Achieving a Comprehensive and Integrated Energy System through Electricity

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Abstract— *A significant achievement of, and threat to, modern society is abandon with which energy is used for vehicles, electricity, and space heating/cooling. The very scale of these activities is changing the atmosphere, the landscape and even the way we think. Yet energy developments have traditionally been piecemeal within electrical, transportation and space heating/cooling sectors. With illustrations from Ontario, this paper seeks to integrate the electrical system in the context of transportation and heating/cooling demands, thus allowing electricity to facilitate a move to cleaner and greener sources. In this new context, the collective benefits of energy optimization, efficiency and storage become even more crucial.*

Index Terms — *Battery, Canada, Cooling, Electricity, Energy, Environment, Fuel, Heating, Infrastructure, Ontario, Policy, Provinces, Public, Storage, Society, Transportation, Vehicle, World.*

1. 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 [6]. Transmission lines already realized in some countries could be a great advantage in North America. In terms of energy transmission, there would be a great benefit, in parallel to any other improvements in energy production and storage, to building a high capacity transmission line that connects the various consumers and generators, and provincial grids as well. Such a system could exploit the time differences between provinces to spread peak energy across Canada, thus reducing the reliance of any one region on both peak energy and peak energy prices [35]. This paper considers infrastructure changes, their significance and, in particular, issues related to the electrical system. The comments are of necessity specific to a particular context and jurisdiction, although the underlying causes are common and thus the challenges more general. Thus, this paper focuses on Canada in general and Ontario in particular, and extensions to other contexts are largely left to the reader.

To state the situation starkly, Canadian provincial systems are relatively small, often largely independent, northern distribution systems with moderate north-source connectors but with weak east-west connections of US systems; there are only a few high capacity transmission lines. This can be one reason sometimes contributing to the instability of the provincial grids. For example, the 2003 blackout was imported from the US into Ontario through a north-south transmission line and propagated nearly province-wide through insufficient running reserves with Ontario.

Significantly, Canada once built railways and the St. Lawrence Seaway, understanding that there were ties of national importance that needed to be established. A next step, no doubt expensive but one that would provide crucial benefits and likely inevitable in the long run, would be to create a truly Canadian transmission system with strong interprovincial links.

For the early decades of the 21st century, it seems likely that changes in infrastructure will be driven by stresses related to energy supply [45], [11]. 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

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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. The electrical grid is already crucial, and will likely become even more so with such changes.

Transportation continues to be primarily by automobiles and trucks fuelled by gasoline and diesel, likely (despite the current correction) with increasing prices. Electricity generation by coal has been planned to be phased out locally, and replaced by natural gas, nuclear and renewable generating facilities, plus the contribution from conservation.

Ontario is expected to substantially increase its nuclear power generating capacity, as well as the role of renewable sources. Yet Ontario cities continue to develop with auto-dominated urban form. The influence on air quality with a switch to hybrid or plug-in electric vehicles would be profound.

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 [24].

2. Ontario Economy Overview

Ontario's trade is dominated by the auto sector, which accounted for almost $92 billion of exports in 2004. This is counterbalanced by $54 billion of imports in the same sector, leaving a net export of almost $38 billion (Table 1). The next highest sectors in terms of net exports are wholesaling margins; professional and related services; FIRE (finance, insurance, real estate); 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 almost $18 billion in 2004.

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 1. Ontario's Top and Bottom Five Economic Sectors by Net Exports, 2004 (analysis based on Statistics Canada, CANSIM[1], international and inter-provincial trade data [23]

The province's economy is supported by substantial transportation and energy infrastructure. Ontario has 16,525 kilometers of provincial highway, amongst a 72,350 km network of paved roads. The province's electricity generating capacity was just over 31,000 megawatts (MW), as of August 2007, comprising 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. The delivery system consists of close to 300 transmission stations and about 30,000 km of transmission circuits.

The province's accounts for 2007 also show that revenues from gasoline and motive fuel taxes ($3.083 billion) and motor vehicle licenses ($1.114 billion) contributed approximately half of the $8.83 billion spent on transportation and communications. 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.

