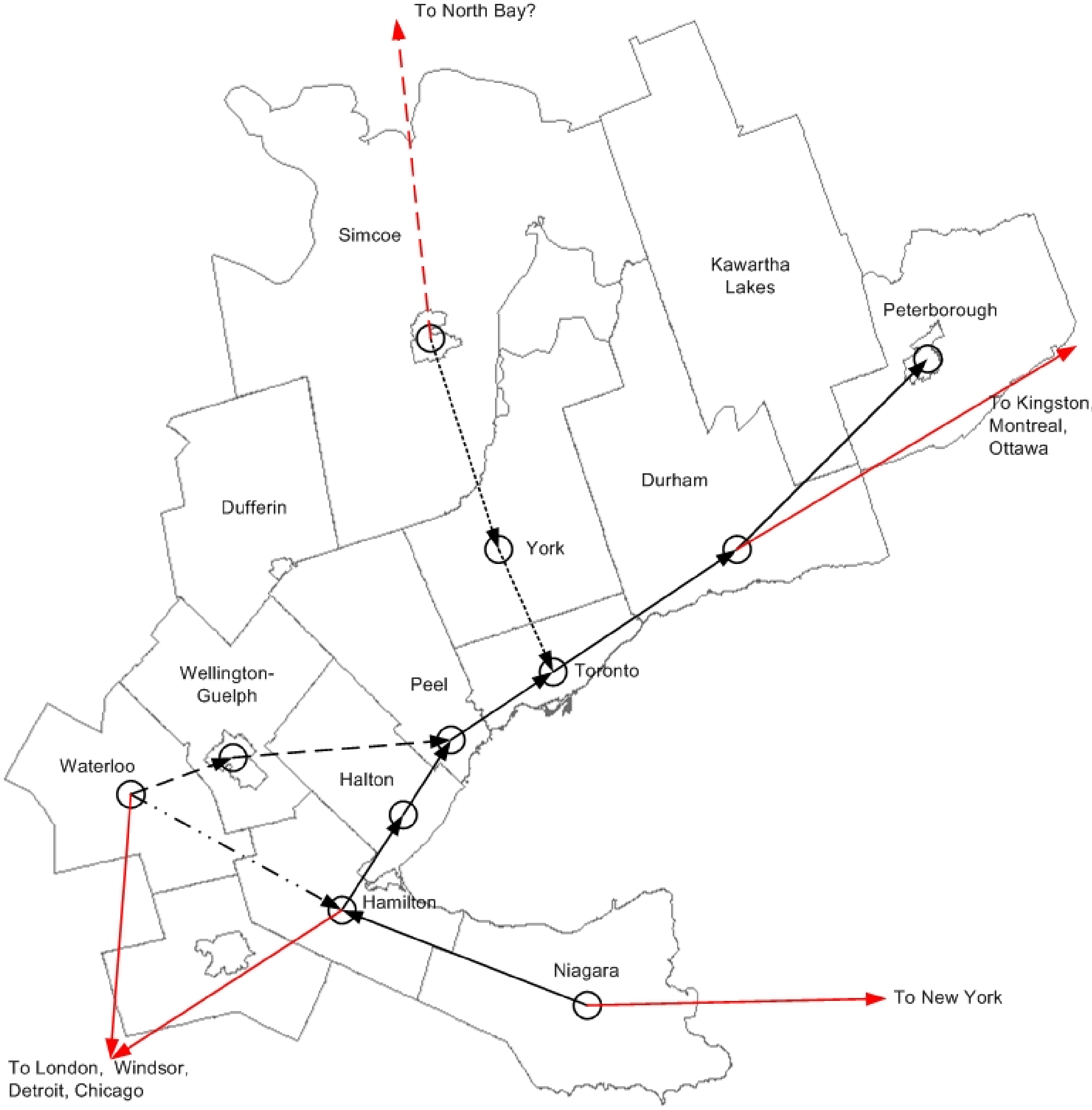

Figure 4. Envisioning a high-speed rail network in the GGH with extension outside

