CANADIAN ACADEMY OF ENGINEERING

Report of the Canada Power Grid Task Force

Volume I
Findings, Conclusions and Recommendations

ELECTRICITY: INTERCONNECTING CANADA – A STRATEGIC ADVANTAGE

GREEN PAPER

Canadian Academy of Engineering

Electricity: Interconnecting Canada
A Strategic Advantage

Report of the Canada Power Grid Task Force
Volume I – Findings, Conclusions and Recommendations

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Electricity: Interconnecting Canada – A Strategic Advantage

PREFACE

The Canadian Academy of Engineering (CAE) is the national institution through which Canada's most distinguished and experienced engineers provide strategic advice on matters of critical importance to the nation. The Academy is an independent, self-governing and non-profit organization established in 1987 to serve the nation in matters of engineering concern. Fellows of the Academy are committed to ensuring that Canada’s engineering expertise is applied to the benefit of all Canadians.

The Canadian Academy of Engineering works with other senior academies in Canada and abroad. It is a founding member of the *Council of Canadian Academies (CCA),* along with the *Royal Society of Canada* and the *Canadian Academy of Health Sciences.* It is a member of the International Council of Academies of Engineering and Technological Sciences (CAETS), which includes some 26 similar national bodies around the world.

The Academy also collaborates with the constituent members of the *Canadian Engineering Leadership Forum, i.e., Engineers Canada,* the *Engineering Institute of Canada,* the *Association of Consulting Engineering Companies - Canada,* the *National Council of Deans of Engineering,* and the *Canadian Federation of Engineering Students.* Jointly, we are all committed to ensuring a safer, cleaner, healthier and more competitive Canada.

In 2007, the Academy published the *Energy Pathways Task Force Phase 1 – Final Report* which recommended a major upgrade to Canada’s electrical infrastructure, including improved access for wind and solar energy sources and enhanced capacity for energy storage. The report resulted in a follow-up project that develops the case for expanded electricity connections in order to meet Canada’s electricity needs for the next 25 years. The findings and conclusions of this project are documented in the Report of the Canada Power Grid Task Force – *“Electricity: Interconnecting Canada – A Strategic Advantage”.* The report, which is in two parts: *Volume I - Findings, Conclusions and Recommendations* and *Volume II - Background and Assessment,* provides the basis and focus for an informed debate on the opportunities afforded by “interconnecting Canada” with the view to ensuring that the nation’s electricity needs are met in a sustainable and environmentally sound manner.

On behalf of the Canadian Academy of Engineering, I wish to thank the authors and the many other contributors to a most valuable report.

Dr. Axel Meisen, FCAE
President, Canadian Academy of Engineering
December 2009

Electricity: Interconnecting Canada
A Strategic Advantage

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Electricity: Interconnecting Canada
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1. THE SITUATION AND OUR RECOMMENDATIONS

Canada's electricity system was designed and built historically on a province by province basis, with limited emphasis on provincial interconnections. This report has addressed the question of whether Canada should invest in enhanced east-west electrical interconnections. We have been told with current business practices that this would negatively affect ratepayers and that economics for new interconnections favour north-south connections to the U.S.

The climate change imperative and the potential for new low GHG emitting generation are important signals that the situation has changed. The International Energy Agency has estimated that Canada's electricity sector will require US$190 billion in new investment from now to 2030. This may be the time to consider strategic national electrical infrastructure investments.

Energy may be Canada's last chance to achieve *a sustainable competitive advantage*, something we have not succeeded in building in other key sectors of the economy. We have a unique opportunity to prepare an electrical energy plan that is more than the sum of its parts.

Recommendations

It is recommended that the Federal Government:

1. **As an Immediate Infrastructure Project**, fund on a cost-shared basis with provinces and possibly the private sector, new electrical grid interconnections between two or more provinces based on cost-benefit analyses of the longer-term national strategic value of achieving some of the following goals: a) reduced GHG emissions through improved access by renewables such as large hydro and wind, b) enhanced energy storage capability, c) reduced energy costs by the receiving province(s), d) new markets for stranded or new power generation, and e) the strategic security advantages of developing a high capacity trans-Canada transmission backbone.