Energy supplied by the combustion of fossil

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[2] CANSIM is Statistics Canada's key socioeconomic database. Updated daily, CANSIM provides fast and easy access to a large range of the latest statistics available in Canada. CANSIM brings the power of information directly to you. http://www.statcan.gc.ca/

fuels accounted for 84.6% of the province's 201.6 tonnes of carbon dioxide equivalent (t eCO_2) GHG emissions in 2005. The contributions from electricity generation, natural gas and motor gasoline were relatively similar 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. Ontario Electricity

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 environmentally, the accumulations from this scale of activity are changing the atmosphere, excavating mountains, transforming the landscape and 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, and indeed the world. 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 even broader implications that have not yet been fully appreciated.

The basic facts in favor 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 liter and a litter 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 15-20% 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 to convert electricity into motion would move an equivalent car five to ten times farther than with gasoline.

Considerable attention has been given to questions of moving vehicles by conventional internal combustion engines, versus using some portion of grid-based electrical supply. The sustainability implications of plug-in hybrid electric vehicles [8], energy analysis of both battery electric vehicles and fuel cell electric vehicles [9], and focusing on Canada [44] conduct an analysis to compare different vehicle technologies and the current status of electric vehicles and other alternative fuelled vehicles.

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 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 favoring the tax structure – gasoline taxes are locally 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 form of roadways, 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 be assumed 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" Ontario projection of gasoline usage for 2021 as 18 billion liters. What portion of this can be transferred to the grid? Certainly, estimates vary and many factors will influence the number chosen (see also [40]). If we provisionally assume that 25% or 4.5 billion liters 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 require about 5,000 MW additional nighttime production capacity, at least half of which might well be obtained by load leveling 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[2]'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, though large, are not overwhelming. The increase in production would create further challenges in terms of the grid improvements and investments already mentioned, 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 [8] also reported that "A number of studies have shown that the electrical power requirements of PHEV[3]s can be met by the grid for even a very large infiltration of PHEVs."

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, Ontario, like so many places, is somewhat 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, and indeed for many places, to step forward and recognize the benefits available through a more comprehensive vision of infrastructure planning.

4. Managing GENERATION

Since electrical capacity is crucial, it is interesting to note that there is a latent potential in an unexpected source, for it comes not from installing new capacity, but from a better utilization of existing capacity. The economy of

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[3] Ontario Power Authority.

[4] Plug-in hybrid electric vehicle

power plant design implies that units' maximum efficiency is at lower outputs then the so-called rated one, which is the maximum output as well. If the system were to be optimized to produce at the lowest price, the difference between the generating power and maximum (rated) power (some generators in addition could be 10% overloaded) of all units in operation will be an essentially free spinning reserve which will stabilize the system (market) and the production costs will not only be reduced, but will be less variable and the system as a whole will be protected from blackouts. The two most important goals achieved are: (i) free spinning reserve, and (ii) the best price of electricity (cheapest electricity production $/kWh) [32], [33], [34], [36]. Such an approach would help the whole economy to flourish. To achieve this goal the Ontario Power Authority, the Ontario Energy Board, Ontario Power Generation, the universities, investors, manufacturers and designers must act together to fully exploit and develop the generation mix, upgrade the transmission and distribution system and reaffirm Ontario's (Canada's) Kyoto commitment. The crippling effect of an undefined market and investment uncertainty must be clarified and solved, or erratic prices will continue and the effective control of the whole system could be forfeited.

A key issue in providing a reliable and affordable electricity system is that of the price of energy consumed and a reasonable variation in this cost. Yet, without explicit consideration of production and spinning reserves in power generation, we contend that stability will be difficult achieve, and any instability will create large economic and social consequences. Although the 2003 blackout was imported from the US, the provincial blackout occurred locally because Ontario had insufficient running power and weak connections with the provinces; thus, overall, the province had insufficient reserve capacity to stabilize the system after a sudden and unexpected loss of imported power.

