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# Canada’s Low Carbon Electricity Advantage: Unlocking the Potential of Inter-Regional Trade

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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 and significant reductions in fossil fuel use (primarily coal) in the North American energy system. A ten to twenty-fold increase in clean electricity trade from current levels of about $2 billion per year would be required to deliver on such lofty goals, but the transition can be achieved over the next 30-50 years through development of the necessary transmission infrastructure.

Major expansion of electricity trade between the US and Canada, buttressed by interconnections and transmission links acting as “regional hubs” between provinces and neighbouring states is part of the plan to meet the goals. Trade—as opposed to regulations and targets—is a powerful arbiter of mutual benefit and perhaps 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. The weight of history is one; geography, long distances and large investment costs are others; but the most difficult aspect is the political calculus of the day that conspires against a long view of an energy trade strategy searching to realize the fullest potential of clean electricity from Canada. The paradigm of “province wide self-sufficiency” dominates the public discourse and is prevalent in regulatory and system planning decisions. Support for expansion of electricity generation and transmission facilities – on a vastly increased scale – as part of a deliberate national “export driven” strategy is either limited or all too often met with derision or outright hostility.

Twinning Canada’s electricity trade strategy with climate change goals – through high value electricity production and transmission - has the potential to deliver economic prosperity with a much lower national carbon footprint. 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 a price that internalizes the economic cost of emissions. Currently, the lack of a high enough price signal for carbon emissions, combined with expectations that low natural gas prices will prevail, presents barriers to investment decisions for an alternate future. Beyond pricing of carbon, strong policies and commitments to incent investments in transmission and interconnections may be necessary to pave the way for enhanced trade.

A dramatic shift in thinking and support for a national energy strategy is required that has, at its fulcrum, large-scale cross border inter-regional trade in electricity. The national strategic opportunity is for Canada's low carbon electricity advantage to become fully integrated with energy trade and climate change policies of Canada and the US synchronized for mutual benefit.

# Introduction

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

It is widely 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 strength of policy interventions and the specific stringency of environmental compliance requirements (i.e. GHG prices or abatement costs) and broader macro-economic factors.

It is in this context that we investigate whether enhanced electricity trade between Canada and the 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 interconnected 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 stages and nearly 34GW proposed, especially in the major exporting provinces of Manitoba, Ontario, Quebec, Newfoundland and BC (Baker et al. 2011), Canada can begin to envision clean electricity trade as the primary driver for pushing coal out of the North American energy mix over a 50-70 year time frame.

A helpful geographical perspective can be gained by considering Europe; for example, there is a striking similarity between Denmark and Ontario with two major hydro producers (Norway and Sweden) to the north and east and a major coal-based system (Germany) to the south. For Denmark, regional integration became a key factor in making high-level wind generation practical. Denmark has interconnections with its neighbours equal to about 80% of its generating capacity. The North Sea underwater grid, currently under development to connect offshore wind projects, will further enhance linkage among Norway, Sweden, Denmark, Holland, Germany and France.

In the present Canadian context, a fundamental problem is that the planning processes for electricity system expansion remain paralyzed within the context of a "provincial self-sufficiency" argument, and justification for capital investments in the grid is 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 interconnections and the system is not geared to advance large-scale trade comparable in scale and scope to energy trade through pipelines. Recognition of electricity exports as a "manufactured" high value-added product with a large potential for delivering economic prosperity is not part of the public discourse.

Several recent studies, including Carr (2010), the Canadian Academy of Engineering (2010), the Pembina Institute (2009), and Bernard (2003), provide comprehensive reviews 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 inter-provincial synergies and effective utilization of national renewable energy resources.

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). Such an infrastructure deficit arises 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 inter-provincial and international electricity sale."

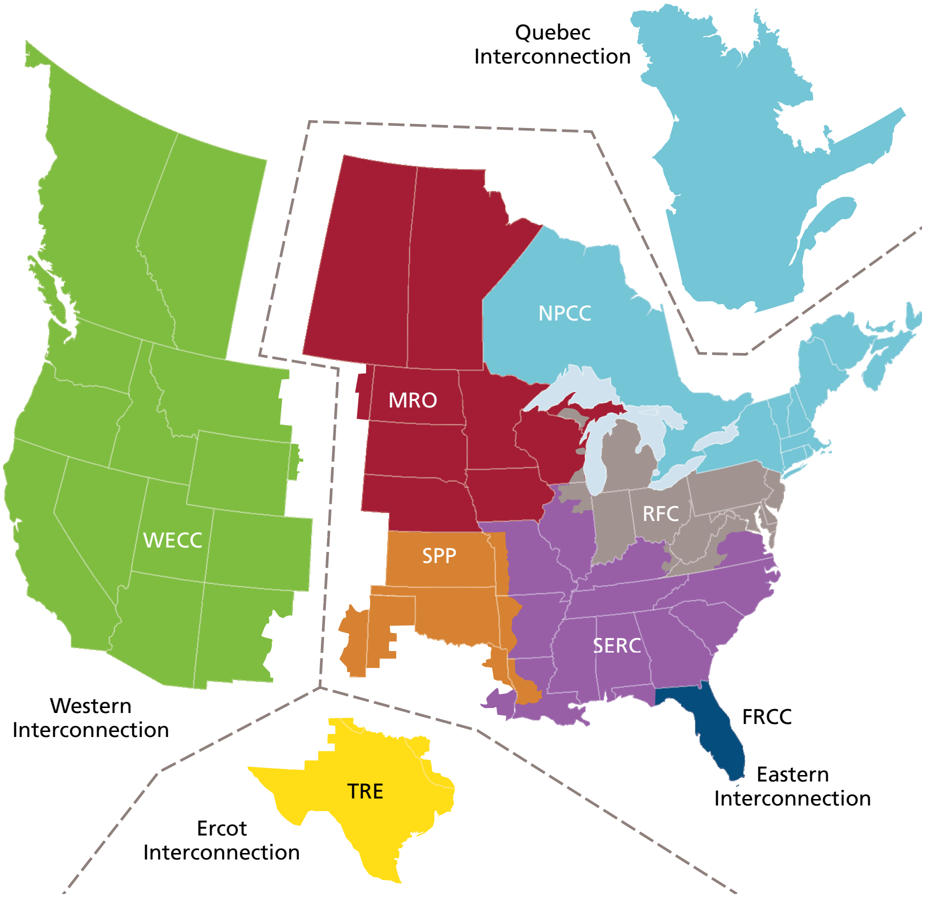
# Historical Context

The existing interconnection between Canada and the US, which has its roots in historical developments, is 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 Electric Reliability Council of Texas (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 comprising many connected generators. The three interconnections are independent in that they are not synchronized with each other, but are linked through limited direct current (DC) ties. The Eastern and Western Interconnections are linked to the electrical grids in Canada. The Eastern Interconnection is the largest synchronous electrical 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 lines 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 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 has delivered impressive results in its capability to withstand unanticipated disturbances of bulk power production in the network.

After the 2003 Blackout, however, the North American Reliability Council (NERC) was reformulated from what was effectively a voluntary organization to a self-funding quasi-governmental organization operating under delegated authority from the Federal Energy Regulatory Commission (Cooper 2011). This change has resulted in NERC reliability standards moving from being voluntary to becoming mandatory and enforceable standards through compliance.