2. **As a Long Term Plan**, establish and fund a Cross-Sectoral Management Entity to prepare a technology and business framework for the electrical industry investments needed over the next 25 years to capture wealth generation opportunities and to address GHG issues. The entity should examine initially two scenarios (a) the interconnection and strengthening of the Canadian electricity grid, enabling the passage of large blocks of power both east-west and north-south to the U.S., (b) the above 'basic' scenario, with expanded interconnections to an anticipated U.S. east-west electrical grid to provide an intercontinental electrical network.

Electricity: Interconnecting Canada – A Strategic Advantage

2. EXECUTIVE SUMMARY

The Canadian Academy of Engineering's Energy Pathways Task Force Phase 1 Report recommended a major upgrade to Canada's electrical infrastructure with improved access of wind and solar energy sources and enhanced capacity for energy storage[1]. This led to this follow-up project to develop a case for expanded electricity interconnections to meet the needs of Canada for the next 25 years. The findings and conclusions of this project are highlighted below.

The Situation/Challenges	The Opportunities
The Question Does Canada need enhanced east-west electrical grid interconnections? Two arguments have been advanced against this: a) with current business practices there would be a negative effect on ratepayers and b) economics for new interconnections favour north-south connections to the U.S.	**But is this our best long term view?** The climate change imperative and the potential for new low-GHG emitting generation are important signals that this may be the time for national electrical infrastructure investments, particularly in the transmission area, east-west and north-south.
The climate change issue Canada has the image of a producer of 'dirty oil' and as a laggard in greenhouse gas emission reduction. This could limit our export trade in energy products.	**The true story** Canada's release of GHG is 34 megatonnes per exajoule from electricity generation. The comparative figure for the U.S. is 162. This advantage should be promoted if increasing exports are to be achieved.
An aging electricity infrastructure Canada's electricity system was designed and built many years ago. Seventy-three percent of the electricity that Canada produces is from low-GHG emitting capacity, mainly hydro and nuclear. Two thirds of the remainder (high-GHG emitting technology) is over 30 years old, which provides opportunities for replacement with lower GHG emitting technology (i.e. hydro, nuclear, renewables and fossil fuels, using CO_2 capture.)	**Interconnections as enablers** Benefits of interconnections include: • Increased access to generation capacity • Expanded export capacity • Time-shifted peak loads • Liberated stranded electrical power • Energized key energy corridors

[1] Canadian Academy of Engineering – Energy Pathways Task Force Phase 1 Final Report, May 2007

<table>
<tr>
<td>Demand is increasing
The world is evolving increasingly to an electrical economy, with greater demand in the consumer, commercial and industrial sectors. Use in the transportation sector is small today but expansion could be rapid.</td>
<td>Canada can meet any expected demand
Canada can increase electricity supply significantly in:
• Traditional hydro
• Nuclear
• Coal gasification (with CO_2 capture)
With increasing contributions from renewable power (e.g. wind, solar, biomass) and energy storage (e.g. pumped hydro)</td>
</tr>
<tr>
<td>The International situation
Canada exports 4% of the electricity it generates to the U.S. The U.S. has no plans to increase its import of electricity from Canada but ‘grid collaboration’ was discussed in recent meetings between the Prime Minister and the President. The U.S. is developing a conceptual plan for a major new grid network to accommodate renewable energy.</td>
<td>An export goal
Electricity is not a commodity – it is a value-added energy currency. Canada can retain and expand its export market by strengthening its own grid and developing an agreement with the U.S. and Mexico to link clean Canadian electricity to continental and intercontinental markets.</td>
</tr>
<tr>
<td>Limitations of the current design
Opportunities to distribute electricity from regions with excess supply (now stranded) to those with increasing demand, and to meet time dependent peak loads are limited. Canada at present has more electrical connections with the U.S. than it has among all the provinces (34 to the U.S. compared to 31 among provinces). The interprovincial connections tend to have small transfer capabilities whereas many of the connections to the U.S. can transfer quantities equivalent to the output from major hydro or nuclear plants.</td>
<td>Building on current plans
A number of grid expansions to meet increases in forecast regional demands are already in the planning stage. Expanding, completing and adding new interconnections would give Canadian industry and consumers a reliable and long term supply of power, with the ability to wheel large amounts of power to U.S. grids. There are new and emerging technology options for:
• Strengthening and increasing transmission capacity (e.g., FACTS devices such as static var compensators)
• Long distance electricity transmission,
• Short term and long term energy storage,
• Smart grids for consumer load management and grid control
• Improved grid access by renewable energy sources such as wind and solar.
• New analytical tools and models to help in the design of system architecture.</td>
</tr>
</table>

