Canada's Low Carbon Electricity Advantage:

The Case for an Inter-Regional Trade Strategy

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Abstract

The goals of energy security and substantial reduction of GHGs on a continent-wide scale are achievable through enhanced electricity trade utilizing Canada's low carbon electricity advantage pushing fossil fuels (primarily coal) out of the North American energy system. Immediate steps taken now would be required to deliver on such a lofty goal but the transition can be achieved over the next 30-50 years through development of the necessary infrastructure.

Major expansion of electricity trade between US and Canada, buttressed by interconnections and transmission links acting as "regional hubs" between provinces and neighboring states is part of the answer. Trade—as opposed to regulations and targets—is a powerful arbiter of mutual benefit and is a more promising pathway to a lower carbon energy future for North America.

Lined up against a vision of expanded electricity trade are a number of formidable forces. It is partly geography but also the weight of history and the political calculus of the day that tend to conspire against a trade strategy searching to realize the fullest potential of clean energy from Canada. The paradigm of 'province wide self-sufficiency' prevails in the public discourse. Support for expansion of electricity generation and transmission facilities as part of a deliberate "export driven" strategy is either limited or all too often met with derision or outright hostility.

In the long run, the strategy will be heavily influenced by a price on carbon in North America. Whether a "shadow" price on carbon emerges through regulations, an effective cap-and trade-regime or a tax, the economic rationale for specific investments will pivot on such a price that comprises a penalty on carbon emissions. Current abatement costs are low and the lack of a carbon price, combined with the view that low gas prices will prevail, remains a significant barrier.

In this paper, we argue for a dramatic shift in thinking for a coherent national energy strategy that has, at its fulcrum, large-scale cross border inter-regional trade in electricity. The national strategic opportunity is for energy trade to become fully integrated with climate change policies of both countries that is mutually beneficial.

Keywords:

Electricity trade, low-carbon economic growth, de-carbonization, low-carbon energy resources, energy system

Introduction

Is there an economic opportunity for Canada to promote trade in electricity based on its existing clean energy advantage? And if so, can electricity trade become a central force in helping decarbonize the North American energy system through large-scale expansion? And can this carbon mitigation strategy deliver a cost effective solution against other options on a scale large enough and timelines meaningful enough to make a difference to the threat of climate change?

It is well recognized that the transition from a fossil fuel-based energy system to a low-carbon energy system will be a slow process spanning decades. Resource availability and forecasts of scarcity or abundance of fossil fuels (coal, oil, and gas) at the right price is one factor. However, emerging constraints on carbon emissions—either through stringent regulations, a carbon tax or a cap-and-trade regime, will put an upward pressure on electricity prices in those jurisdictions where coal is dominant.

In the short term, low prices of natural gas will be driven by the US shale gas boom. In the medium to long term, electricity prices and profits will be determined by the rate of substitution of non-carbon generation and the advantage will shift to these resources because they will not attract a carbon penalty. The rate of change will undoubtedly vary across regions depending upon the existing supply mix, the stringency of environmental compliance requirements (i.e. GHG prices or abatement costs) and general economic conditions.

It is in this context that we investigate whether enhanced electricity trade between Canada-US offers a strategic environmental and economic advantage that would benefit the entire North American economy and accelerate the process of low-carbon development in a meaningful way.

The inter-connected electricity system between Canada and the US, with significant further enhancements, has the potential to become a powerful regional asset to allow a vast number of distant and dispersed generation sources (hydro, wind, nuclear, bioenergy, geothermal) to play an active part in an integrated market that is responsive to the challenge of decarbonizing the North American energy economy. With more than 17GW of new generation capacity under construction or at advanced planning stage and nearly 34GW being proposed, especially in major exporting provinces of Manitoba, Ontario, Quebec, Newfoundland and BC (Baker et al. 2011), Canada can almost begin to envision clean electricity trade as the primary vector for pushing coal out of the North American energy mix over a 50-70 year time frame.

A current problem is that the planning processes for electricity system expansion remains paralyzed within the context of a ‘provincial self-sufficiency argument and justification for capital investments in the grid are subject to the criteria of meeting ‘own’ needs, province by province. Trade and export of electricity as part of a deliberate strategy to address the climate change challenge is neither part of the discussion nor an explicit consideration in the planning processes or approvals. The consequence is that integration of regional markets is constrained by limits on inter-connections and the system is not geared to advance large-scale trade comparable in scale and scope of energy trade through pipelines.

Several recent studies Carr (2010), the Canadian Academy of Engineering (2010), the Pembina Institute (2009), and Bernard (2003) provide a comprehensive review of the state of inter-provincial trade in Canada. A compelling rationale exists for increased electricity trade from several perspectives that include short-term operational and long-term planning benefits, untapped international and interprovincial synergies and effective utilization of national renewable energy resource.

As noted by Carr, 'while trade cannot happen without appropriate transmission infrastructure, it must be concluded that any infrastructure deficit is the result rather than the cause, of limited trading potential' (Carr 2010) arising from policy constraints and lack of a coherent national framework. This echoes the view as argued by Blue (2009) that the 'federal government should empower the National Energy Board to regulate transmission access on provincial electricity systems including the authority to order a provincial utility to construct new facilities, for the purpose of creating a truly national electricity system and facilitating interprovincial and international electricity sale.'

Historical Context

The existing interconnection between Canada and the US has its roots in historical developments that are an artifact of geography and history. Ever since the Northeast Blackout of 1965, reliability has been the primary focus in the design, development, and operation of the interconnected grid.

The three principal electric networks in North America are the Eastern Interconnection, the Western Interconnection and the ERCOT Interconnection. The Hydro Quebec system is distinct from these three systems but is connected to Ontario, New York and New England by DC Interconnections. Each of these operates synchronously and each can be viewed as a single machine composed of many connected generators. The three interconnections are independent in that they are not synchronized with each other but they are linked through limited direct current (DC) ties. The Eastern and Western Interconnections are linked to the electrical grids in Canada and these two interconnects also have DC links with the Hydro Quebec grid. The Eastern Interconnection is the largest synchronous electric system in the world comprising more than 60% of the circuit length of the transmission lines.

The map below shows the North American Electric Reliability Corporation (NERC) Interconnections and its networks and regions. The entire system has some 211,000 miles (340,000 km) of high-voltage transmission line and serves 334 million people (North American Electric Reliability Corporation 2012).

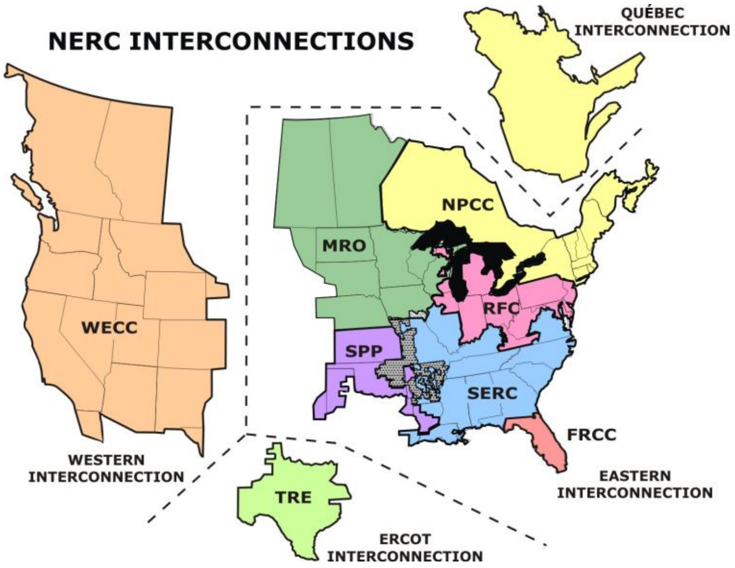


Figure 1: Networks and regions within the NERC Interconnections (North American Electric Reliability Corporation 2012)

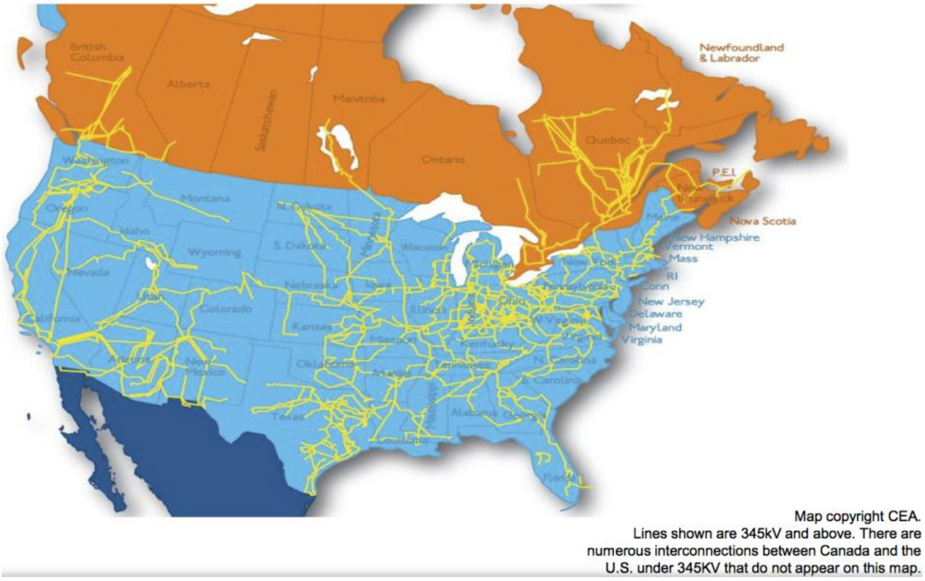
Power can flow from James Bay in Northern Quebec or from anywhere in Ontario as far south as the Florida or through any of the contiguous states such as Michigan, Ohio or Pennsylvania within the Eastern Interconnection.

The benefits delivered through the interconnections across a vast geography have been widely recognized in terms of provision of emergency support, reserve sharing, improved reliability and mitigation of supply risk. Over the past four decades, the system continued to deliver impressive results in its capability to withstand unanticipated disturbances of bulk power production in the network.