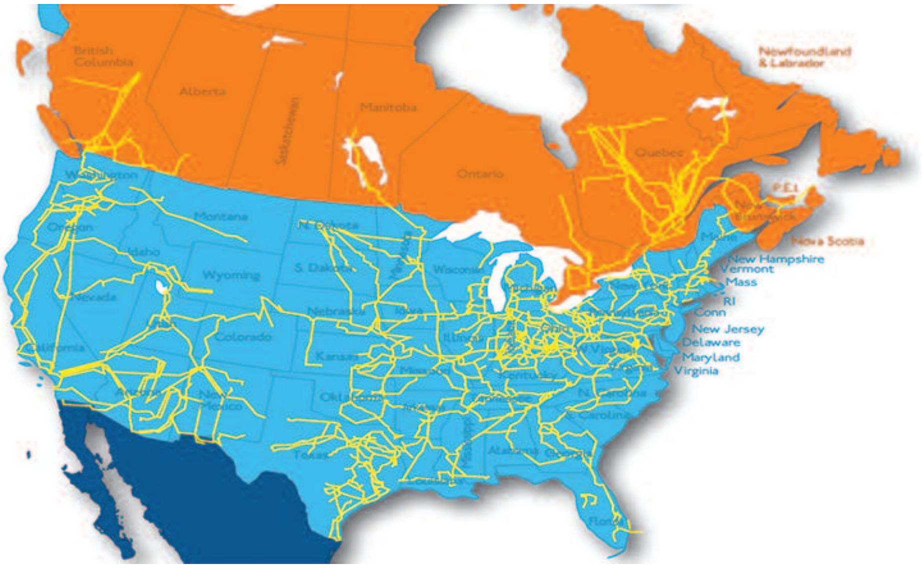
## What Role for Electricity Trade?

Even though the historical roots of the North American grid can be traced to 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.

**Figure 2**
**Major US-Canada Transmission Interconnections**

(Canadian Electricity Association 2011)

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



This extensive network of existing assets and its potential to shape the broader climate change policy and the political discourse on a strategy for enhancing inter-regional electricity trade has not been explored fully. A national strategy to promote significant expansion of electricity trade, perhaps by ten to twenty-fold or higher, would test this central premise and help to 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?
- Does seasonal diversity of demand and generation resource offer the possibility of arbitrage and lower costs across regions?
- Do the "levelized cost of energy" (LCOE) and the newer concept of "levelized avoided cost of energy" (LACE) provide a reasonable indicator of the different cost and value of generation technologies?
- If significant reductions of carbon emissions are to be achieved on a continent-wide scale, does inter-regional electricity trade offer better prospects for cost effective carbon mitigation compared to investments in carbon capture and sequestration (CCS) technologies?

## Export Markets to Drive Regional Integration

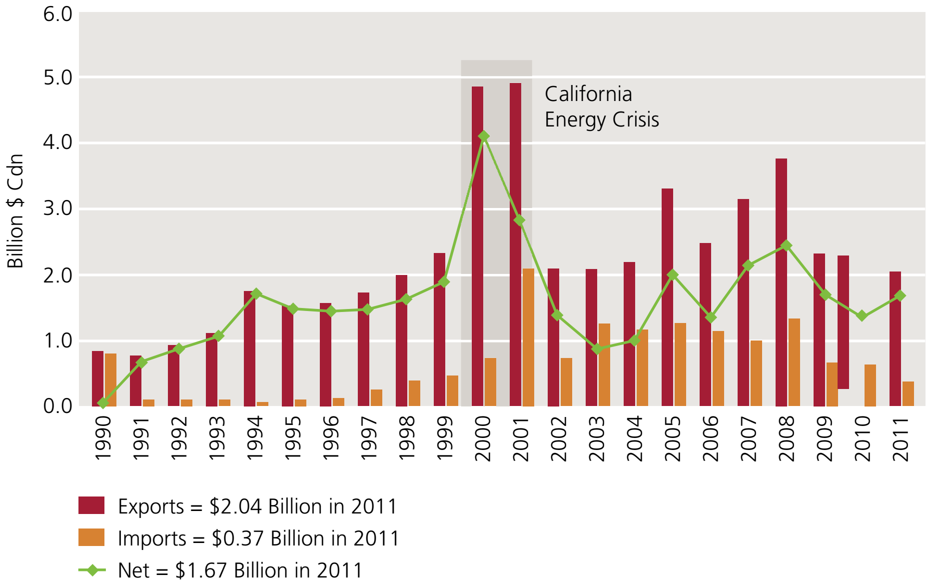
Canada is the largest supplier to the US of oil, and Canada's crude and natural gas exports to the US were valued at $101.9 billion in 2011 (Office of the United States Trade Representative 2012). The current level of electricity trade, by the standards of overall energy trade, is at best anemic. According to the National Energy Board (see Figure 3), 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 were 36.8TWh totaling $1.67 billion in revenue (Canadian Electricity Association 2011; National Energy Board 2013).

Electricity is a high value energy product and a large proportion of Canada's electrical generation has a low carbon emission profile. If the potential for clean energy exports from Canada is vast, why are electricity exports not higher?

Most of the Canada-US electricity trade occurs via interconnections between the provinces of British Columbia, Manitoba, Ontario, Quebec and New Brunswick and neighbouring US

**Figure 3**
**US-Canada Electricity Trade Revenue, 1990-2011**

(Canadian Electricity Association 2011)



states. The existing flow of power from Canadian hydro sites goes to a limited number of US states. Historically, much of the trade was limited by long-term fixed rate contracts (i.e. Quebec into New England states) and a limited ability to take advantage of peak markets (see Figure 4).

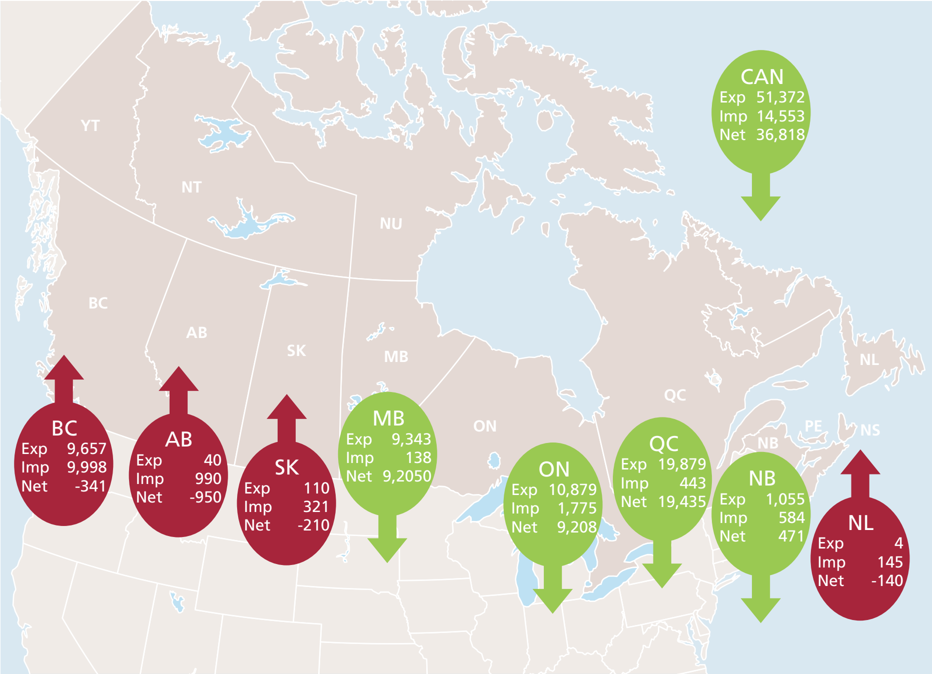


**Figure 4**
**US-Canada Electricity Trade by Province, 2011 (GWh)**

(Canadian Electricity Association 2011; National Energy Board 2013)

With the opening of the markets, sales of electricity currently are through the interactions of power markets (Ontario with New York, Midwest ISO; Manitoba with MISO as well; Quebec with New York, Ontario and New England). The creation of open markets in Ontario and in the Northeast US has resulted in significant changes in how these transactions take place. While 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, developments currently underway will change the situation for these provinces.