Canada's energy challenge Previous studies have stressed that Canada's energy endowment should increasingly be viewed as an integrated system, with strong interconnected flows of electricity, feedstocks, products and by-products, including fossil fuel derived fuel and chemical products, hydrogen, and carbon dioxide. There are opportunities to improve system integration and reduce the CO_2 footprint (e.g. use nuclear energy, or coal gasification with CO_2 capture).	**Completing the energy system** In combination with our extensive gas and oil pipelines, expanded electrical interconnections will complete our energy corridors and ensure that they are internationally competitive. Such corridors may also house associated pipelines for hydrogen and carbon dioxide servicing the electrical and petrochemical industries.
Canada's jurisdictional complexity Electrical power is the responsibility of provincial governments, with an increasing number of participants in the generation/transmission system, and more participation by the private sector. This increases the complexity and difficulty in developing a coordinated national strategy and plan.	**Need and role of a coordinated plan** There is a commonality of goals across the country, such as increasing the use of low-GHG emission technologies, ensuring reliable and secure energy supplies, maintaining consistency with North American transmission standards, and expanding renewable sources of electricity. With so many players, this increases the importance of having a national strategy that is more than the sum of regional projects, which by themselves will only marginally expand existing North-South connections to the U.S.
Investment Forecast The International Energy Agency has estimated that Canada will spend US$190 B until 2030 for new investments in the electricity sector. Part of this amount is for planned interconnections.	**Investment considerations** It is not reasonable to expect provincial ratepayers to fully fund Canada's longer term energy and environmental goals. The incremental costs for enhancing planned interconnection capacity to help reduce Canada's GHG footprint could be funded as a long-term Canadian strategic infrastructure investment. Such incremental costs need to be determined.

Recommendations

It is recommended that the Federal Government:

1. **As an Immediate Infrastructure Project**, fund on a cost-shared basis with provinces and possibly the private sector, new electrical grid interconnections between two or more provinces based on cost-benefit analyses of the longer-term national strategic value of achieving some of the following goals: a) reduced GHG emissions through improved access by renewables such as large hydro and wind, b) enhanced energy storage capability, c) reduced energy costs by the receiving province(s), d) new markets for stranded or new power generation, and e) the strategic security advantages of developing a high capacity trans-Canada transmission backbone.

2. **As a Long Term Plan**, establish and fund a Cross-Sectoral Management Entity to prepare a technology and business framework for the electrical industry investments needed over the next 25 years to capture wealth generation opportunities and to address GHG issues. The entity should examine initially two scenarios (a) the interconnection and strengthening of the Canadian electricity grid, enabling the passage of large blocks of power both east-west and north-south to the U.S., (b) the above 'basic' scenario, with expanded interconnections to an anticipated U.S. east-west electrical grid to provide an intercontinental electrical network.

As a post-script

Energy may be Canada's last chance to achieve a sustainable competitive advantage, something we have not succeeded in building in other key sectors of the economy. The benefits of ensuring that such investments are undertaken with future needs in mind are well demonstrated by the foresight in adding a lower deck for the Bloor-Danforth viaduct in Toronto for the subway line that was built several decades later. The national will and leadership that built our railways, the airport network, pipelines, and the St. Lawrence Seaway is urgently needed for the Canadian electric power sector.

3. INTRODUCTION

The Canadian Academy of Engineering's Energy Pathways Task Force Phase 1 Report recommended that Canada proceed with three National Technology Projects[2].

- Gasification of fossil fuels and biomass
- GHG emission reduction (carbon dioxide capture followed by transportation, long term storage and/or use)
- Upgrades to electrical infrastructure, with improved access by wind and solar sources, and capacity for energy storage

This report focuses on the upgrades to electrical infrastructure for enhanced interconnections for the Canadian electricity grid. Such a grid would provide the opportunity for the provinces to operate their power systems more effectively, while at the same time providing significant reductions in greenhouse gas emissions.