However, after the 2003 Blackout, the North American Reliability Council (NERC) was reformulated from what was effectively a voluntary organization to a self-funding quasi-government organization operating under delegated authority from the Federal Energy Regulatory Commission (FERC) ((Cooper 2011). This makeover turned NERC reliability standards from voluntary to mandatory and enforceable.

What Role for Electricity Trade?

Even though the historical roots of the North American grid are within the paradigm of reliability as the primary determinant, it is worthwhile to explore how this vast interconnected system of wires and generators over a large geography operating as a synchronous machine can also be used to lower energy costs and reduce greenhouse gas emissions on a continent wide scale. Figure 2 below shows the extensive nature of the high voltage electricity transmission system on the continental scale.



Map copyright CEA.
Lines shown are 345kV and above. There are numerous interconnections between Canada and the U.S. under 345KV that do not appear on this map.

Figure 2: Major US-Canada Transmission Interconnections (Canadian Electricity Association 2011)

This extensive network of existing assets and its potential to shape the broader policy and political discourse has not been explored fully. A strategy for significant expansion of electricity trade by tenfold to twenty fold or higher for example, would test this central premise and help identify limitations of the existing infrastructure and to answer practical questions such as:

- Is access to lower cost supply from distant resources feasible?
- Would trade reduce price volatility and how would it benefit consumers?
- Is it possible to exploit energy storage capabilities and peak shaving opportunities on a diurnal and seasonal basis and what would be the scale of such an opportunity?
- Is utilization of seasonal diversity between regions possible?
- Is the levelized cost of energy (LCOE) a reasonable indicator of the differentiator of the cost structure and value of generation options?
- Is cost effective carbon mitigation achievable through inter-regional trade?

Export Markets to Drive Regional Integration

Canada is the largest supplier to US of oil and Canada's exports to US (crude and natural gas) were at a level of $101.9 billion in 2011 (Office of the United States Trade Representative 2012). The current level of electricity trade, by the standards of overall energy trade, is at best anemic. According to the National Energy Board, the export volume of Canadian electricity to the US in 2011 amounted to 51.4TWh, valued at $2.04 billion dollars, whereas import volume reached 14.6TWh at $0.37 billion. Net exports sat at 36.8TWh that totaled $1.67 billion in revenue(Canadian Electricity Association 2011; National Energy Board 2013).

Given electricity is a high value energy product and the potential for clean energy exports from Canada is vast, why are electricity exports not higher?

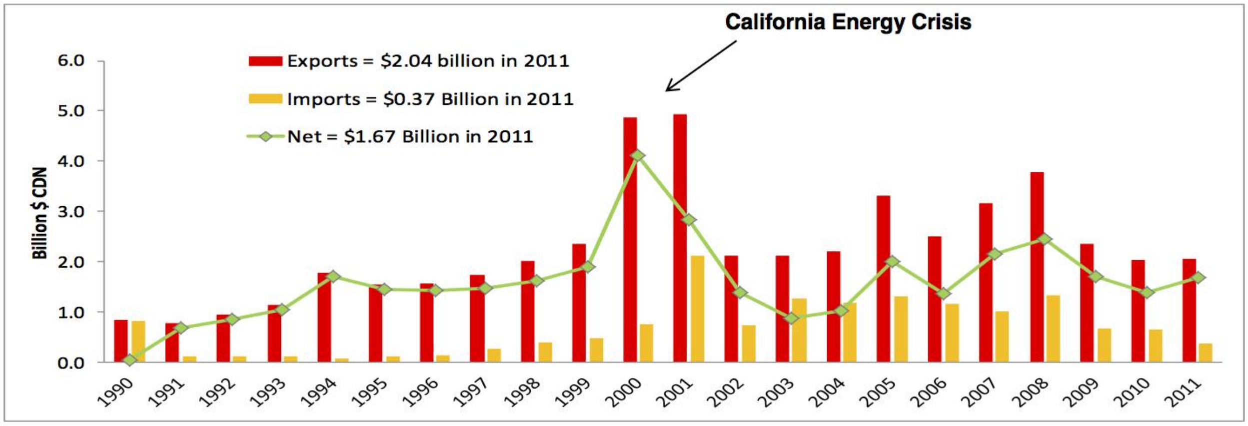


Figure 3: US-Canada Electricity Trade Revenue, 1990-2011 (Canadian Electricity Association 2011)

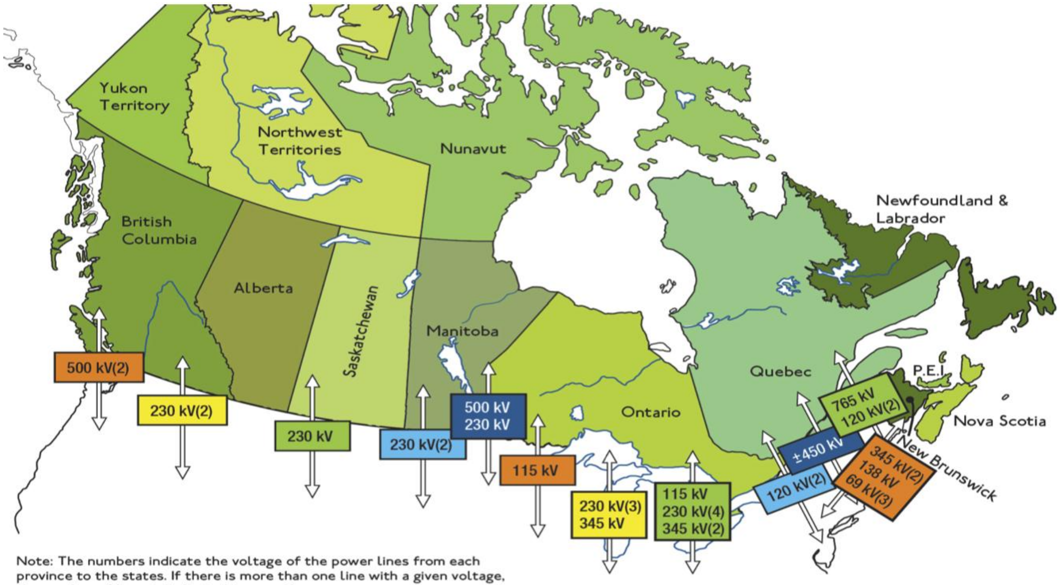
Most of the Canada-US electricity trade occurs via interconnections between the provinces of British Columbia, Manitoba, Ontario, Quebec and New Brunswick and neighboring US states. The existing flow of power from Canadian hydro sites goes to a limited number of US states. Historically, much of the trade was tied up under long-term fixed rate contracts (i.e. Quebec into New England states) and the ability to take advantage of peak markets was limited.

With the opening of the markets, sales of electricity currently are through the interaction of power markets (Ontario with New York, Midwest ISO, Manitoba with MISO as well, Quebec with New York, Ontario, New England e). The creation of open markets in Ontario and in the Northeast US has resulted in significant changes in how these transactions take place. Alberta, Nova Scotia, and Newfoundland and Labrador currently do not have direct access to US markets but could rely on interprovincial transmission lines for indirect access although developments currently underway will change the situation.

We observe that, while the direction of the market structure to enable electricity trade is evolving in a positive direction, not sufficient attention has been given to the development of the necessary infrastructure to foster trade on a very large scale to make a difference with respect to impacts on a climate change strategy.

Figure 4: US-Canada Electricity Trade by Province, 2011 (GWh) (Canadian Electricity Association 2011; National Energy Board 2013)

The following figures show the major transmission arteries between the two countries. Note that the large majority of Quebec exports go to Vermont and New England. Access to the Great Lakes region is limited for Quebec except through Ontario. Similarly 90% of Manitoba exports go to a single market—Minnesota, which makes them a captive provider.



Note: The numbers indicate the voltage of the power lines from each province to the states. If there is more than one line with a given voltage, the number of lines is indicated in parentheses.
Source: NEB, Canadian Electricity Association and Natural Resources Canada.

Figure 5: Major US-Canada Transmission Interconnections (Canadian Electricity Association 2011)

If a deliberate strategy for increased international and interprovincial exports of clean electricity were to be adopted by Provincial, States and the Federal Governments, then there would be good potential for reducing carbon emissions in the North American context through inter-regional trade[3].

The economic case would rest on the development of cleaner (non-carbon emitting generation resources) in Canada and the United States but realization of benefits would occur through trade on a continent-wide scale made possible by the transmission network. Such an approach – as distinct from arduous negotiations about regulations, or carbon taxes or emission targets – would also introduce more flexibility and ensure reliability of the system. For cost-effective investments, either in generation or transmission assets, a price on carbon would be necessary for optimal decisions.

Canada’s Clean Energy: A Strategic Environmental Advantage

As the threat of anthropogenic climate change increasingly becomes a concern for policy makers, the need for economy-wide de-carbonization becomes urgent. In this case, clean energy (in the form of electricity from low-carbon energy sources) trade between Canada and the US offers a strategic environmental advantage from a North American perspective.

The first clue to Canada’s clean electricity advantage arises from existing installed capacity of the generation supply mix and the low level of greenhouse gas emissions from the generation output.

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[3] We note that in the US, the best wind resources tend to be in States far from large markets, so expanded inter-regional trade is also beneficial within the US national context but it does require a clear regulatory framework to foster investments in transmission that takes into account regional wide benefits...