Although the direction of the market structures to promote and enable electricity trade is evolving positively, insufficient attention has been paid to the development of the necessary infrastructure to foster electricity trade on a very large scale. For example, developing inter-regional trading hubs could make a significant positive difference in climate change policies.

Figure 5 shows the major transmission arteries between Canada and the US. 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 Manitoba a captive provider.

If a deliberate strategy for increased international and interprovincial exports of clean electricity was to be adopted by provincial, state and the federal governments, then there would be good potential for reducing carbon emissions in the North American context through inter-regional trade[1].

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

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[1] 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.

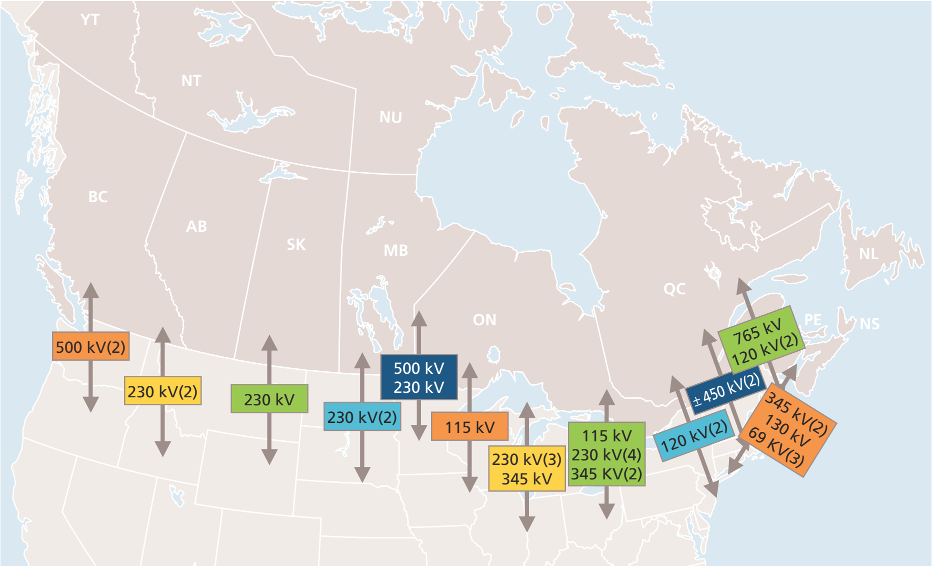

**Figure 5**
**Major US-Canada Transmission Interconnections**

(Canadian Electricity Association 2011)

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 decarbonization 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.

Evidence of Canada's clean electricity advantage is found in the existing installed capacity of the generation supply mix and the low level of greenhouse gas emissions from the generation output. Figure 6 shows the installed base of generation capacity (in GW).

Figure 7 illustrates the significant differences in the mix of generation supplies between the US and Canada on the basis of actual generation (in TWh) as reflected in the capacity utilization of the installed generation base. Whereas Canada has over 75% clean non-carbon energy (nuclear, wind and hydro) in the mix, the US has only a little over 30%. 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[2] of electricity generation compared to 0.58 Mt of $CO_2$ per TWh of electricity in the US (approximately 5

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[2] Alternatively: Canada's emissions = 34 Mt $CO_2$ per EJ and US = 162 Mt per EJ. 1 EJ = 1018 J = 277.7 TWh

**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).

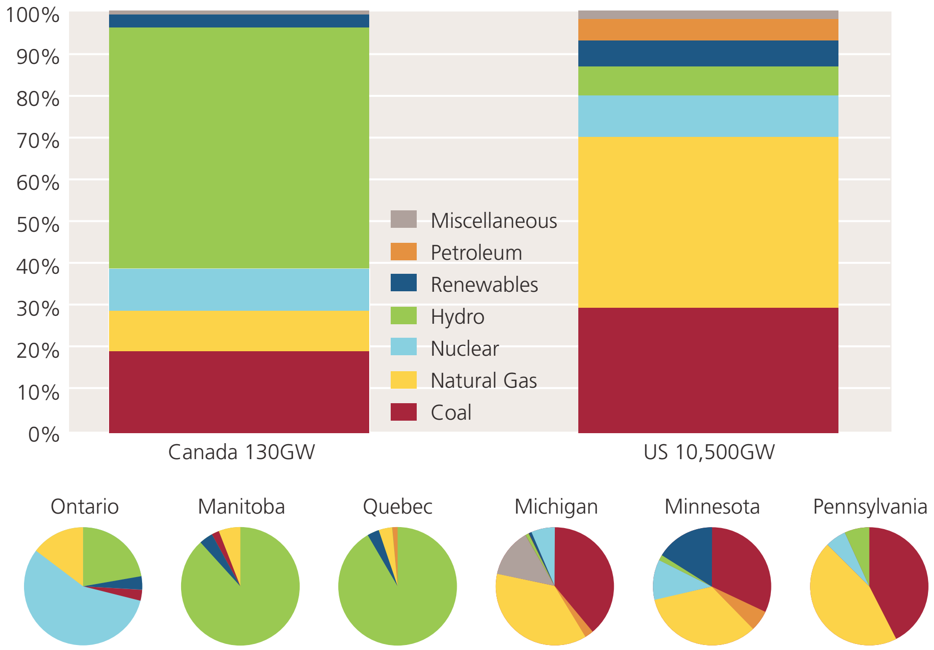
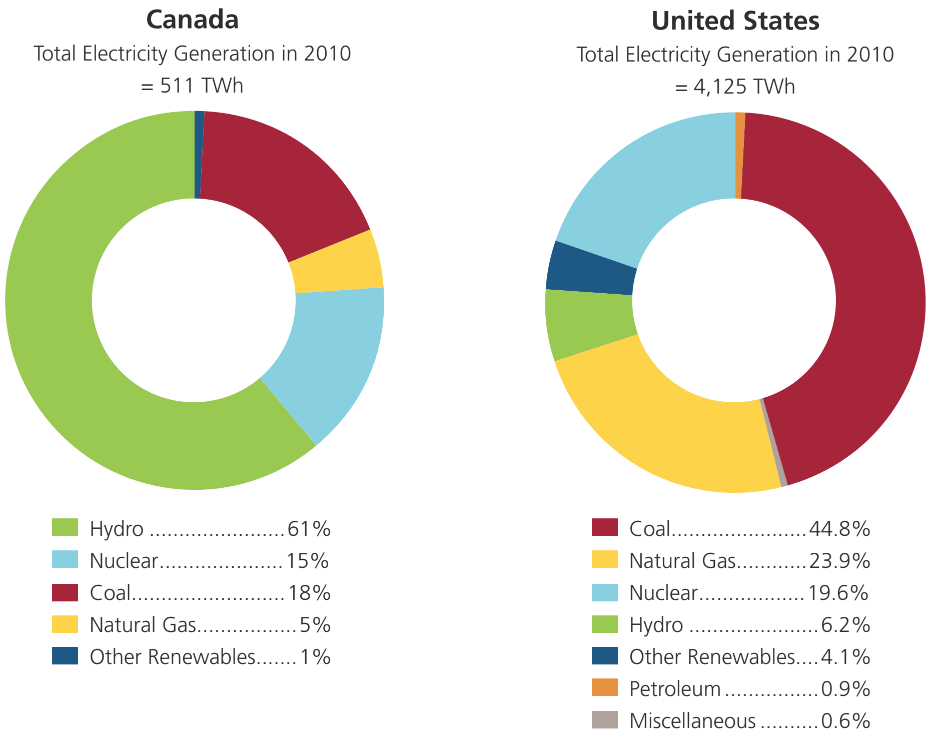


**Figure 7**
**Electricity Generation in the US and Canada by Fuel Type, 2010**

(Canadian Electricity Association 2011)



times higher). Of these resources, hydro, wind and nuclear power are established forms of electricity generation in many regions of Canada. Canada's large natural resource endowment, especially hydropower, coupled with much broader regional development in the coming decades, provides 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 – see Table 1). 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 which is 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 inter-ties that link hydro plants with the US market. Large-scale trade is contingent on future expansion of the transmission capacity.