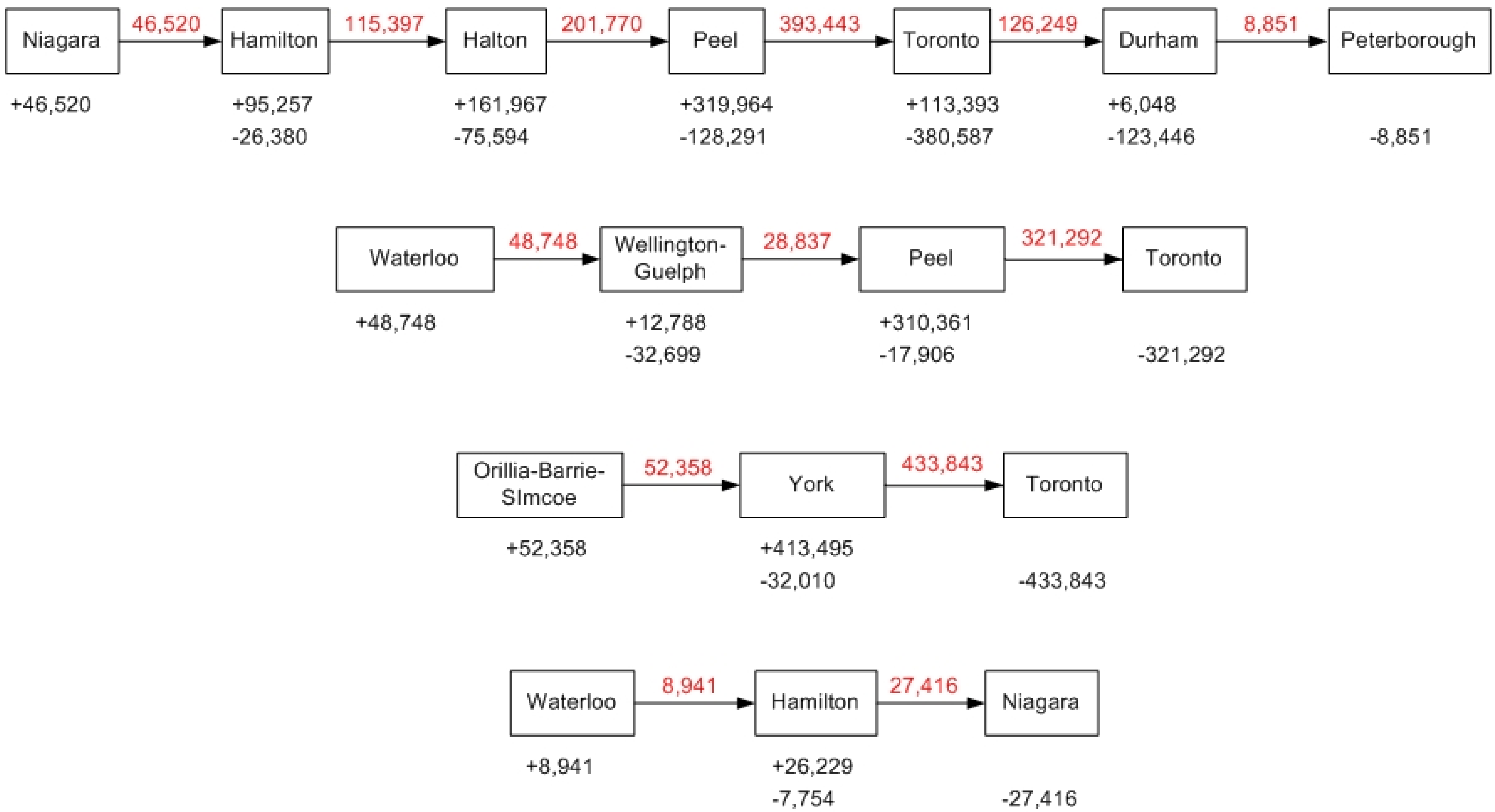

Figure 5. Daily trip flows on selected corridors in the GGH. The positive sign indicates that the trips are originating from the county; the negative sign indicates that the trips are destined to the county. The net trips are featured on top of the arrows. ***(Source, 2006 Transportation Tomorrow Survey)***