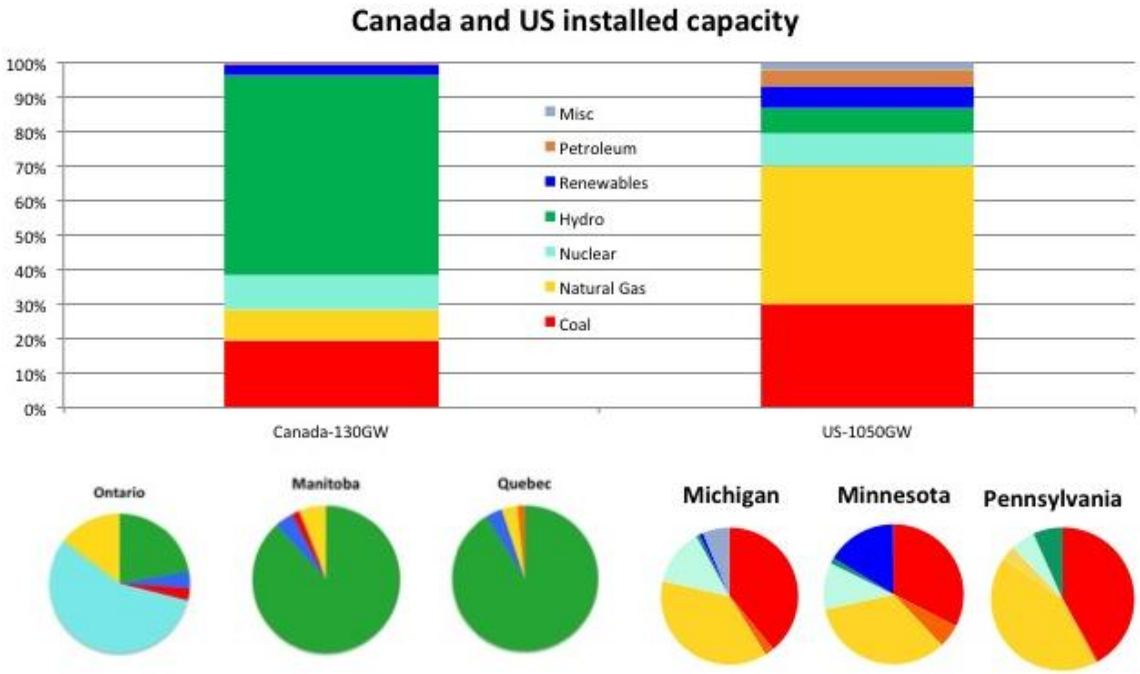

Figure 6: 2011 installed generation capacity in Canada and the US. (Center for Energy 2012; Independent Electricity System Operator 2012b; US Energy Information Administration 2012b)

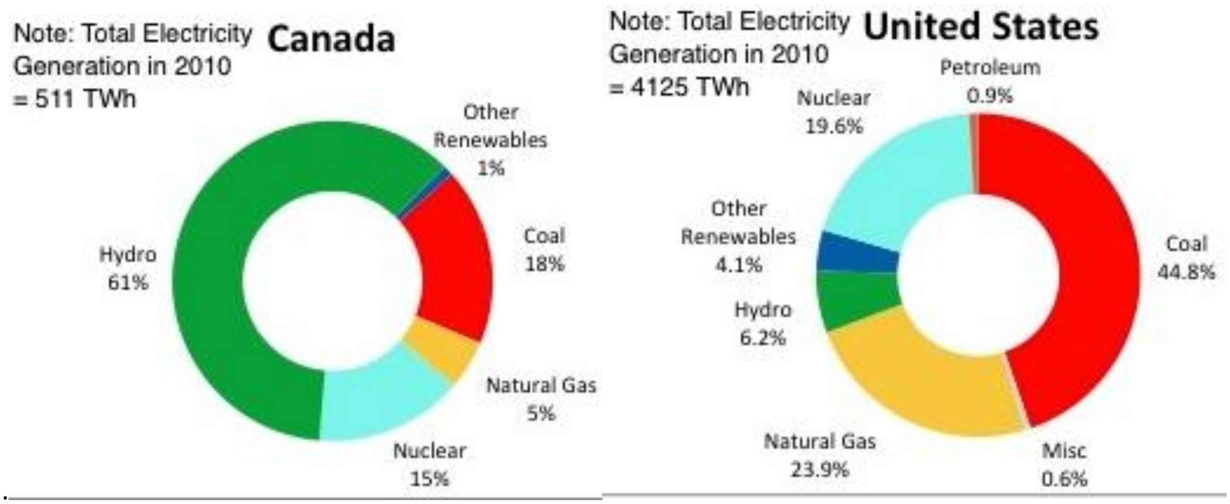

Figure 7: Electricity Generation in the US and Canada by Fuel Type, 2010 (Canadian Electricity Association 2011)

There are significant differences in the mix of generation supplies between the US and Canada. The figure above illustrates the contrast between fuel mixes in Canada and the US. Whereas Canada has over 75% clean non-carbon energy (nuclear, wind and hydro) in the mix, the US has only a little over 25%. Coal fire plants account for 18% of electricity generation in Canada compared to 44.8% in the US—a 14.8% increase from its 2009 level (Canadian Electricity Association 2011) and Ontario is on track to becoming coal-free by 2014. Canada's electricity generation contributed 14.2% of the country's total GHG emissions in contrast to the US electric power sector, which accounts for 33.1% of that country's total GHG emissions.

The abundance of clean energy resources puts Canada in a strong position to expand its low-carbon generation export portfolio. Canada releases 0.122 Mt of CO_2 per TWh[4] of electricity generation compared to 0.58 Mt of CO_2 per TWh of electricity in the US (approximately 5 times higher). Of these resources, hydro, wind and nuclear power are already established forms of electricity generation in many regions of Canada, and given the large natural resource endowment, much broader regional development in the coming decades, especially hydropower, would provide the economic impetus for a robust trade based on price differentials against carbon sources, if GHG emissions were appropriately priced.

Canada ranks second globally in hydropower production and third in installed capacity. Hydropower provides 60% of the country's electricity, with an installed capacity of 70,858 megawatts. Canada's hydropower maximum technical potential is 7.44 EJ and the economic potential is estimated at 1.93EJ (International Institute for Applied Systems Analysis 2012).

Investments of nearly $50 billion (Tal and Shenfeld 2011) in large hydro projects are under active consideration and the potential installed capacity projections to 2025 from these large power projects in Canada is 15,000 MW (Goodman 2010). Projects include:

- Site C project on the Peace River in British Columbia;
- The Conawapa generating station on the lower Nelson River; and
- Gull Island (I/S post 2020) and Muskrat Falls (I/S 2017) on the Lower Churchill in Labrador;
- Eastmain A, Sarcelle, Romaine, Petit Mecatina in Quebec

These new projects would still only tap a small proportion of Canada's unused hydro potential estimated at 163,000 MW (Canadian Hydropower Association 2008). While the top producing provinces are Quebec, British Columbia, Manitoba, Ontario and Newfoundland and Labrador, hydropower is easily accessible to nearly all regions in Canada

The Canadian energy advantage is dependent on existing transmission interties that link hydro plants with US markets and large-scale trade is contingent on future expansion of the transmission capacity.

Province	Project	MW	Possible In-service Date
Newfoundland and Labrador	Muskrat Falls	824	2017+
	Gull Island	2250	2020+
Quebec	Eastmain A & Sacrelle	918	2012
	Romaine	1500	2015+
	Petit Mecatina	1500	2020+
Manitoba	Wuskwatim	200	2011

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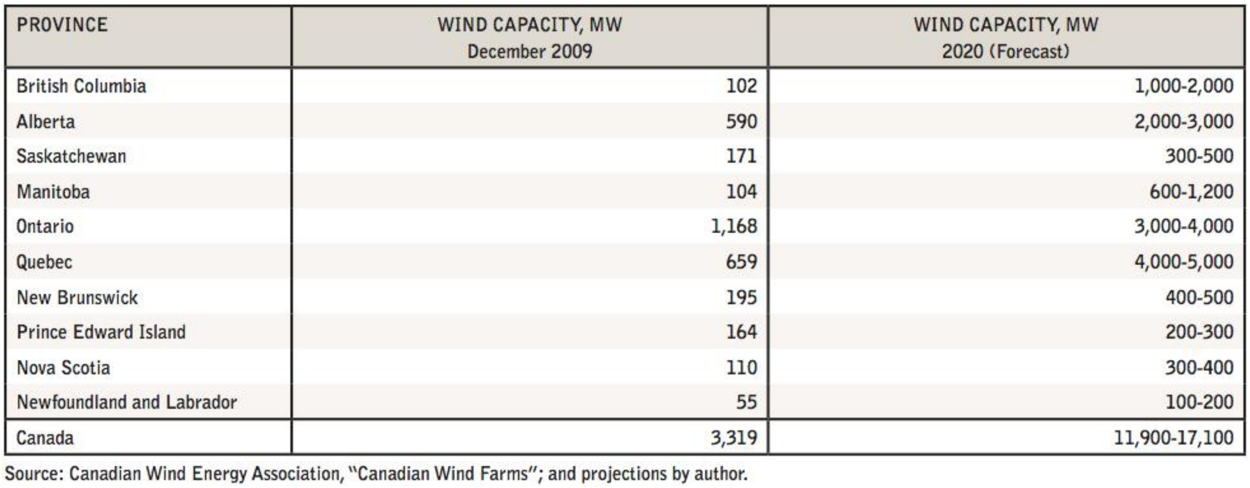
[4] Alternatively: Canada's emissions = 34 Mt CO2 per EJ and US = 162 Mt per EJ. 1 EJ = 10^{18} J = 277.7 TWh

	Gull	600	2020+
	Keeyask	695	2020+
	Conawapa	1485	2025+
Alberta	Slave River	1800	2020+
British Columbia	Revelstoke Unit 5	500	2011
	Mica Units 5 and 6	1000	2015
	Peace "C"	900	2020+
	Plutonic Power	1000	2015

Figure 8: Potential Large Hydroelectric Power Projects in Canada, 2009-25 (Goodman 2010; Hydro Quebec 2013; Manitoba Hydro 2013; Nalcor Energy 2013)

Canada also has high-quality wind resources and most areas of the country have pockets of economically viable wind. Ontario, Quebec and Alberta are leading provinces in wind development, with strong public policy commitments. Canada's wind resources offer a stronger economic proposition in terms of cost-effectiveness because the vast and readily accessible hydropower can provide storage capacity to complement wind power's variability and intermittency.