**Table 1**
**Potential Large Hydroelectric Power Projects in Canada, 2009-25**

(Goodman 2010; Hydro Quebec 2013; Manitoba Hydro 2013; Nalcor Energy 2013)

| 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 |
| | 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 |

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 Table 2 shows both the current installed capacity and near term forecast, there is far more potential for wind in Labrador and other regions of Canada. For example, large scale development of wind with complementary development of hydro at Lower Churchill would be economically feasible if the storage capacity that hydro offers can be integrated with the variable output of wind.

Finally, Canada maintains a strong presence in nuclear power development, with significant technological achievements in the development of the CANDU (CANadian Deuterium

**Table 2**
**Wind Capacity in Canada, 2009 and 2020 (Forecast)**

(Goodman 2010)

| 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 |

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. 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 a piece in 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.

As early as 1999, policy makers recognized the challenges of creating a competitive market for electricity generation in the U.S. and initiated FERC issued Order 2000 to centralize coordination and control of electricity transmission companies into regional transmission organizations (RTOs). Implicit in the order was a clear recognition that operation and control across a broader geography would more efficiently utilize a larger generation resource base, relieve local transmission congestion issues and remove transmission "rate pancaking" that hampers the continued development of wholesale energy markets.

> *"Order No. 2000 is a critical step toward broad market reforms in bulk power markets. It is about operating the nation's greatest energy network – high voltage transmission lines – on a regional basis, with few economic or operational impediments to trade, a high level of transparency and ease of entry and exit."*
>
> James J. Hoecker, Former FERC Chairman, FERC news release, (December 15, 1999)

The importance of expanded access to and from neighbouring regions to support competitive electricity markets has been clearly recognized through various restructurings of the electricity sector around the world.

The concept of expanded transmission capacity and interconnections as part of an inter-regional electricity trading “Hub” creates a wide range of benefits, principally, through lower prices, improved reliability and positive environmental impact.

## Lower Prices

The most significant benefit from an inter-regional trading “Hub” is a more efficient use of generation resources across a broader geography. By strengthening the transmission interconnections and removing inter-regional bottlenecks, the market (and utilities) can more efficiently operate generating resources to meet the hour-by-hour needs of customers across a larger region. Aggregating the generation units would allow the market to utilize limited but valuable resources during periods of high demand (e.g., storable hydro) and to make better use of the operating characteristics of individual plants (i.e., run base-load plants as base-load without having to “back-down” the units during off-peak hours). Without adequate transmission investment, these units would remain isolated or inaccessible within their immediate locations

## Reducing Congestion Costs

Congestion costs are largely driven by local imbalances between supply and demand that are exacerbated by transmission constraints. By improving access to new markets and facilitating larger scale energy transfers, the Hub will help reduce inter-regional congestion costs that underlie market price differentials. Ultimately, decreased congestion results in lower prices to consumers.

## Reducing Price Volatility by Diversifying the Supply Base

Local supply and demand imbalances also contribute to price volatility. Competitive markets that are more physically isolated tend to experience greater volatility in price than those with greater resource diversity and supply liquidity. By creating greater access to generating resources throughout the region, local imbalances can be mitigated as more competitors participate in meeting energy requirements.

Increased interconnectivity also allows a broader geographic region to benefit from access to a more diverse portfolio of generation sources. Interconnections can provide a hedge against outages, equipment failures, and fuel price volatility arising from extreme weather events or bottlenecks in the supply chain for any particular fuel source. Over the past decade, for example, natural gas prices have exhibited sufficient price volatility to suggest unpredictable reversals of low price forecasts. By providing access to a greater mix of generating resources, energy providers can protect against rising natural gas prices (and periodic spikes in the prices of other fuels) and thereby lower the overall cost to consumers.

### Improved Reliability

The future cannot be predicted with certainty and thus a robust network helps mitigate the risks associated with unforeseen events. For example, when a large portion of Ontario's nuclear fleet went down for safety reasons in 1997, the transmission infrastructure protected the citizens of Ontario from rolling brownouts and blackouts. Similarly, during the 1998 ice storm, Ontario's interconnectedness helped reduce the impact of severe energy shortages. Without the inter-ties to surrounding regions, far more than 230,000 households would have lost power as downed transmission lines isolated certain generators from the rest of the grid.

Although the ability to mitigate the impact of a major contingency in the past does not necessarily guarantee energy system security in the future, system planners in various jurisdictions have recognized the values of flexibility and strength that existing regional interconnections provide to enhance reliability. Leveraging a neighbour's assets in times of crisis is good practice. The ability to provide protection by any one utility across a region is a positive, but unintended, consequence of an inter-regional electricity trade system that improves the general robustness of the grid.

### Positive Environmental Impact

An inter-regional electricity "Hub" provides significant environmental benefits through a more efficient use of regional generating resources. By substituting low-emission Canadian hydro and nuclear for high emission thermal generation, aggregate regional emissions are reduced significantly.

As the markets for emissions trading develop, Ontario, and Canada as a whole may be able to realize the financial upside of cleaner electricity resources. In doing so, generators avoid costs associated with the purchase of environmental "pollution credits" and additional equipment required for abatement.

## Enhancing Canadian Regional Integration

Low-carbon 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 currently being developed in Canada. The concept of regional integration opportunities, on a continent-wide scale, is shown in Figure 8.

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 while the US has a summer-peaking system. 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

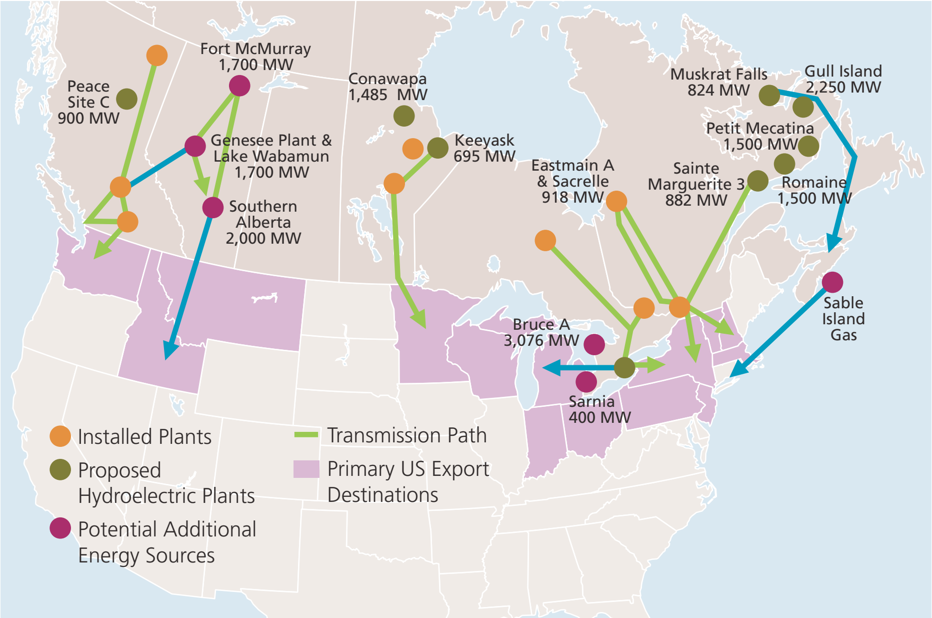


**Figure 8**
**Regional Integration Opportunities**[3]

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 customers would be through lower power rates (Goodman 2010).