The current situation regarding electrical transmission systems can be described as follows:

- Canada is moving towards a national position on the question of climate change and GHGs.
- The Canadian Chamber of Commerce has noted[3] that 'a substantial amount of Canada's power potential is stranded because there is no transmission grid to tap that power and ship it to market'.
- Newfoundland and Labrador Hydro has stated that[4] '…without sustained action on a strong east-west grid that will support this country's growing demand for clean energy, Canadians may find themselves squandering a key competitive advantage…'.
- The United States is investigating several inter-regional connections to add to their grids, driven in large part by planned expansion of renewable energy. These include reinforcing the north-south intertie in the Western states to provide power for Nevada and California and connections from the Great Plains with load centers to the east and west.

A National Advisory Panel on Sustainable Energy Science and Technology has stressed the importance of seeing the Canadian energy sector as "an integrated system with strong interdependence between producers and users of energy"[5]. This provides urgency in examining the interconnection of electricity with the other energy 'currencies' in Canada's major energy corridors. New infrastructure may be needed to capture the full value of Canada's extensive energy resources. With the current economic downturn this would be the appropriate time to make energy infrastructure investments that would have long term economic, social and environmental benefits.

[2] Canadian Academy of Engineering – Energy Pathways Task Force Phase 1 Final Report, May 2007
[3] Canadian Chamber of Commerce, Development of a National East-West Grid Plan, 2007
[4] Globe and Mail, Report on Business, August 25, 2008
[5] Powerful Connections, Priorities and Directions in Energy Science and Technology in Canada, Report of the National Advisory Panel on Sustainable Energy Science and Technology, 2007

Two scenarios describe options for an upgraded Canadian electrical transmission system:

Scenario 1: Greater interconnection and strengthening of the Canadian provincial grids, enabling the passage of greater blocks of power both east-west and north-south to the U.S.

Scenario 2: Scenario 1, with expanded interconnections to an anticipated U.S. east-west electrical grid to provide an intercontinental electrical network.

The technology available has changed considerably since the current Canadian electrical system was put in place. Two specific advances are the use of extra- and ultra- high voltage AC and DC transmission and the potential for energy storage; both are examined in this report. The U.S. Department of Energy "Roadmap"[6] describes another important technology objective, namely the need for analytical tools as well as techniques to overlay next generation technologies onto the existing grid. More sophisticated control strategies are also needed, such as the asymmetric operation of transmission corridors, and many others. The following excerpt expands on this need.

> *"Whether a national backbone develops along a predominantly evolutionary or revolutionary path, there are a number of technical challenges that must be addressed in the design of the architecture of the system through research, development, and demonstration projects. The most urgent challenge to address is the lack of analytical tools, as well as an organizational research infrastructure, to properly model the nation's entire electric grid. Such tools will be needed to develop conceptual designs and system requirements. Improved tools are also needed to simulate and analyze the alternative technology pathways for the national electricity backbone, including the design and costs and benefits".*

In addition to specific technology changes, there has been a decrease in the enrolment of students in power engineering courses across Canada. Combined with the expected retirement of teachers and practitioners active in this field, this leads to a major concern regarding Canada's ability to undertake ambitious new electric power projects.

A key concept considered by the Task Force was the value in building infrastructure not just for immediate short term needs but preparing for game changing future needs. A Toronto example began circa 1910, when architect Edmond Burke and engineer Thomas Taylor designed the Bloor-Danforth viaduct to span the Don Valley. They anticipated that, before the close of the just opened-century, Toronto would build a subway system requiring a Don Valley crossing. So they designed and built the bridge with a lower deck to accommodate subway trains. The decks for a "future" subway added but a modest increase to the construction cost. But when the first trains on the Bloor-Danforth line crossed the Don Valley in 1954, this was a reminder of our forefathers' foresight.