Whereas the Table below shows the current installed capacity, there is far more potential for wind in Labrador and other regions of Canada. For example, large scale- scale development of wind with complementary development of hydro in the Lower Churchill would be economically feasible if the storage capacity that hydro offers can be integrated with the variable output of wind.



PROVINCE	WIND CAPACITY, MW December 2009	WIND CAPACITY, MW 2020 (Forecast)
British Columbia	102	1,000-2,000
Alberta	590	2,000-3,000
Saskatchewan	171	300-500
Manitoba	104	600-1,200
Ontario	1,168	3,000-4,000
Quebec	659	4,000-5,000
New Brunswick	195	400-500
Prince Edward Island	164	200-300
Nova Scotia	110	300-400
Newfoundland and Labrador	55	100-200
Canada	3,319	11,900-17,100

Source: Canadian Wind Energy Association, "Canadian Wind Farms"; and projections by author.

Figure 9: Wind Capacity in Canada, 2009 and 2020 (Forecast) (Goodman 2010)

Finally, Canada maintains a strong presence in nuclear power development, with significant technological achievements in the development of so-called CANDU (“CANadian Deuterium Uranium) nuclear reactor. CANDU technology offers high fuel efficiency and flexibility due to its fuel-capability uniqueness and characteristics such as on-power fuelling, high neutron economy, core tailoring, compact fuel bundle, and versatile pressure tube design and so on. In the Canadian context, nuclear power becomes a particularly intriguing peaking resource when combined with hydropower (where geography permits).

Nuclear power has the potential to be part of a broader energy solution beyond the domestic market. Whereas nuclear power faces challenges in terms of high upfront capital cost, on a levelized cost of energy it would remain competitive against fossil resources if carbon emissions were fully priced. Hydro resources are already attractive economically as generation alternatives to coal and natural gas in some regions and availability of storage capacity can enhance competitiveness of wind resources.

Transmission Expansion and Inter-regional Trade

Clean new “renewable” or “non-carbon” forms of generation from Canada are part of the answer to the bigger puzzle of a low carbon energy future for the North American economy. The primary opportunity, contingent on a strong policy framework in support of interprovincial and international trade, arises from regional integration with transmission expansion possibilities.

Enhancing Regional Integration

Low-carbon forms of generation projects, when developed, would be connected into the high voltage grid in order to deliver their power to markets through strong regional integration. Projects to link remote renewable generation (mostly hydro) with major markets are being developed in Canada. The concept of regional integration opportunities, on a continent wide scale, is shown in the map below.

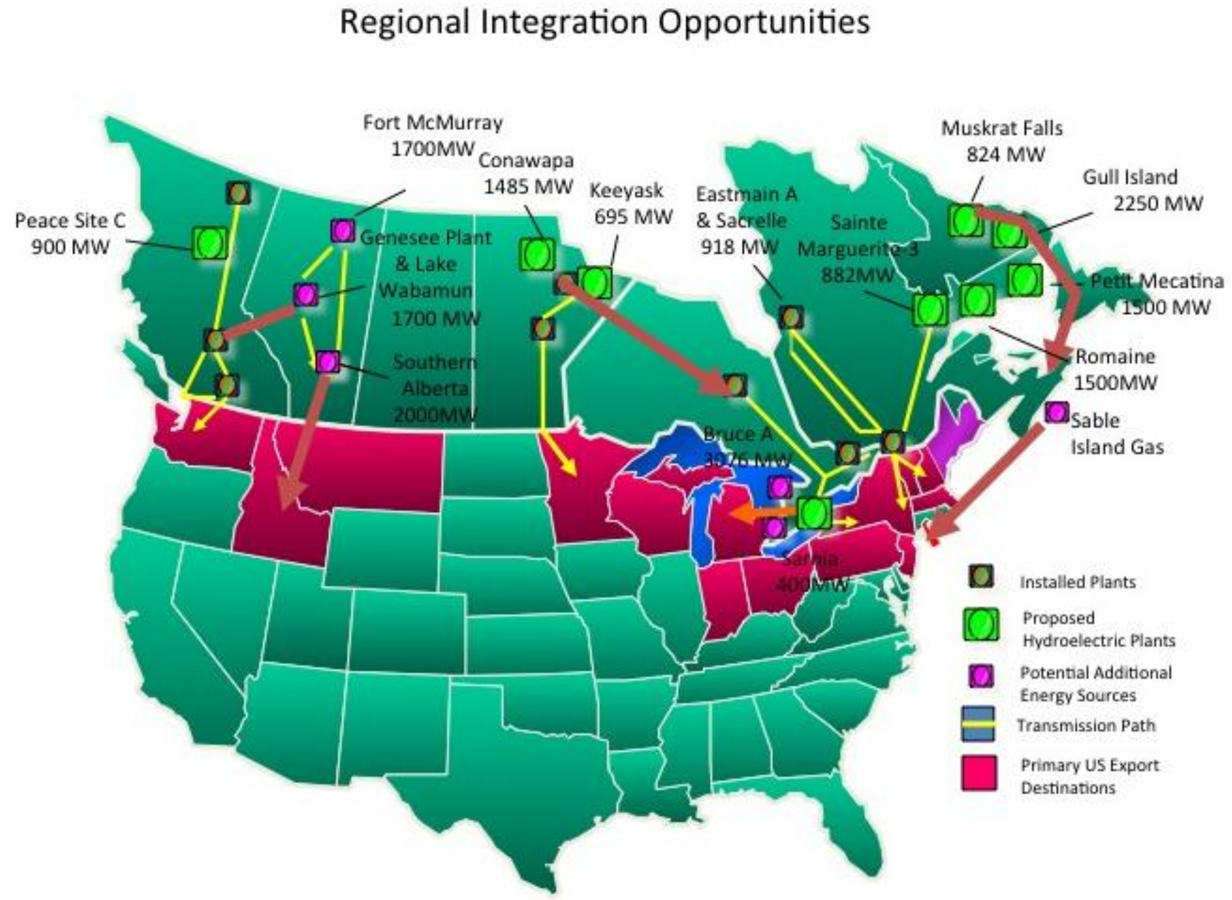


Figure 10: Regional Integration Opportunities.[5]

Integration on a vast geographic scale can also unlock lower cost supply by reducing price volatility. For example, it offers opportunities for peak shaving through the utilization of seasonal diversity between regions. In the US-Canadian context, seasonal factors are particularly relevant, given that Canada generally has a winter-peaking electricity system and US a summer-peaking one. Similar complementarities exist between Ontario, now a summer peaking system, and Quebec, Manitoba and Newfoundland – all winter peaking systems. Stronger interprovincial connections would create the capacity for arbitrage between off-peak and on-peak prices on a seasonal and diurnal basis. This would allow utilities to better manage their resources and optimize their operational needs by meeting their peak demand without having to construct new generation and transmission facilities. Because export prices tend to be higher than price points that can be achieved domestically, private energy providers can maximize economic profits and, in the case of Canadian Crown corporations, the benefit to domestic customer would be through lower power rates (Goodman 2010).

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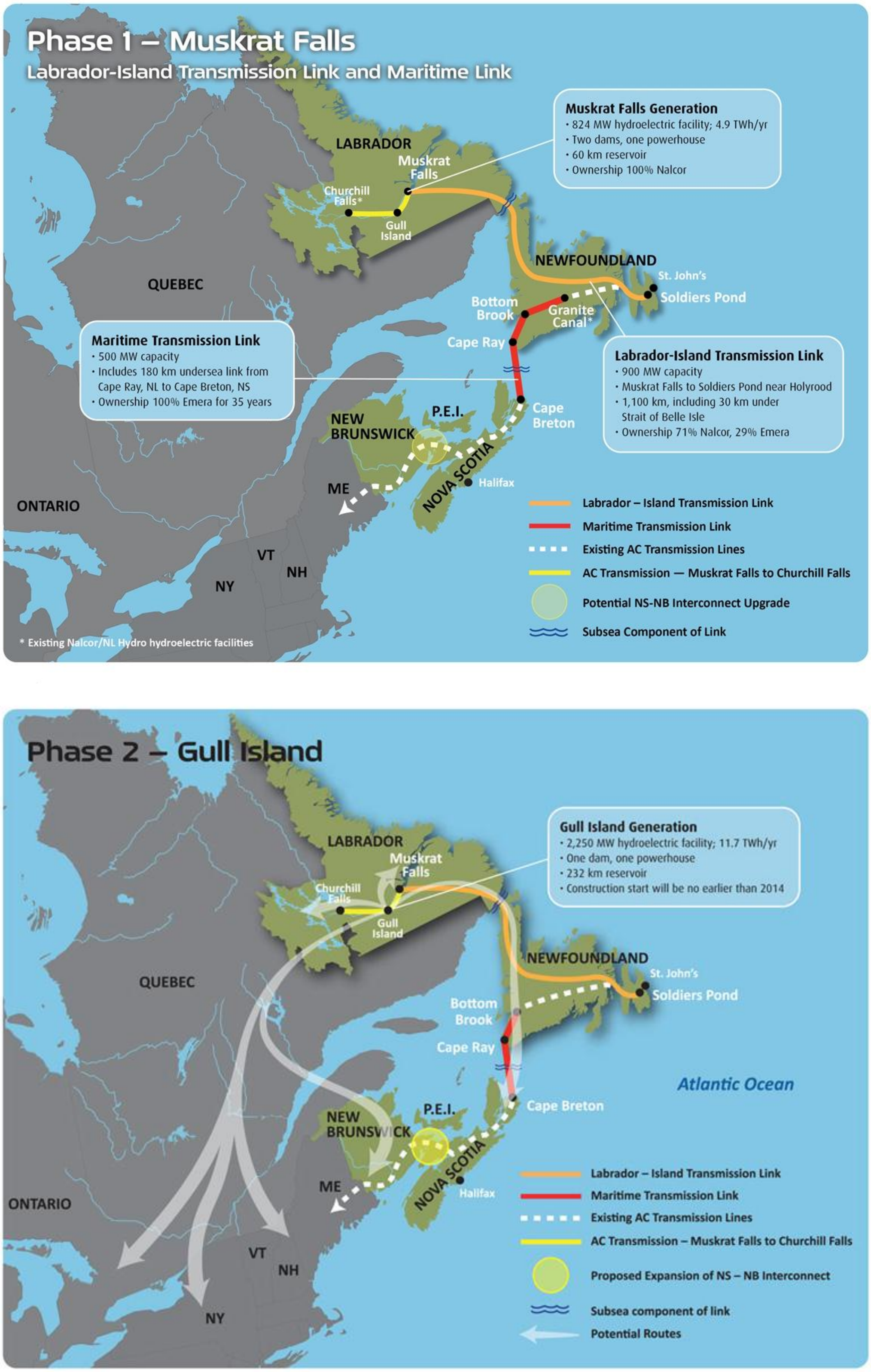
[5] Adapted by the author from various sources: (Goodman 2010; Hydro Quebec 2013; Manitoba Hydro 2013; Nalcor Energy 2013)