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 develop and link Labrador's Lower Churchill hydro-electric capacity via an underwater DC link to Newfoundland with a second underwater DC link between Newfoundland and Nova Scotia and on to New Brunswick and New England is one example (Figure 9). This DC link to Nova Scotia is also a clear example of how 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 to offset variability in wind production and transfer of off-peak base load from Ontario back into Quebec to save valuable hydropower, is another example.

Additional examples include: the British Columbia and Alberta links; expansion of the British Columbia grid into Northwestern BC to serve mining development and to connect to hydro potential in Yukon and Alaska to the British Columbia system; regional integration between Saskatchewan and Manitoba; and New Brunswick's efforts to build itself into an energy hub

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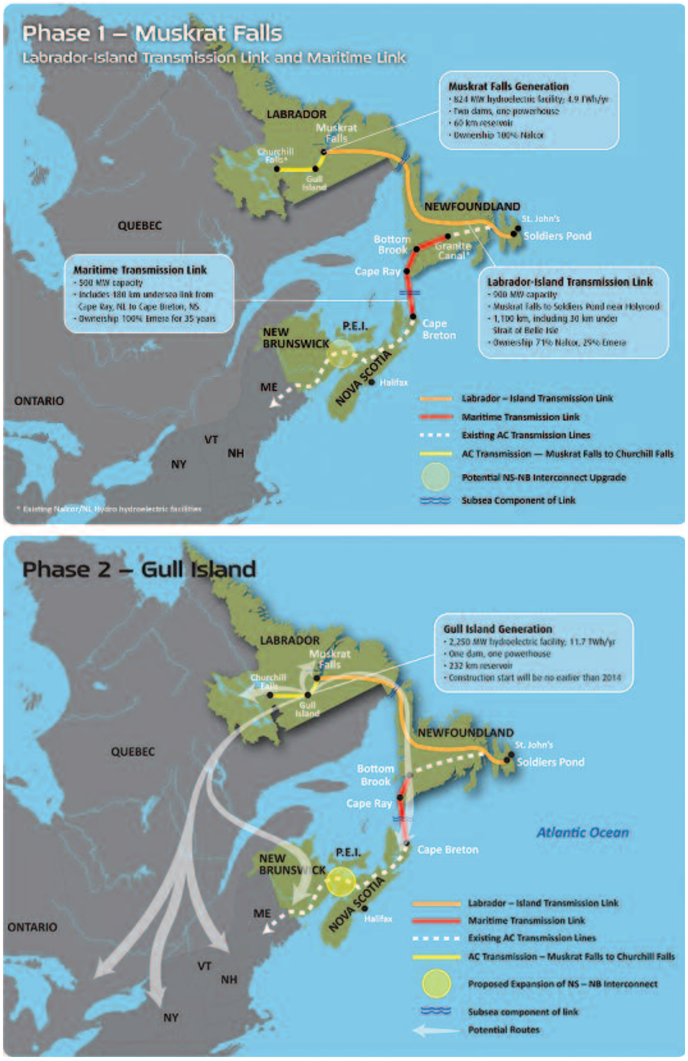
[3] Adapted by the author from various sources: (Goodman 2010; Hydro Quebec 2013; Manitoba Hydro 2013; Nalcor Energy 2013)

**Figure 9**
**Phase 1 and 2 of the Lower Churchill Project.**

(Nalcor Energy 2013)

Further details on the Muskrat Falls project are provided in Chapter 7.



for eastern North America, trading hydro power, nuclear power and natural gas throughout the region. The development of hydro resources in Manitoba (i.e., the Conawapa project) with access through Ontario and to the US markets further 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 US Northwest and Alberta.

The recently completed back-to-back DC link 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 region of Lake Ontario. 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

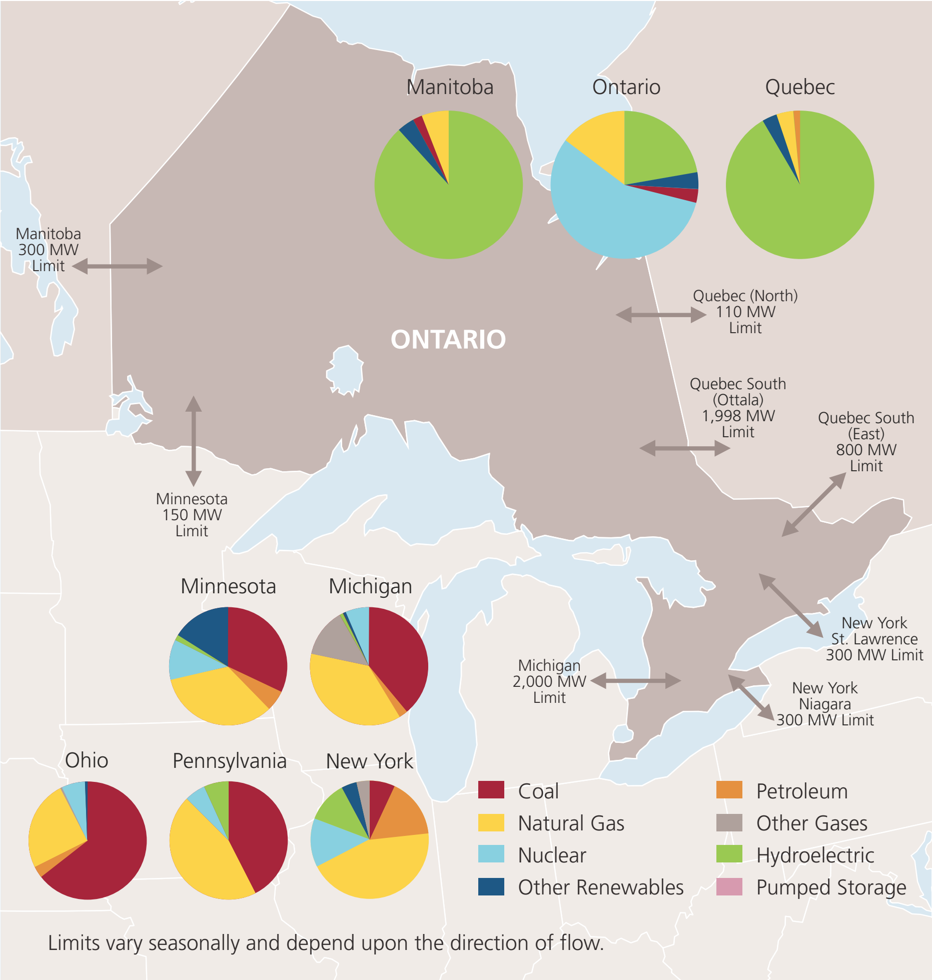
2014. Of all the provinces, Ontario is the most highly connected to neighbouring states and provinces. As shown in Figure 10, Ontario has a diversity of energy supply resources with seventeen interconnections (or circuits) at nine locations with neighbouring jurisdictions.