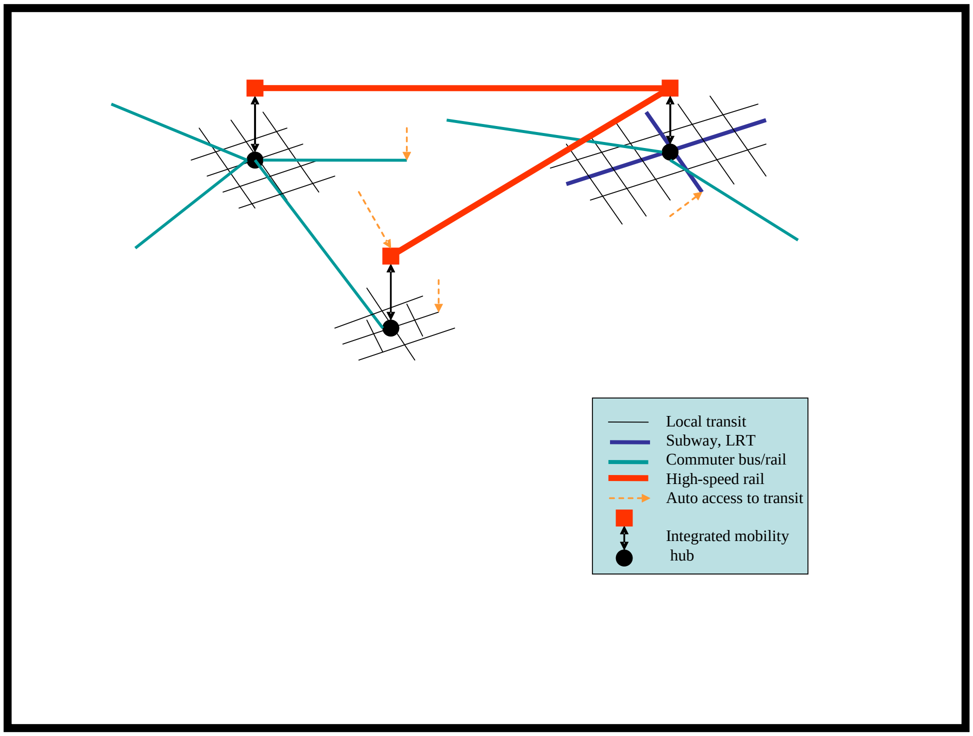

Figure 6. Hierarchical Transit System Schematic

1. Construction jobs
2. Multiplier effects
3. Changes to productivity
4. Changes in consumption and household savings
5. Quality of place; attraction of creative workers

Table 1. Hierarchy of economic impacts resulting from changes to infrastructure

Goods producing sector	**1,552,400**
Agriculture	96,100
Forestry, fishing, mining, oil and gas	34,800
Utilities	58,300
Construction	412,600
Manufacturing	950,600
Services-producing sector	**5,041,400**
Trade	1,027,200
Transportation and warehousing	304,100
Finance, insurance, real estate and leasing	474,400
Professional, scientific and technical services	477,800
Business, building and other support services	294,900
Educational services	466,100
Health care and social assistance	671,000
Information, culture and recreation	328,200
Accommodation and food services	399,700
Other services	267,100
Public administration	331,000
Total employed, all industries	**6,593,800**

Table 2. Ontario Employment as of Jan 1, 2007 (Source: Statistics Canada, CANSIM)

Sector	Net Exports ($ Billion)
Top Five	
Motor vehicles, other transportation equipment and parts	37.768
Wholesaling margins	12.960
Professional, scientific, technical, computer, administrative, support, and related services	8.021
Finance, insurance and real estate services	5.357
Fruits, vegetables and other food products and feeds	4.347
Bottom Five	
Miscellaneous manufactured products	- 4.140
Hosiery, clothing and accessories	- 4.444
Machinery	- 5.020
Electrical, electronic and communications products	- 6.670
Mineral fuels	- 17.856