With greater integration of renewable energy sources, the handicap associated with the characteristic output of intermittent and dispersed resources such as solar and wind, could be overcome in an interconnected system that also presents opportunities for exploitation of large-scale hydro energy storage. Development of cost-effective storage on a large-scale – exploiting Canada’s geographic advantage to the fullest for hydro storage capacity - has the potential to reduce the overall costs of variable wind generation because an inter-regional electricity trading market would have the capacity to optimize and manage temporal and spatial variations across large distances through peak-shaving and load following. Hydro storage coupled with wind generation on a large scale, in effect, would allow wind generation to “mimic” characteristics of baseload generation.

Addressing constraints in transmission networks could diversify access, increase the value of potential generation investment, and ensure network readiness for large volume of trade.

The recently announced Atlantic project to link Newfoundland's Lower Churchill in Labrador sites to serve Newfoundland and an underwater DC link Nova Scotia and on to New Brunswick and New England is one example. This DC link to Nova Scotia is also a clear example of clean hydro power can displace coal based generation in Nova Scotia. A new DC back-to-back link between Ontario and Quebec that allows clean power transmission into Ontario to meet peak demands and offset variability in wind production and transfer of off peak base load from Ontario back into Quebec to save valuable hydropower is another example.



Phase 1 – Muskrat Falls

Labrador-Island Transmission Link and Maritime Link

Muskrat Falls Generation
- 824 MW hydroelectric facility; 4.9 TWh/yr
- Two dams, one powerhouse
- 60 km reservoir
- Ownership 100% Nalcor

Maritime Transmission Link
- 500 MW capacity
- Includes 180 km undersea link from Cape Ray, NL to Cape Breton, NS
- Ownership 100% Emera for 35 years

Labrador-Island Transmission Link
- 900 MW capacity
- Muskrat Falls to Soldiers Pond near Holyrood
- 1,100 km, including 30 km under Strait of Belle Isle
- Ownership 71% Nalcor, 29% Emera

* Existing Nalcor/NL Hydro hydroelectric facilities

Phase 2 – Gull Island

Gull Island Generation
- 2,250 MW hydroelectric facility; 11.7 TWh/yr
- One dam, one powerhouse
- 232 km reservoir
- Construction start will be no earlier than 2014

Figure 11: Phase 1 and 2 of the Lower Churchill Project. (Nalcor Energy 2013)

Additional examples include: The BC and Alberta links and expansion of BC grid into Northwestern BC to serve mining development and potentially to connect to hydro potential in Yukon and Alaska to the BC system, regional integration between Saskatchewan and Manitoba and New Brunswick's efforts to build itself into an energy hub for eastern North America, trading hydro power, nuclear power and natural gas throughout the region. Development of hydro resources in Manitoba (i.e. Conawapa project) with access through Ontario and to the US markets south would provide Manitoba with an alternate path to the existing link into Minnesota. The Montana-Alberta Tie-Line (MATL) power transmission project (a 300 (MW), 230-kilovolt (KV) transmission line) would support ongoing development of a rich wind-powered generation resource and allow much-needed energy to flow in both directions, ensuring more reliable supplies of electricity into the U.S. Northwest and Alberta.

The recently completed back-to-back DC linkage between Ontario and Quebec can save valuable hydro power by allowing clean power transmission into Ontario to meet peak demands, to offset variability in wind production, and to ship off peak base load from Ontario back into Quebec. Expanded back-to-back interconnections between the two provinces could allow further development of these opportunities, together with expanded wheeling of power into the Great Lakes states to replace coal-fired generation.

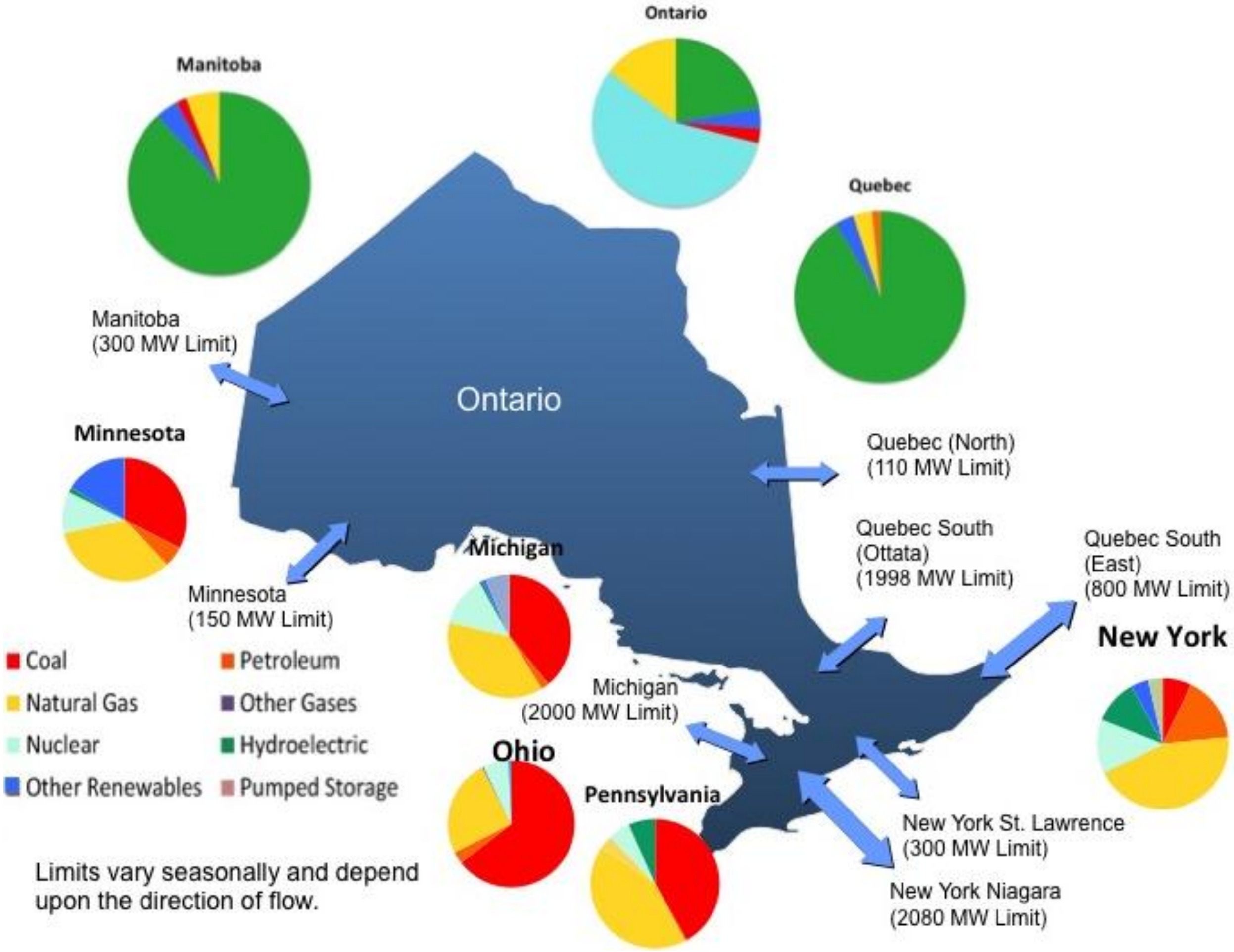
Ontario's Geographic Advantage

Ontario is a large Canadian province adjacent to the US industrial heartland. It has the ideal geographic, policy and existing transmission infrastructure to play an important role as an energy-trading hub for the Great Lakes regions.

The province is situated between two hydro-rich provinces with its population concentrated in the Greater Golden Horseshoe. It relies on nuclear as the primary baseload source of power and is on track to meet the closure of coal as a generation source by 2014. Of the all the provinces, Ontario is the most highly connected to neighboring states and provinces. As shown in Figure below, Ontario has 17 interconnections (or circuits) at 9 locations with neighboring jurisdictions. The diversity of energy supply resources around Ontario is shown below.

From a geographic perspective, there is a striking similarity between Denmark and Ontario with two major hydro producers (Norway and Sweden) to the north and east, as well as a major coal-based system (Germany) to the south. For Denmark, it became clear that regional integration was key to making high-level wind generation practical. Denmark has interconnections with its neighbors equal to about 80% of its generating capacity. In stark contrast, Ontario has about 20%. Currently under development is the North Sea underwater grid designed to connect offshore wind projects into the grid that will greatly enhance linkage among Norway, Sweden, Denmark, Holland, Germany and France.

The principal value of interconnections between multiple markets is not limited to enhancement of trade flows between one province and the neighboring state. Interconnections between multiple markets offer generators pathways for electricity access to more diverse markets. Low-cost generators can benefit from greater exports to US states in the mid-west and south of Ontario by displacing less efficient generators (ie. high-cost peaking plants) from the market. More efficient use of generators on both sides of the border and effective utilitization of the storage capacity of the Quebec system would lower prices, reduce price volatility, enhance reliability and improve the environmental benefits.