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 neighbours equal to about 80% of its generating capacity. In stark contrast, Ontario has about 20%. The North Sea underwater grid is currently under development to connect offshore wind projects and significantly enhance linkage among Norway, Sweden, Denmark, Holland, Germany and France.

The principal value of interconnections between multiple markets is not limited to the enhancement of trade flows between one province and a neighbouring 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 Midwest 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 utilization of the storage capacity of the Quebec system would lower prices, reduce price volatility, enhance reliability and improve the environmental benefits.

**Figure 10**
**Ontario Interconnections**

(Center for Energy 2012; Independent Electricity System Operator 2012a, 2012b)



Limits vary seasonally and depend upon the direction of flow.

# Price Regimes and Costs

Realization of the environmental benefits needs a strong economic premise, and it is important to consider the regional and state price regimes along the North-South neighbouring states within the Eastern Interconnection.

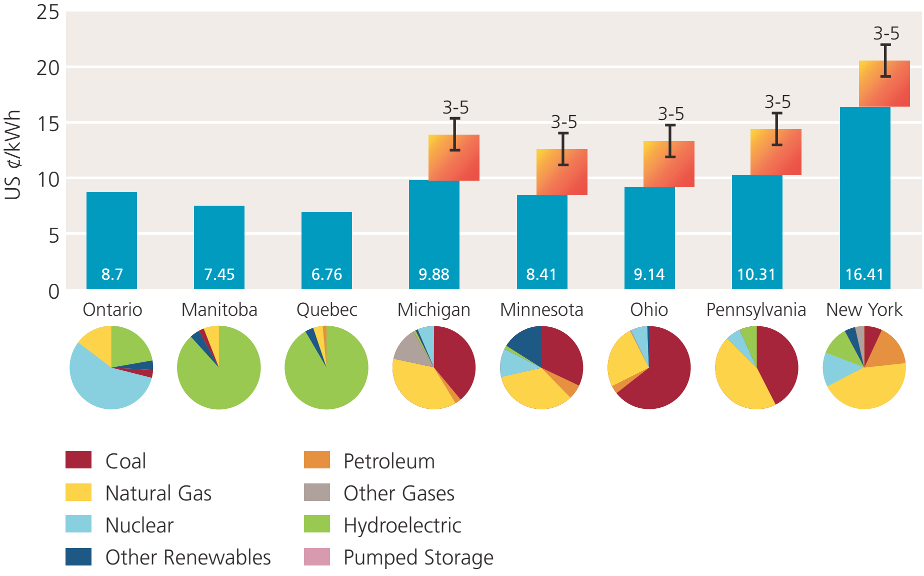
Electricity prices are linked to the supply mix. For those jurisdictions where fossil resources are dominant, the prices tend to be on the lower end of the spectrum. Upward pressures on prices arising from a carbon penalty, however, would change that evaluation. Companies with large emissions must find ways to meet regulations and may find supply of clean power from Canada attractive. Given that there is no established mechanism for pricing carbon, there are 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.

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). A consensus is emerging 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, may foreshadow a strong regulatory commitment from the agency to decarbonization and several utility executives have indicated a commitment to full phase-out of coal fired generation.

Figure 11 is a snapshot of current prices which 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 reflect the cost to the consumers

**Figure 11**
**Comparison of Electricity Prices and Energy Mix in Major North American Cities**[4]

(Center for Energy 2012; Hydro Quebec 2012; Independent Electricity System Operator 2012b; Ontario Energy Board 2013; US Energy Information Administration 2012b)



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[4] 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. www.ontarioenergyboard.ca/OEB/Consumers/Electricity/Electricity+Prices

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 12 illustrates the costs of different generation options. The "levelized cost of energy" (LCOE)[5] 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 by other factors, such as the cost of financing, the cost of regulatory approvals, and available policy incentives.

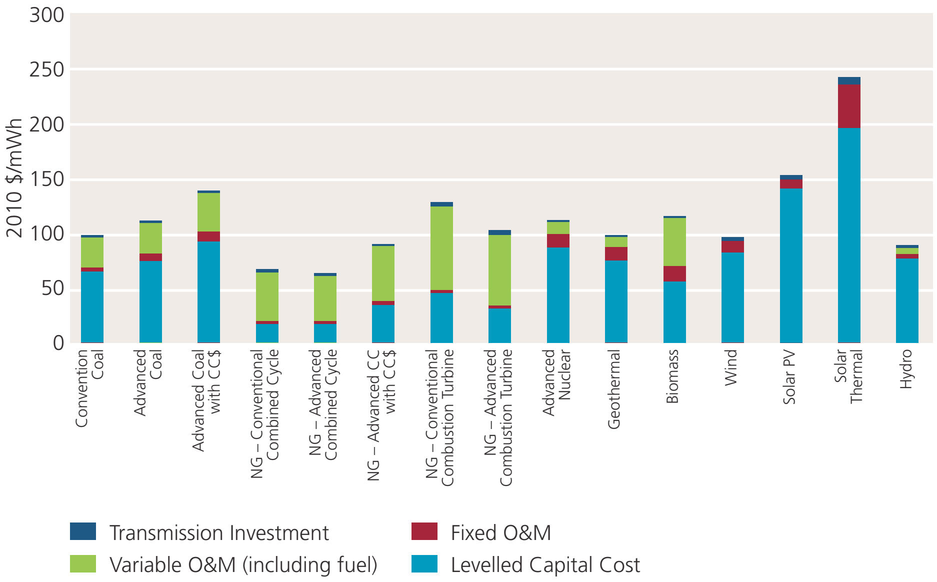

**Figure 12**
**US Average Levelized Costs for Plants Entering Service in 2017**

(US Energy Information Administration 2012a)

The projected utilization rate, which depends on the load shape and the existing resource mix in an area where additional capacity is needed, also affects the investment decision. 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 natural gas generation will usually have a different value than one that would displace existing coal generation (US Energy Information Administration 2012a) based on the unit cost of gas versus coal generation.

A related investment decision factor is the capacity value which corresponds to 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. A 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.

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[5] 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).

Recently, the EIA has developed a metric to provide a more useful tool for comparative analysis (EIA, 2013). The "levelized avoided cost of energy" (LACE) is based on the system value of a generation resource and is derived from the "avoided cost" or the cost of displaced energy and capacity and is presented in "levelized" terms. Similar to the LCOE, which is an estimate of the revenue requirements for a given resource, LACE is an estimate of the revenues available to that resource through an assessment of the generation displaced, on a time-of-day and seasonal basis, and the need for additional generation or capacity resources. A comparison of LCOE to LACE for any given technology provides a quick, intuitive indicator of economic attractiveness; projects have a positive net economic value when LACE is greater than LCOE.

Whereas specific investment decisions would require detailed analysis, 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.