Table 3. Ontario's Top and Bottom Five Economic Sectors by Net Exports, 2004 (Source: Authors' analysis based on Statistics Canada, CANSIM, international and inter-provincial trade data)

	$ Billion
Total revenue	**141.489**
Income taxes	39.504
Consumption taxes	24.576
Property and related taxes	24.489
Sales of goods and services	17.945
Transfers	18.355
Other	16.620
Total expenditures	**141.908**
Protection of persons and property	8.624
Transportation and communication	8.830
Health	42.591
Social services	18.781
Education	33.888
Other	29.194
Surplus	**-0. 419**

Table 4. Ontario's consolidated provincial and local government revenue and expenditures for 2007-08. Note: Data for the provincial government is as at March 31 and the local government data are at December 31. (Source: Statistics Canada, CANSIM, table 385-0001).

	Residential	Commercial / Institutional	Industrial	Transportation	Agriculture	Total
Electricity	164.3	189.2	154.3	1.4	8.1	**517.3**
Natural Gas	342.5	221.7	290.7	1.5	9.6	**866.0**
Motor Gasoline	0	0	0	542.2	12.8	**555.0**
Diesel Fuel Oils	0	0	33.3	236.3	11.1	**280.7**
Aviation Fuel	0	0	0	61.0	0	**61.0**
Other	52	43.1	385.5	11.4	6.5	**498.5**
Total	**558.8**	**454**	**863.8**	**853.8**	**48.1**	**2778.5**

Table 5. Ontario Secondary Energy Use (PJ) 2005 (Source: Natural Resources Canada, Office of Energy Efficiency. 2005. National energy use database query system)

	GHG Emissions Mt eCO_2	GHG Emissions %
Energy		
Electricity[1]	33.0	17.6
Natural Gas[2]	42.7	21.2
Motor Gasoline[2]	38.7	19.2
Diesel Fuel Oils[2]	20.8	10.3
Aviation Fuels[2]	4.2	2.1
Other[2]	28.7	14.2
Industrial Processes & Solvents[1]	14.0	6.9
Agriculture[1]	10.0	5.0
Waste[1]	7.1	3.5
Total	**201.6**	**100**

Table 6. Ontario Greenhouse Gas Emissions for 2005
(1: Environment Canada, 2007; 2: Natural Resource Canada, Office of Energy Efficiency)

		Toronto	*Rest of GTHA*	*Rest of GGH*
Toronto	**Total Trips**	**4,184,745**	**854,079**	**40,702**
	Auto drive and passenger	2,728,062 (65.19%)	729,210 (85.38%)	37,583 (92.34%)
	GO Rail	13,593 (0.32%)	36,548 (4.28%)	522 (1.28%)
Rest of GTHA	**Total Trips**	**857,537**	**5,448,672**	**138,749**
	Auto drive and passenger	730,469 (85.18%)	4,761,816 (87.39%)	135,677 (97.79%)
	GO Rail	38,014 (4.43%)	1,023 (0.02%)	38 (0.03%)
Rest of GGH	**Total Trips**	**39,688**	**135,740**	**2,309,859**
	Auto drive and passenger	36,571 (92.15%)	132,681 (97.75%)	2,041,993 (88.40%)
	GO Rail	510 (1.29%)	38 (0.03%)	0 (0.00%)

Source: Compiled from 2001 Transportation Tomorrow Survey Data (Data Management Group, University of Toronto)

Table 7(a). All-day trips conducted between Toronto, the GTHA, and the GGH (excluding Waterloo region) in 2001.