Limits vary seasonally and depend upon the direction of flow.

Figure 12: Ontario Interconnections. (Center for Energy 2012; Independent Electricity System Operator 2012a, 2012b)

Price Regimes and Costs

Realization of the environmental benefits needs a strong economic premise. We illustrate regional and state price regimes along the North-South neighboring states within the Eastern Interconnection.

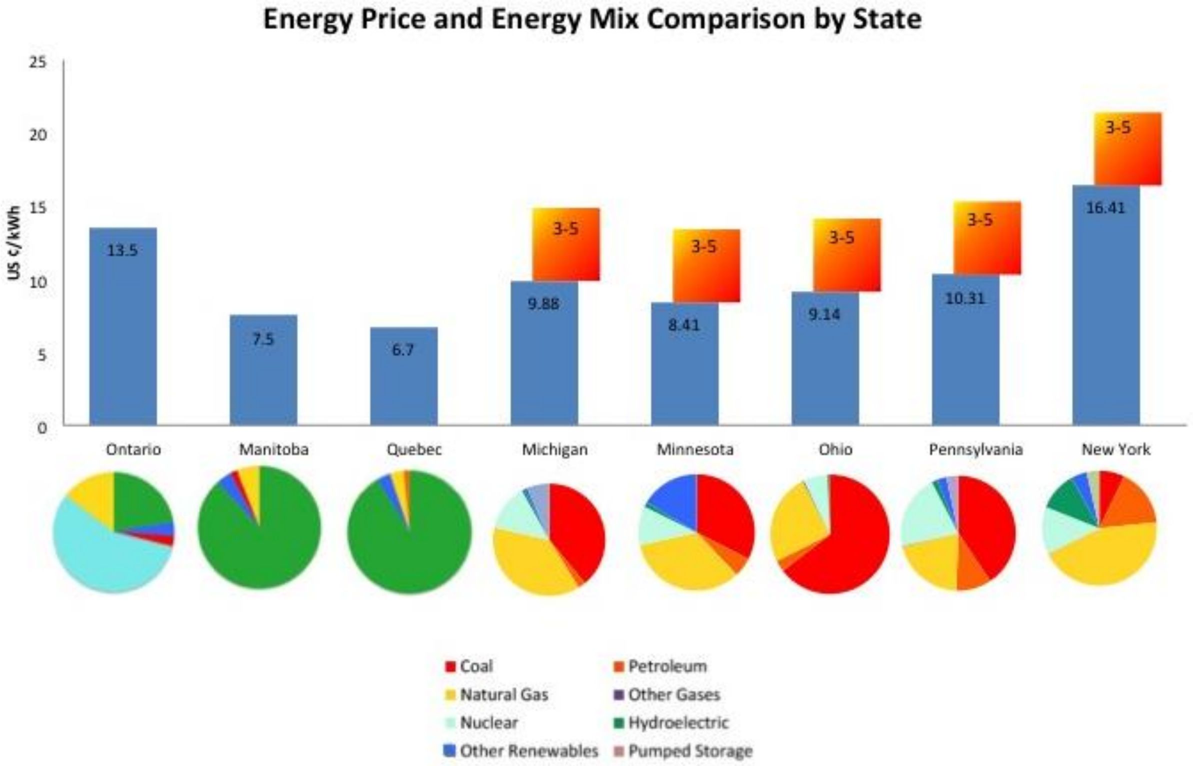


Figure 13: Comparison of Electricity Prices and Energy Mix in Major North American Cities[6] (Center for Energy 2012; Hydro Quebec 2012; Independent Electricity System Operator 2012b; Ontario Energy Board 2013; US Energy Information Administration 2012b)

Electricity prices are linked to the supply mix. For those jurisdictions where fossil resources are dominant, the prices tend to be on the lower end of the spectrum. However, upward pressures on prices arising from a carbon penalty would change that evaluation. Companies with large emissions will need to find ways to meet regulations and may find supply of clean power from Canada attractive. Given that we do not have an established mechanism for pricing carbon, we show a range of additional costs - anywhere from 3 -5 cents per kWh – that would emerge for each jurisdiction depending on the role of coal in its generation mix.

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[6] Regulated Price Plan (RPP) in Ontario includes two tiers of pricing, with 7.4 cents/kWh on the lower-tier and 8.7 cents/kWh on the higher-tier. Current tier threshold is 1,000 kWh per month in the winter and 600 kWh per month during summer. http://www.ontarioenergyboard.ca/OEB/Consumers/Electricity/Electricity+Prices

Surrounding Ontario are the states more heavily dependent on fossil resources and most vulnerable to the impacts arising from the Federal Environmental Protection Agency (EPA) regulations on carbon. The EPA, under Obama's renewed presidency, seems politically ready to take on the responsibility to regulate GHG emissions in the US under the Clean Air Act (CAA). There is emerging a growing consensus on the need for a "price" on carbon and the failure to put cap-and-trade legislation on a firm footing in the US has shifted the focus to EPA regulations. Recent presidential pronouncements provide one indication of commitment to the climate change policy; the closing of the Las Brisas coal power plant, owned by Chase Power in Texas, seems to foreshadow a strong regulatory commitment from the agency to de-carbonization and several utility executives have indicated a commitment to full phase-out of coal fired generation. .

The above illustration is a snapshot of current prices. These prices are indicative of regional pricing on average. Market prices are set hourly and are dynamic with large variations during a year and prices vary from location to location. Broadly, the price regimes largely reflect the cost to the consumers based on the existing base of generation assets – some new, some old and the overall supply mix in the jurisdiction. The price differentials across the provinces and the states are partly determined by the geography (i.e. natural resource endowment) and history: decisions that were made a number of decades ago to develop large hydropower projects continue to yield low cost energy to consumers in Quebec, Manitoba and BC.

For decisions about the future, however, the economic rationale for the development of specific projects will be determined on the basis of incremental costs for the next megawatt of generation capacity.

Figure 14 below is a current comparison that illustrates the costs of different generation options. The levelized cost of energy (LCOE)[7] is a convenient summary measure of the overall competitiveness of different generation technologies and it represents the per kWh cost (in real dollars) of building and operating a facility over an assumed financial life and duty cycle. It is important to note, however, that actual plant investment decisions are affected not only by the specific technological and regional characteristics of a project but several other considerations related to financing, cost of regulatory approvals, policy incentives and other considerations.

The projected utilization rate, which depends on the load shape and the existing resource mix in an area where additional capacity is needed, is one such factor. The existing resource mix in a region can directly affect the economic viability of a new investment through its effect on the economics surrounding the displacement of existing resources. For example, a wind resource that would primarily displace existing

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[7] LCOE: Key inputs include capital costs, fuel costs, fixed and variable OM&A costs, financing costs and a utilization rate for each plant type (US Energy Information Administration 2012a).

natural gas generation will usually have a different value than one that would displace existing coal generation. (US Energy Information Administration 2012a)

A related factor is the capacity value that captures the value of a generating unit to the system: units that can follow demand (dispatchable technologies) generally have more value to a system than less flexible units (non-dispatchable technologies) or those whose operation is tied to the availability of an intermittent resource. An additional caution in interpreting the LCOE data is the influence of policy-related factors, such as investment or production tax credits for specified generation sources that can impact investment decisions.

Whereas specific investment decisions would require detailed analysis, we note that Canada's non-carbon generation technologies will have a clear advantage and can provide a cost effective pathway for displacing coal over a wide range of scenarios if an effective carbon pricing regime were put in place.

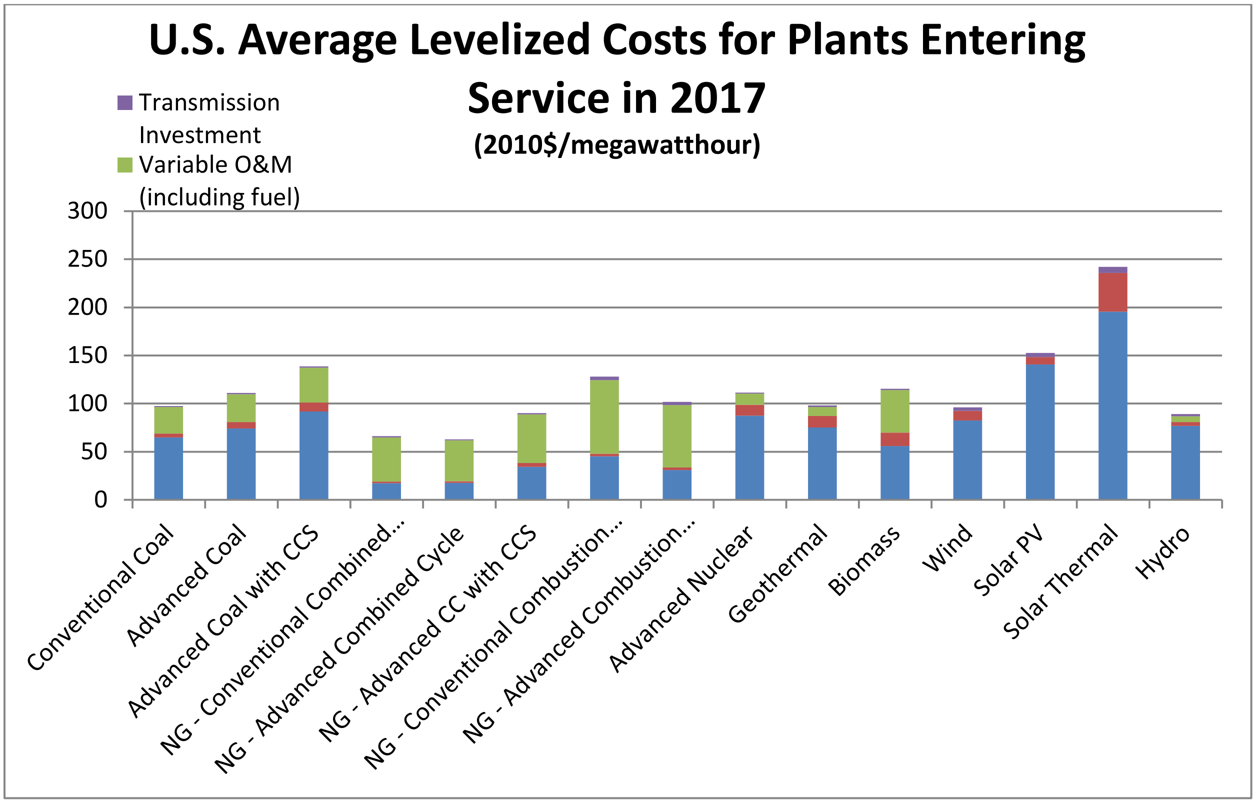

Figure 14: US Average Levelized Costs for Plants Entering Service in 2017. (US Energy Information Administration 2012a)

Shale Gas Impacts

No energy story is complete without natural gas in the mix. It has been argued that the low prices of natural gas, driven by the current US shale gas boom, fundamentally changes the pivot point for investment decisions in the energy infrastructure. In the short term, the market dynamics would suggest this is the case and the current glut of gas is an effective and a profitable substitute for reducing coal generation and reduce the GHG burden.