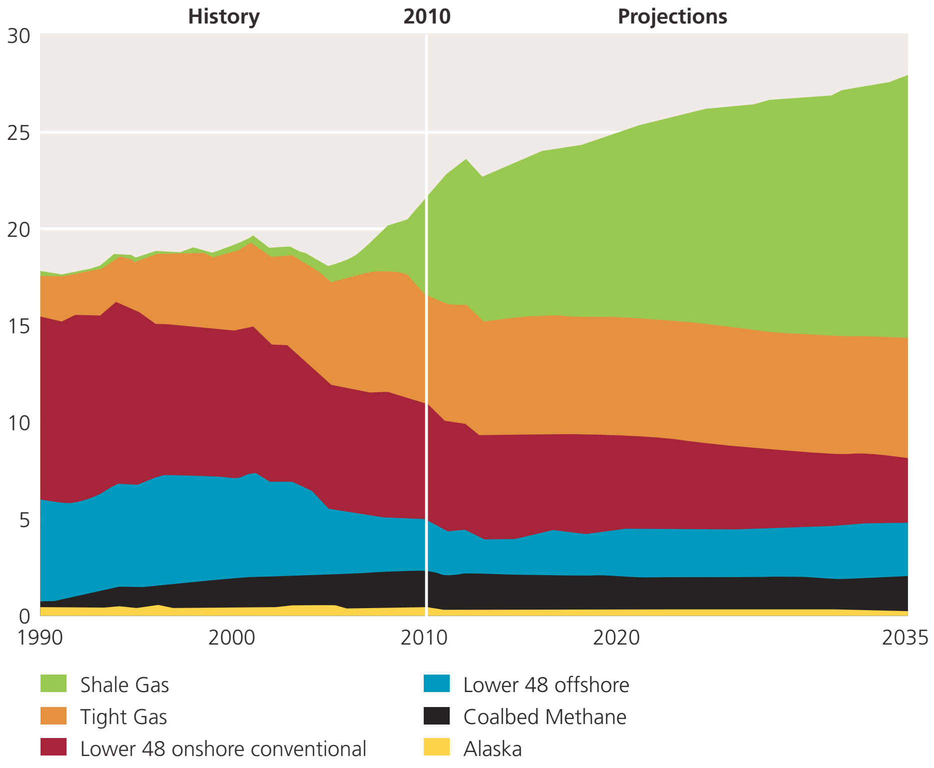
## Shale Gas Impacts

No energy story is complete without including 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 related to energy infrastructure. In the short term, the market dynamics suggest that this is the case and the current glut of gas is an effective and a profitable substitute for reducing coal generation and its associated GHG burden.

The increase in natural gas production results primarily from the continued development of shale gas resources, as shown in Figure 13.

**Figure 13**
**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 is forecasted to account for 49 percent of total U.S. natural gas production by 2035, more than double its 23 percent share in 2010. Estimated proven and unproven 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 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)

The rate at which natural gas prices will 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 – see Figure 14). Alternative cases with different assumptions for these factors are shown in Figure 15. 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 14**
**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)

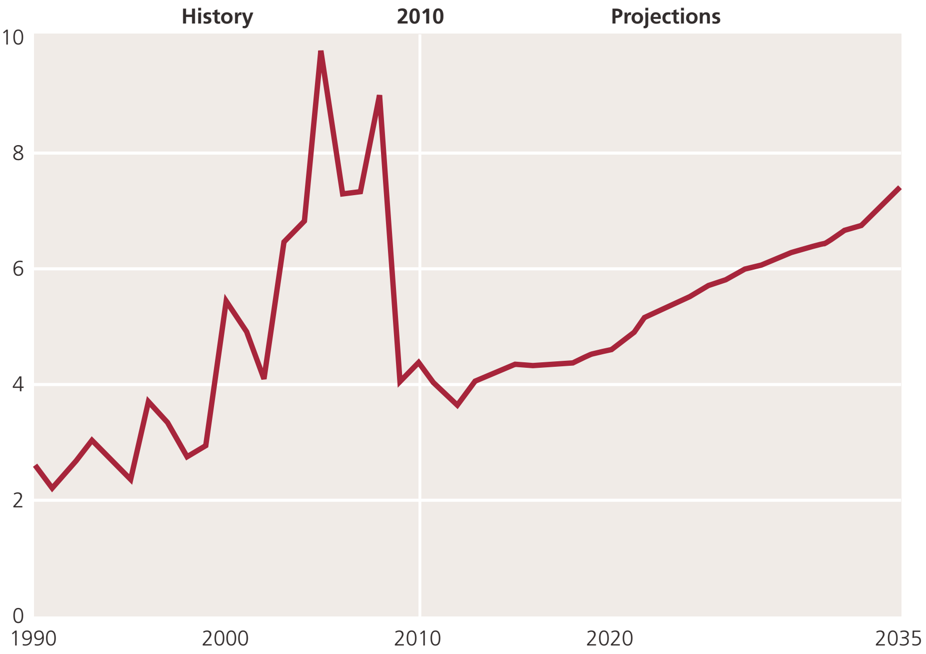
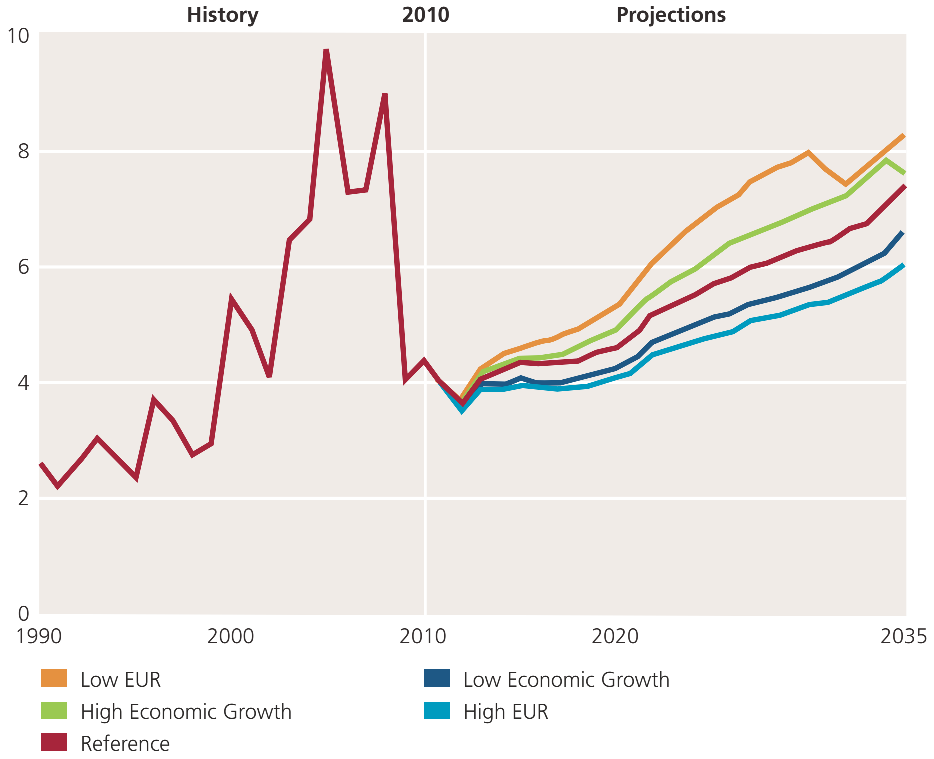


**Figure 15**
**Annual Average Henry Hub Spot Natural Gas Prices in Five Cases, 1990-2035**

(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

U.S. coal production varies across the six cases of Figure 18, 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. As shown in the GHG15 case (Figure 16), 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 US coal production.

From 2010 to 2035, changes in total annual coal production across the cases (excluding the GHG15 case) range from a decrease of 1 percent to an increase of 26 percent.

On average, energy-related $CO_2$ emissions decline by 0.1 percent per year from 2005 to 2035, 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 are projected to 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 an emission reduction requirement of 50% 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.