The demand for power and generation is not uniform in time, and the variable nature in the requirements for energy and its production need to specifically be built into the system if stable and affordable power is to be produced. The minimal spinning reserve and stand-by reserve available must be equal to uncontrolled removal of the biggest generator or biggest power plant, or the power transmitted by an uncertain transmission line, whichever is greater. This operational principle is often called the "n-1" criterion within US energy planning; it is an approach based on the premise that no single event (such as the loss of a line or a generator or an electric plant) should lead to the cascading uncontrolled failure of a large portion of the system.

Storage and reversible pump-turbine storage plants are often an excellent solution for peak power generation, providing "spinning no load" reserve, stand-by reserve, and achieving a low price per unit produced (kWh) and per unit installed (kW capacity) [21], [35]. Droughts do not endanger supply as pumped-turbine storage electric plants do not suffer this limitation and thus overcome this shortage. Despite the long-term promise of other technologies, pumped storage systems remain the key economical way of storing large amounts of clean electricity. When combined with production from thermal pollutant and nuclear power plants, pumped storage plants can reduce contamination from power production by up to 50%, while at the same time minimizing power production costs (dollars per kWh). New variable speed hydraulic machines continually operates at its best efficiency and also greatly reduces vibrations, thus decreasing operating and maintenance cost by up to 50% or more if appropriately managed; total efficacy off the plant is increased up to 85%; in other words electrical energy pumped into the storage at off peak hours generates into the grid up to 85% as expensive peak energy.

Finally, the only generators which could deliver electric energy at the price below 5 cents per kWh are nuclear, hydro and coal fired power plants, but really only if combined with pumped-storage plants and high capacity long distance transition lines connecting provinces into a strong overall system. Variable speed pump-turbines are the best units to deliver spinning and speed no load reserve, optimize energy generation and minimize operating and maintenance cost of big nuclear and thermal generators.

3.3 Coal Fired Generation

Although authorities would not imperil the electricity supply by shutting down coal-fired plants before replacement capacity is available, depletion of fossil fuels will do that soon enough.

Until such time, a reasonable approach would be to upgrade the environmental emission controls by installing the appropriate air pollution control devices, and run these plants to the end of their life. At 36% thermal efficiency for these plants, conversion to natural gas would be uneconomical. The money would be better spent on hydroelectric, pumped storage, gas-fired "peakers" (i.e., plants specifically designed to meet peak load requirements) and transmission lines to connect the Ontario grid not only to the US but to neighboring provinces as well. At the same time, pumped storage plants reduce the maintenance costs of thermal plants.

3.4 Gas Fired Generation

With natural gas prices tripling over the past years, its use as a fuel for power generation has to be carefully scrutinized. Peakers may be attractive for dealing with daily load conditions, especially during the summer. They would only have to run for approximately 1000 to 2000 hours per year. Commercial combined cycle plants with no local steam market may be difficult to develop. It is unlikely developers would carry the fuel risk for such a project.

3.5 Hydroelectric

Surprisingly, hydroelectric power has significant untapped potential in Ontario (and in many other places). Yet if this potential is to be properly and fully realized, one of the most pressing requirements is again to establish a reasonable and stable economic climate that will effectively reward and encourage suitable energy investments. This problem is itself challenging, but is a prerequisite to all other development [46].

5.4 Nuclear, battery, hydrogen, hydro future

Advanced nuclear reactors ought to be capable of producing electricity for about 4 cents per kWh. The best operational model could be mixed use sending electricity to the grid during peak hour, charging electrical vehicles batteries, but at other times making hydrogen and pumping into storage. The proper mix of storage and pumped storage to electricity production would be market and cost dependent. Hydrogen might conceivably replace gasoline; hydroelectric and storage plant will be spinning reserve to cover peaks and protect system from blackouts. Advanced design, hydrogen as a fuel and storage cycles provide an economical, secure and safe energy future. The combination is an extraordinary green idea. Moreover a robust nuclear-hydro-battery-(hydrogen} structure can provide a framework for incorporating energy from wind, solar and other diffuse energy sources, which could become more important as their technology improves.