The increase in natural gas production results primarily from the continued development of shale gas resources, as shown in Figure 15 below:

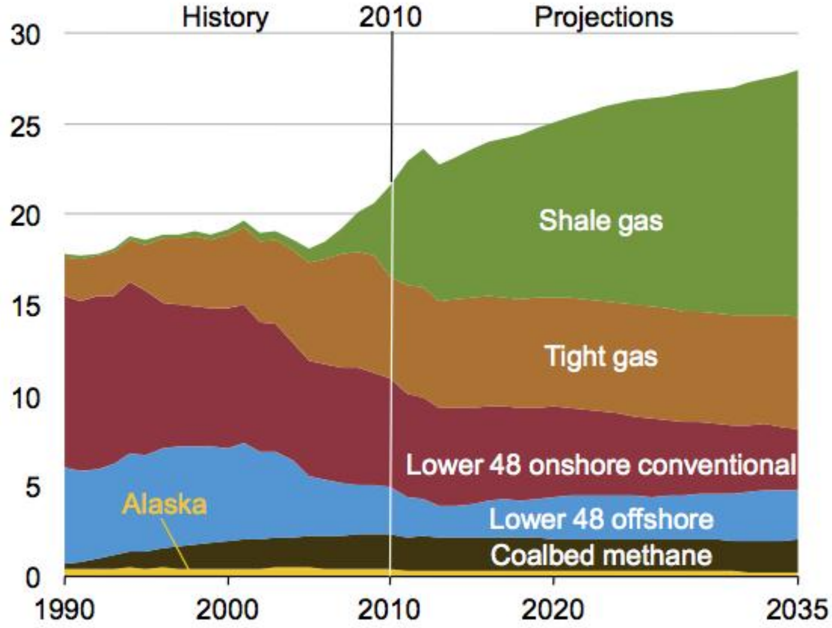

Figure 15: Natural gas production by source, 1990-2035 (trillion cubic feet) (US Energy Information Administration 2012a)

Shale gas is expected to become the largest contributor to production growth and it accounts for 49 percent of total U.S. natural gas production forecast for 2035, more than double its 23-percent share in 2010. Estimated proved and unproved shale gas resources amount to a combined 542 trillion cubic feet, out of a total U.S. resource of 2,203 trillion cubic feet. Estimates of shale gas well productivity remain uncertain.

At current (2012) price levels, natural gas prices are below average replacement cost. As indicated by the latest US EIA price forecasts for the longer term, natural gas prices are expected to rise with the marginal cost of production at a rate of 2.1 percent per year from 2010 through 2035 to an annual average of $7.37 per million Btu (2010 dollars) in 2035. (US Energy Information Administration 2012a)

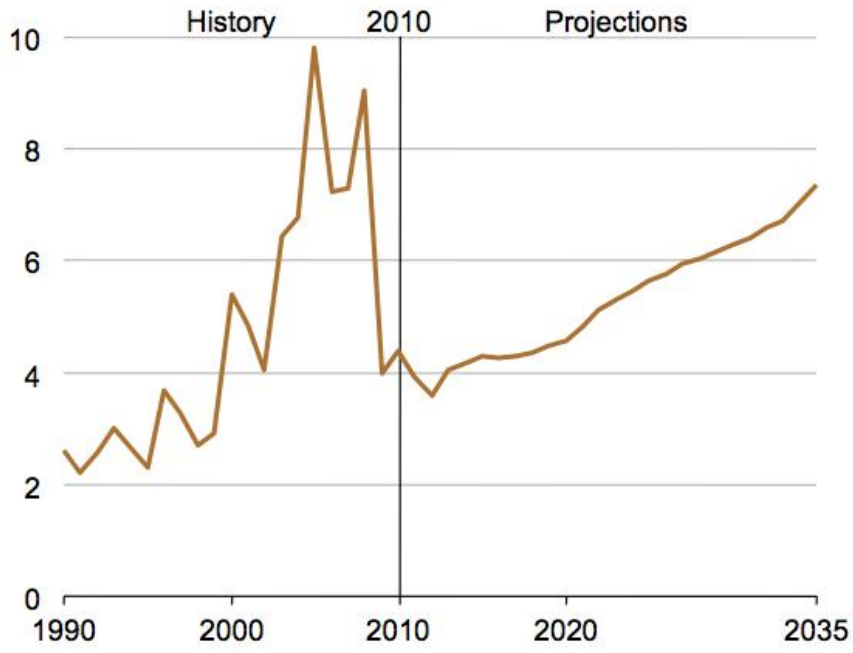

Figure 16: Annual average Henry Hub spot natural gas prices, 1990-2035 (2010 dollars per million Btu). Natural gas prices are expected to rise with the marginal cost of production. (US Energy Information Administration 2012a)

The rate at which natural gas prices change depends on two important factors: the future rate of macroeconomic growth and the expected cumulative production of shale gas wells over their lifetimes—the estimated ultimate recovery (EUR) per well. Alternative cases with different assumptions for these factors are shown in Figure 17 below. Higher rates of economic growth lead to increased consumption of natural gas, causing more rapid depletion of natural gas resources and a more rapid increase in the cost of developing new incremental natural gas production. Conversely, lower rates of economic growth lead to lower levels of natural gas consumption and, ultimately, a slower increase in the cost of developing new production.

For the low EUR case, recovery is decreased by 50 percent. The uncertainties associated with future shale gas well recovery rates will remain an important determinant of future prices. Changes in well recovery rates affect the long-run marginal cost of shale gas production, which in turn affects both natural gas prices and the volumes of new shale gas production developed.

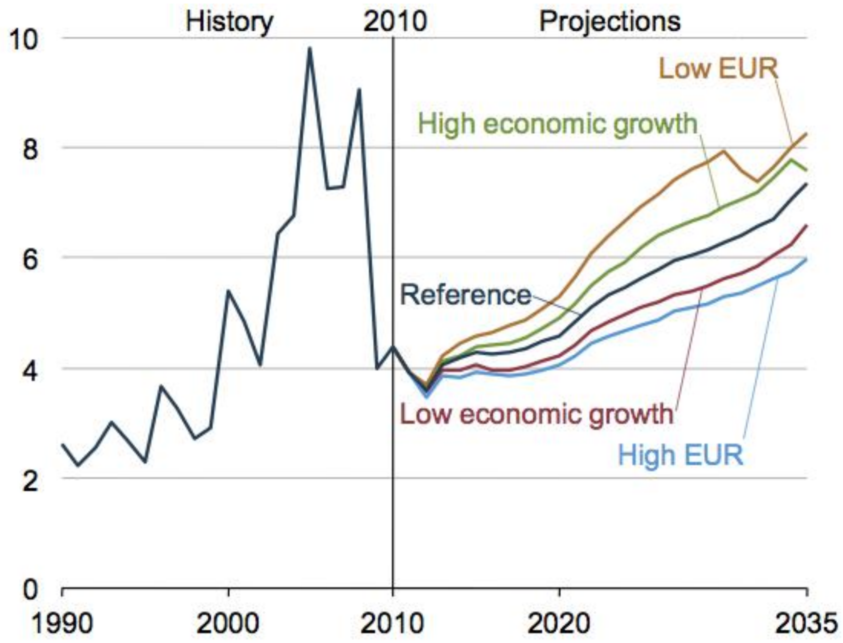

Figure 17: Annual average Henry Hub spot natural gas prices in five cases, 1990-2035 (2010 dollars per million Btu). Natural gas prices vary with economic growth and shale gas well recovery rates. (US Energy Information Administration 2012a)

Coal Production and Emissions

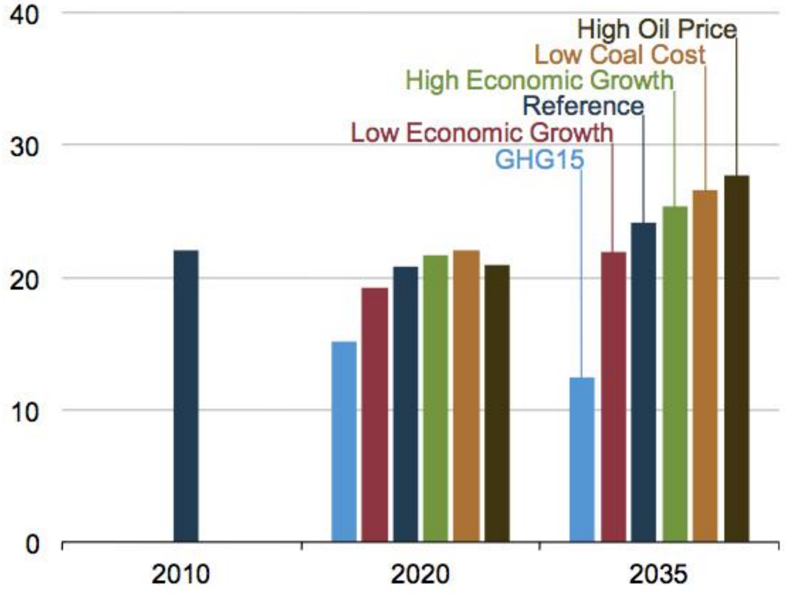

Figure 18: U.S. total coal production in six cases, 2010, 2020, and 2035 (quadrillion Btu). (US Energy Information Administration 2012a)

U.S. coal production varies across the AEO2012 cases, reflecting different assumptions about the costs of producing and transporting coal, the outlook for economic growth, the outlook for world oil prices, and possible restrictions on GHG emissions (Figure 18). As shown in the GHG15 case, where a CO_2 emissions price that grows to $44 per metric ton in 2035 is assumed, actions to restrict or reduce GHG emissions can significantly affect the outlook for U.S. coal production.