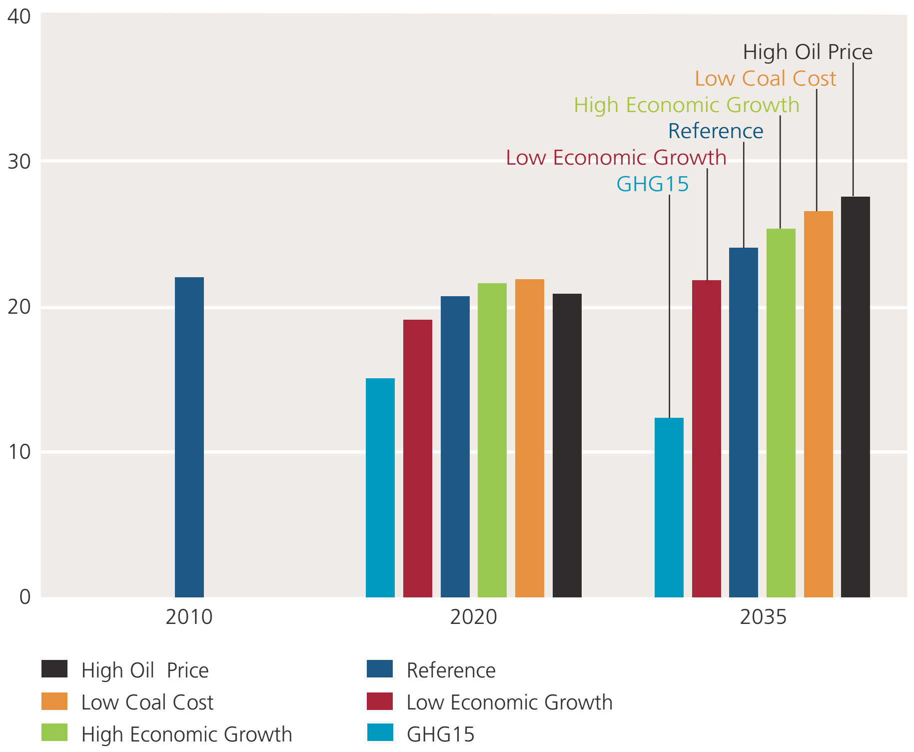


**Figure 16**
**U.S. Total Coal Production in Six Cases, 2010, 2020, and 2035**
(Quadrillion Btu).

(US Energy Information Administration 2012a)

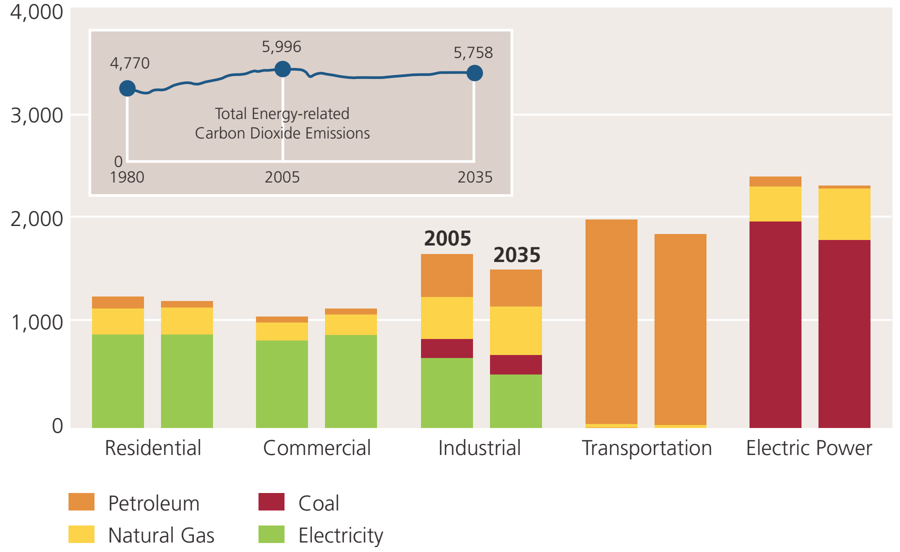


**Figure 17**
**U.S. Energy-related $CO_2$ emissions by sector and fuel, 2005 and 2035 (Million Metric Tons).**

(US Energy EIA 2012a)

In the medium to long term, 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 Figure 17, a carbon penalty of $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 clean energy capacity that is 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 increase the available markets for Canadian generation in the US Northeast and to the south and west of Ontario. Such transmission upgrades would also offer a good possibility for optimizing power flows that can exploit diurnal and seasonal arbitrage through storage of hydro resources. Production from different generation resources can be brought into alignment and optimized for cost and environmental performance even if the generation resources are spread over a large area. The adequacy of transmission capability becomes a key facet of how this can be achieved on a continent-wide scale. This promise needs to be explored fully.

## Summary and Conclusions

In this chapter, it is argued that 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, the promotion of inter-regional trade in electricity. Large scale trade in electricity, across provincial and national boundaries, is a cost effective mechanism for alignment of Canada's climate change policies required for a transition to a low-carbon energy economy.

Enhanced electricity trade – an increase from present levels by ten to twenty-fold or higher to a level greater than $40 billion per year – between Canada and the US offers a strategic environmental and economical advantage that would benefit the entire North American economy. Such an epochal change is conceivable over a 30-50 year time frame consistent with the time lines for achieving a low carbon energy economy.

Realizing the full potential of clean electricity exports from Canada to the US through an expanded power grid requires the provinces, states and federal government to establish a clear policy framework and specific mechanisms to reduce barriers to investment and to the development and approval of specific projects. Upgrades to the existing interconnections and transmission system would be necessary to overcome the current limits to large-scale trade.

Electricity generation is a "high value" manufactured good that has the promise and potential of delivering large economic benefits through inter-regional trade enabled by transmission and interconnections.

To achieve such a goal, however, will require a dramatic shift away from the "provincial self-sufficiency paradigm" to a coherent national energy strategy. Congruent with climate change policies, large scale electricity trade is a promising pathway to a lower carbon energy future for North America. This is in contrast to a climate change policy focused primarily on regulations, targets and treaties.

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## Acknowledgments

The author would like to acknowledge the important contributions of **Mr. Steve Dorey,** Chair of the Energy Council of Canada's Studies Committee, in helping shape the concepts and ideas to foster inter-regional trade in the North American context and **Zhewen Chen** as a co-author for an earlier version of the concept paper. The author would also like to acknowledge the Ontario Council of Universities for support through the Ontario Research Chair Program.

## Biography

Professor **Jatin Nathwani** is the founding Executive Director, Waterloo Institute for Sustainable Energy (WISE). The Institute comprises 95 plus faculty members drawn from all the six faculties at the University of Waterloo. As the Executive Director, he provides leadership to the Institute's research and development efforts to foster the development of large-scale multi-disciplinary research projects in close collaboration with business, industry, government and civil society groups. The vision of the Institute is simple: clean energy, accessible and affordable for all. His current focus is on energy policy developments to enable the social and technological innovations required for the transition of the global energy system to a lower carbon energy economy for long term sustainability. Energy research at WISE spans the full range of renewable energy technologies, energy storage, smart energy networks, sustainable mobility and ICT for micro-power and off-grid access. For additional information, please see: www.wise.uwaterloo.ca. Prof. Nathwani's experience in the Canadian energy sector includes corporate planning and strategy, sector policy developments, regulatory affairs, innovation and R&D linkages and long term plans for the energy sector. He has advised the Ontario Power Authority and the Ministry of Energy on evolving electricity sector issues. Prof. Nathwani serves on several Boards at the provincial and national levels and has appeared frequently in the media (print, TV, radio) and has over 100 publications related to energy and risk management, including seven books.