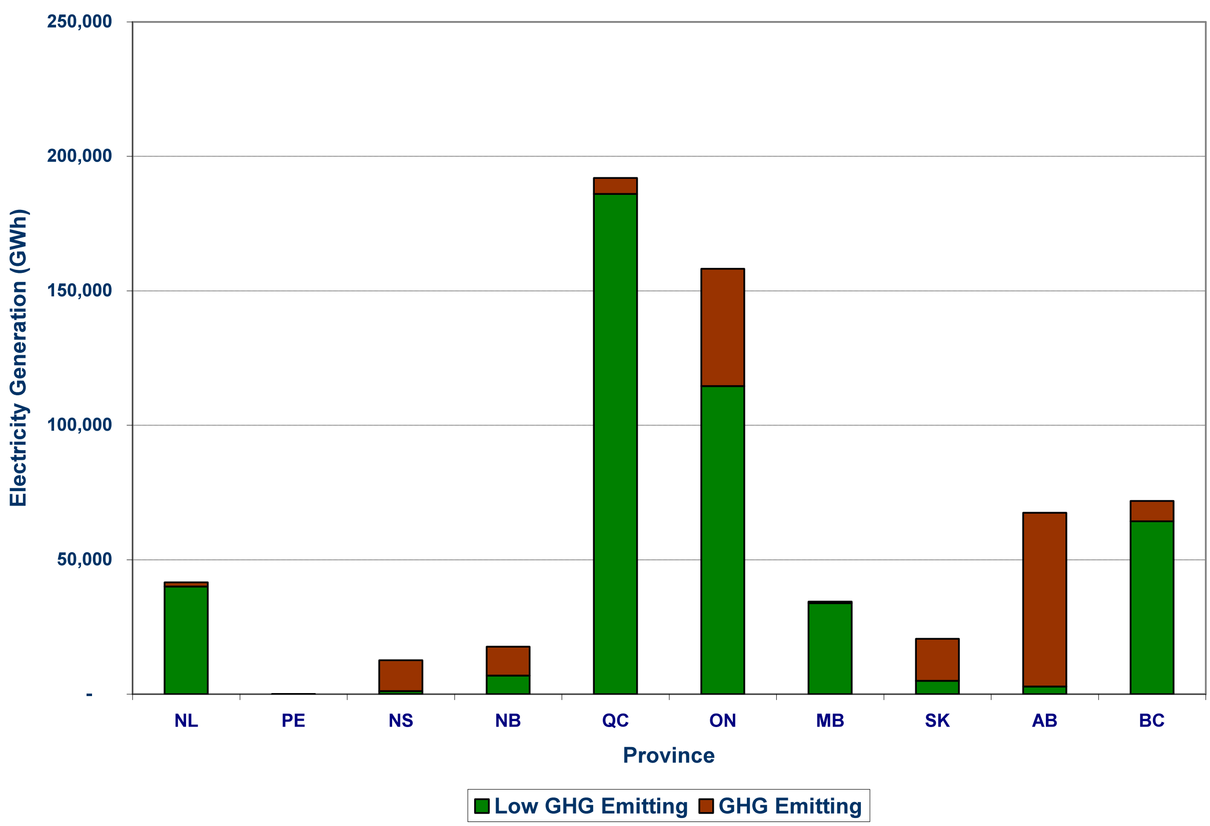
Given Canada's abundant capacities of hydropower in combination with a foreseeable more electricity-intensive economy (including automotive transportation), Canada could become a carbon neutral economy, delivering a sustainable competitive advantage, for which an integrated and comprehensive electrical grid would represent a significant asset. The above factors make this an important time to examine the Canadian electrical industry and its relation to Canada's energy future. This has been undertaken in this project with a summary of the examination described in the following sections. The full description of the examination is provided as an Annex to this report.

[6] National Electric Delivery Technology Roadmap – Transforming the Grid to Revolutionize Electric Power in North America – January 2004

4. OVERVIEW OF THE ELECTRICAL INDUSTRY IN CANADA

Most provinces are close to being self sufficient in electricity. Canada exports 4% of the electricity it generates to the U.S. In 2007, 73% of the electricity that Canada produced was from low-GHG emitting capacity, mainly hydro and nuclear. Of the remaining high-GHG emitting capacity, 65% of this is over 30 years old, providing opportunities for replacement with lower GHG emitting technology, (e.g. hydro, wind, solar biomass and fossil fuels with carbon capture). The ratio of low to high GHG emitting generation for each province is given in Figure 4.1.