		Toronto	*Rest of GTHA*	*Rest of GGH*
Toronto	**Total Trips**	**4,222,138**	**895,399**	**36,251**
	Auto drive and passenger	2,690,944 (63.73%)	739,429 (82.58%)	32,194 (88.81%)
	GO Rail	14,326 (0.34%)	44,165 (4.93%)	773 (2.13%)
Rest of GTHA	**Total Trips**	**900,357**	**6,060,919**	**146,704**
	Auto drive and passenger	741,057 (82.31%)	5,262,568 (86.83%)	143,817 (98.03%)
	GO Rail	46,319 (5.14%)	983 (0.02%)	0 (0.00%)
Rest of GGH	**Total Trips**	**35,533**	**143,302**	**2,454,154**
	Auto drive and passenger	31,479 (88.59%)	140,341 (97.93%)	2,174,057 (88.59%)
	GO Rail	829 (2.33%)	19 (0.01%)	0 (0.00%)

Source: Compiled from 2006 Transportation Tomorrow Survey Data (Data Management Group, University of Toronto)

Table 7(b). All-day trips conducted between Toronto, the GTHA, and the GGH (excluding Waterloo region) in 2006.

Scenario	1		2	3
Description	OPA Integrated Power Systems Plan	Metrolinx draft regional transportation plan for GTHA	Provision of generating capacity to accommodate 25% plug-in hybrid vehicles by 2021	Development of a high speed rail network for the GGH (560 km)
Costs	\$59.4 - \$60.2 billion (over 20 years)	\$48 billion (over 25 years)	\$5 - \$7.5 billion (likely over 10 years); excludes changes to transmission infrastructure	\$4 - \$20 billion (over 10 to 20 years); excludes supporting local transit infrastructure.
GHG Savings	27.5 Mt e CO_2	1.6 Mt e CO_2	~ 12 Mt e CO_2	Not determined (but likely of same order as Metrolinx plan)
Economic Benefits	Rejuvenates ageing power supply infrastructure	Reduces congestion in the GTHA, providing productivity and human capital benefits; possibly creates new economic sectors; may enable household savings rate to recover.	Construction of infrastructure provides economic stimulus with multiplier effects. Adoption of new vehicles could be part of an economic strategy for Ontario's automobile industry.	Significantly expands size of GGH labour, housing and other markets, providing productivity benefits and likely attracting investment. Potentially the key infrastructure in a regional strategy for attracting human capital and increasing the size of innovation clusters.
Key Unknowns	Not covered in this study	Not covered in this study	Critical steps necessary to achieve market take-up of plug-in hybrids. Potential first move advantages to Ontario auto industry of early adoption of plug-in hybrids	Tighter cost estimate requires further study of route location. Ability to bring about necessary transformation in supporting land-use.

Table 8. Summary of findings: Future infrastructure scenarios for Ontario.

Author Bios

Dr. Christopher Kennedy is a Professor of Civil Engineering at the University of Toronto, where he teaches courses in Infrastructure Economics, Engineering Ecology and the Design of Sustainable Cities. He holds a qualification in Economics and an MBA, in addition to his Engineering degrees. Dr. Kennedy has published over 30 technical papers, and has co-authored two books, including contributions to: economics, urban transportation, green architecture, water resources, urban ecology, probability theory and engineering education. He has been a visiting professor at Oxford University and ETH Zurich. Chris has been an advisor on economic impacts of infrastructure investments to the Ontario Ministry of Finance, and a consultant to the Chief Economist of Infrastructure Canada.

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Working Paper Series

This working paper is part of the *Ontario in the Creative Age* series, a project we are conducting for the Ontario Government. The project was first announced in the 2008 Ontario Budget Speech, and its purpose is to understand the changing composition of Ontario's economy and workforce, examine historical changes and projected future trends affecting Ontario, and provide recommendations to the Province for ensuring that Ontario's economy and people remain globally competitive and prosperous.

The purpose of the working papers in this series is to engage selected issues related to our report: *Ontario in the Creative Age*. The series will involve a number of releases over the course of the coming months. Each paper has been reviewed for content and edited for clarity by Martin Prosperity Institute staff and affiliates. As working papers, they have not undergone rigorous academic peer review.

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