From 2010 to 2035, changes in total annual coal production across the cases (excluding the GHG case) range from a decrease of 1 percent to an increase of 26 percent.

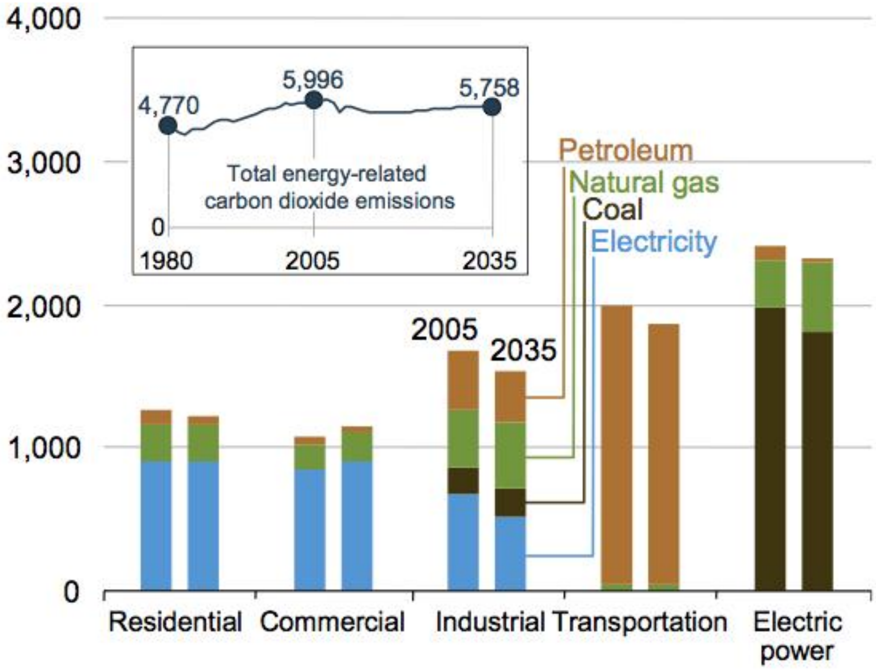

Figure 19: U.S. energy-related CO_2 emissions by sector and fuel, 2005 and 2035 (million metric tons). (US Energy EIA 2012a)

On average, energy-related CO_2 emissions in the AEO2012 Reference case decline by 0.1 percent per year from 2005 to 2035, as compared with an average increase of 0.9 percent per year from 1980 to 2005. Growing use of renewable energy technologies and fuels, efficiency improvements, slower growth in electricity demand, and more use of natural gas all contribute to a projection that ensures energy-related CO_2 emissions remain below 2005 levels through to 2035, when they total 5,758 million metric tons. The important point to note is that carbon dioxide emission levels to 2035 and beyond to 2050 and for the rest of the century would need to be substantially lower to mitigate the threat to climate change.

If the above estimates of the forecast of energy related GHG emissions by the EIA to 2035 were to prevail, then the ability to limit the rise in temperature to a maximum 2-3 degree warming, to stabilize impacts on the climate would not be feasible. Associated with a 2-3 degree warming of the climate is a reduction requirement of 50% in emission by 2050 and 80% through to the end of the century. This makes for a compelling case for a dramatic shift in thinking towards an energy market that thrives on cleaner, non-carbon sources of supply.

In the medium to long term, the electricity prices and profits will be determined by the rate of substitution of non-carbon generation—with some ongoing role for shale gas—and the advantage will shift to those resources with a lower carbon penalty. As is shown in the figure above, a $44 per metric ton translates into a significant reduction in coal production. The rate of change will undoubtedly vary across regions depending upon the existing supply mix, the stringency of environmental compliance requirements (i.e. GHG prices or abatement costs), general economic conditions and natural gas prices.

While Canada is well equipped with the clean energy capacity economically attractive for export, trading of electricity in the North American context would not make sense if it brings inefficiency, higher power prices, decreased reliability or creates large environmental liabilities.

Canada's clean electricity advantage can be realized through new transmission upgrades that would not only increase the available markets for Canadian generation in the US northeast and to the south and west of Ontario, there is also a good possibility for optimizing power flows that can exploit diurnal and seasonal arbitrage through storage of hydro resources. Optimization of generation resources over a large area with adequate transmission capability is an important part of the answer that needs to be explored fully.

Summary and Conclusions

1. Canada's low carbon electricity advantage is capable of making a major contribution to the reduction of greenhouse gases (GHGs) on a continent wide scale through a strategy that has, at its core, promotion of inter-regional trade in electricity.

2. Large scale trade in electricity, across provincial and national boundaries, is a cost effective mechanism for alignment of climate change policies required to transition to a low-carbon energy economy.

3. Upgrades to the existing interconnections and transmission system would be necessary to overcome the current limits to large-scale trade.

4. To realize the full potential of clean electricity exports from Canada to the US through an expanded power grid, the Provinces, States and Federal Government would have to establish a clear policy framework and specific mechanism to reduce barriers to the development and approval of specific projects.

5. Enhanced electricity trade between Canada and US offers a strategic environmental and economic advantage that would benefit the entire North American economy.

6. A dramatic shift away from the 'provincial self-sufficiency paradigm' to a coherent national energy strategy congruent with climate change policies, based on inter-regional trade as opposed to regulations and targets as the primary focus, is a promising pathway for a lower carbon energy future for North America.

Works Cited

Baker, Barbara et al. 2011. *Canada's Electricity Infrastructure: Building a Case for Investment*. The Conference Board of Canada.

Bernard, Jean-Thomas. 2003. *Seamless Electricity Trade between Canada and US Northeast*. Quebec: Universite Laval, Department of Economics.

Blue, Ian. 2009. "Off the Grid: Jurisdiction and the Canadian Electricity Sector." *The Dalhousie Law Journal* 32.

Canadian Academy of Engineering. 2010. *Electricity: Interconnecting Canada, A Strategic Advantage*. Ottawa: Canadian Academy of Engineering.

Canadian Electricity Association. 2011. *Canada's Electricity Industry*. Canadian Electricity Association.

Canadian Hydropower Association. 2008. *Hydropower in Canada: Past, Present and Future*. Canadian Hydropower Association.

Carr, Jan. 2010. *Power Sharing: Developing Inter-Provincial Electricity Trade*. C.D. Howe Institute. C.D. Howe Institute Commentary.

Center for Energy. 2012. "Energy Facts & Statistics." *centreforenergy.com*. http://www.centreforenergy.com/FactsStats.

Cooper, Daniel E. 2011. "What's Happening with NERC Reliability Standards." *Michigan Municipal Electric Association Currents Newsletter*.

Goodman, Roger J. 2010. *Power Connections: Canadian Electricity Trade and Foreign Policy*. Canadian International Council.

Hydro Quebec. 2012. *Comparison of Electricity Prices in Major North American Cities: Rates in Effect April 1, 2012*. Hydro Quebec.

———. 2013. "Eastmain-A/Sacrelle/Rupert Project." *Hydroquebec.com*. http://www.hydroquebec.com/rupert/en/.

Independent Electricity System Operator. 2012a. *Ontario Transmission System*. Independent Electricity System Operator (IESO).

———. 2012b. "Supply Review." http://www.ieso.ca/imoweb/media/md_supply.asp.

International Institute for Applied Systems Analysis. 2012. *Global Energy Assessment*. International Institute for Applied Systems Analysis (IIASA).

Manitoba Hydro. 2013. "Conawapa Generating Station." *hydro.mb.ca*. http://www.hydro.mb.ca/projects/conawapa/index.shtml.

Nalcor Energy. 2013. "Lower Churchill Project." http://www.nalcorenergy.com/Lower-Churchill-Project.asp.

National Energy Board. 2013. "Electricity Export and Imports 2011." http://www.neb.gc.ca/clf-nsi/rnrgynfmtn/sttstc/lctrctyxprtmprt/lctrctyxprtmprt-eng.html.

North American Electric Reliability Corporation. 2012. "NERC Regional Entities." http://www.nerc.com/page.php?cid=1%7C9%7C119.

Office of the United States Trade Representative. 2012. "US-Canada Trade Fact." http://www.ustr.gov/countries-regions/americas/canada.

Ontario Energy Board. 2013. "Electricity Prices." http://www.ontarioenergyboard.ca/OEB/Consumers/Electricity/Electricity+Prices.

Pembina Institute, and David Suzuki Foundation. 2009. *"Climate Leadership, Economic Prosperity: Final Report on an Economic Study of Greenhouse Gas Targets and Policies for Canada*. Ottawa: Pembina Institute and David Suzuki Foundation.

Tal, Benjamin, and Avery Shenfeld. 2011. *Energizing Infrastructure*. Toronto: CIBC World Markets Inc.

US Energy Information Administration. 2012a. *Annual Energy Outlook 2012 with Projections to 2035*. US Energy Information Administration (EIA).

———. 2012b. *State Electricity Profiles 2010*. US Energy Information Administration (EIA).

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