2.2 Renewable – Solar, Biomass and Wind

The greatest difficulty in implementing such systems in Southern Ontario was that we do not have enough sunny days. In remote areas in Northern Ontario, solar power has somewhat limited potential. Therefore, its impact has been negligible on the overall power generating capacity of Ontario.

Significant amounts of wood waste are available throughout Ontario, mostly from sawmills. A few of the larger sources have already been developed for power generation and are financially viable, provided the discarded wood is available at no cost. The biggest problem with wood waste plants is that plant capital costs become excessive below an output capacity of around 10 MW (due to economics of scale) and transporting wood waste for more than 150 km is usually too costly and becomes energy intensive in its own right. Having said this, there are several wood waste projects under consideration and this energy source can provide several hundred MW of relatively "green power."

Another good source of energy is biogas from sewage treatment plants and landfill sites. Biogas can be used to fuel reciprocating engines down to several hundred kW in size and are relatively simple and inexpensive to build, particularly since they are dealing with a waste and producing a useful product.

Wind power is probably the best-known renewable energy source under consideration. Although the technology to build windmills has evolved significantly, wind power plants are still relatively costly, though this cost has been decreasing. Also, since power is variable, win plants are not firm and must be backed up by conventional generation plants; they are often best viewed as a fuel saving opportunity for fossil fuel plants. Having said this, wind power is capable of providing over 1000 MW of electrical power here in Ontario, and it thus can play a role in achieving an overall solution. More importantly, wind's effectiveness increases greatly when used in conjunction with pumped storage, batteries, and hydrogen production; in this case, power can be produced whenever wind is available, and the energy consumed whenever the energy is required, and not simply when the wind blows. All investments should be balanced, or at least carefully re-evaluated, and the money saved put into basic and peak generators.

2.3 Small Power Plants

The biggest problem with small generators is that plant capital costs become excessive below an output capacity of around 10 MW due to economies of scale. There is considerable opportunity to develop new power plants, particularly of small to medium size, without significant environmental or economic problems. These are particularly attractive in sites where most of the other power production infrastructure is already in place. Yet it is probably unrealistically to think that small power plants can by themselves meet all of Ontario's energy challenges.

2.4 Deep Lake Water Cooling Project cools Toronto

Toronto has developed an alternative cooling system, which uses the cool energy in cold water (4^0C) to air condition high-rise buildings in downtown Toronto. This innovative system has great environmental benefits as it reduces energy consumption, and so reduces carbon dioxide emissions.

2.5 Geothermal

Geothermal systems are offering relief for many homes and businesses and could reduce total energy demand. A geothermal, heat pump is a mechanical appliance that transfers heat from one source to another pulling heat from the earth and transfer it to homes or buildings. Heat pumps can provide both heating and cooling using 30%-70% less electricity than conventional electric heating and cooling systems.

5. Public Policy

Perhaps nowhere in recent experience have engineering insights and public policy development interacted more strongly than in the intersection of energy, environmental and the economic issues. Take, for example, the seemingly straightforward question of what light bulb to choose and whether to replace inefficient refrigerator.

Significant attention related to environmental-energy policy has been focused on the question of which are better, fluorescent or incandescent light bulbs?

The question seems at first glance clear, yet the answer, which is critical to good policy, is not. Conventional wisdom suggests that fluorescent bulbs are preferred because they consume less energy in the form of "wasted" heat. Yet, in a cold Canadian home during winter, is the heat emitted by such a bulb really wasted?

If lights do indeed provide a kind of electrical subsidy to fossil fuel heating, than should the policy choice take into account the electrical and heating technology mix? And when does the symbolic power of a simple action get lost in the complexity of real world evaluation? These are not easy questions [12].

In a similar way, due to the balance of heating and cooling in a house, the replacement of old refrigerators in cold countries generates significantly less energy and cost savings than expected. Furthermore, the provincial electricity mix and the use of different energy sources to meet heating and cooling requirements lead to a smaller decrease in GHG emissions than expected, and in some provinces, actually increase GHG emissions.

As expected, detailed analysis shows that there is an overall household reduction in energy use for each province when replacing the old refrigerator by an efficient one; however, these energy savings are less than what we would expect when looking at the energy consumption of refrigerators alone. Actually, effective energy savings are only between 10 and 50% of expected energy savings based on consideration of refrigerators efficiency alone (see Figure 1). This is because of the increase of space heating energy requirements caused by the replacement of the refrigerator.

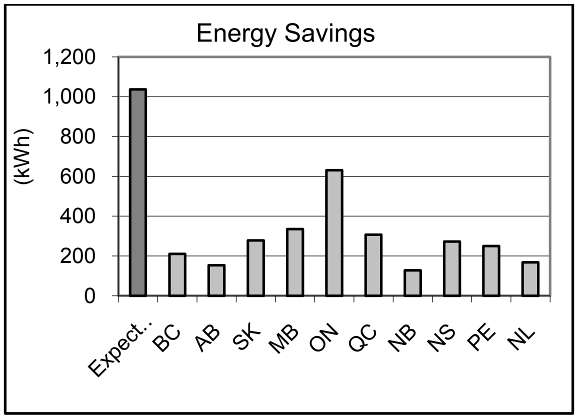

Figure 1: Energy savings expected and estimated in this study for Canadian provinces: British Columbia (BC), Alberta (AB), Saskatchewan (SK), Manitoba (MB), Ontario (ON), Quebec (QC), New Brunswick (NB), Nova Scotia (NS), Prince Edward Island (PE), and Newfoundland and Labrador (NL).

On the other hand, the replacement of an old refrigerator in provinces such as British Columbia, Manitoba, Quebec, and Newfoundland and Labrador causes an increase of GHG emissions. This striking consequence can be explained by the energy sources used to meet heating requirements and used for electricity generation. In these provinces, hydroelectricity produces little GHG. A part of the households are heated with electricity. For these households, the replacement of the old refrigerator doesn't have any consequence on GHG emissions. But other households are heated with oil or natural gas, which are GHG emitting technologies; in such households, the replacement of the refrigerator causes an increase of GHG emissions. The percentage change of GHG emissions is least for Newfoundland and Labrador where it represents an increase of 2% of residential GHG emissions in 2002 and greatest for British Columbia where it represents an increase of 5% of residential GHG emissions (see Figure 2)

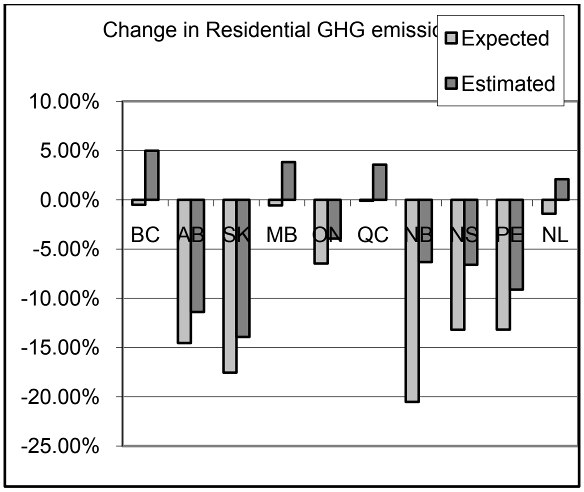

Figure 2. Changes expected and estimated in this study in residential GHG emissions in Canadian provinces

6. Conclusion

We have summarized a new vision for Ontario's future energy infrastructure, with comparison to current plans, which may be necessary responses to stresses over energy supply. Two investments – using plug-in hybrid electric vehicles to begin to displace the conventional automobiles fuelled by gasoline along with an improved electrical grid supplemented by strategic investments in electrical production – may well be required to reduce Ontario's dependence on fossil fuels.

Under current provincial plans to rejuvenate the electricity grid, phasing out coal, and to provide an extensive new transportation system for the GTHA[4], Ontario is expected to spend on average about $5 billion per year. To put the main infrastructure components in place for the new scenarios will likely require up to another $2 billion per year. This rough estimate does not include increases to transmission capacity or purchasing of land [25].

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

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[4] Greater Toronto and Hamilton Area

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 [26], [27], 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.

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.

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