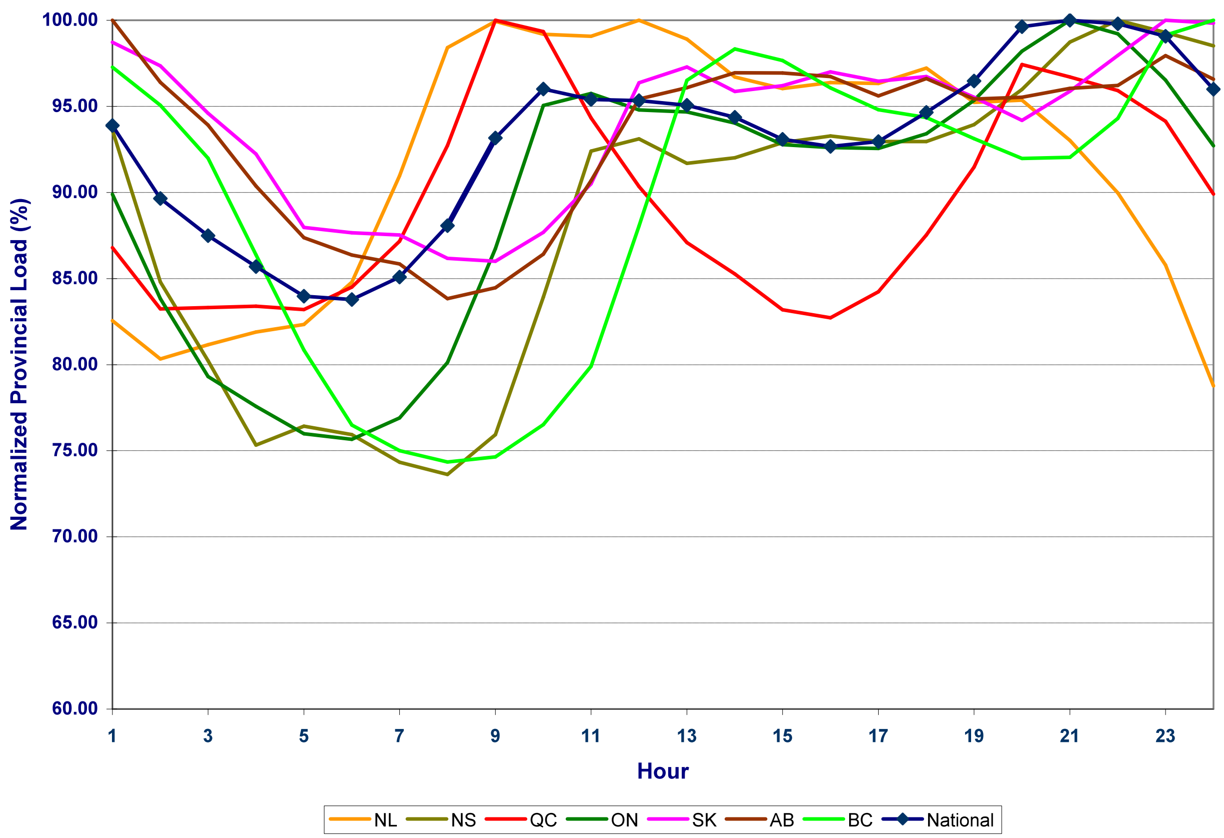
Figure 4.1 – Electrical Generation (GWh) in Canada – 2007[7]



All provinces, except Ontario, have their peak demands in winter. This suggests that an interconnected grid would allow Ontario to reduce its peak load generating capacity in summer by a shift in power from provinces to the east or west of Ontario. Due to the number of time zones within our nation, the real-time national load requirement indicates excess capacity in hours 3 to 7 which could be shifted one or two time zones to match provincial loads, or captured by improved storage technology. Quebec has a significant excess capacity from hours 13 to 18 which could be shifted east or west, or south to a U.S. grid which peaks in the summer overall. These lags in load requirements are captured in Figure 4.2 whereby all loads are set to Atlantic Time.

[7] Electric Power Generation, Transmission and Distribution – 2007, Statistics Canada

Figure 4.2 Hourly Load Variation (%) Over 24 Hours[8]



Although responsibility for electrical power is that of provincial governments, there are an increasing number of participants in the generation/transmission system, with more participation by the private sector. This increases the complexity and difficulty in developing a coordinated national strategy and plan. With so many players, it also increases the importance of having said strategy and plan to be more than the sum of regional projects.

It is also significant that there is a commonality of goals across the country, such as increasing the use of low-GHG emission technologies, ensuring reliable and secure energy supplies, maintaining consistency with North American transmission standards, and expanding the development of renewable energy sources. There are opportunities for collaboration on specific objectives, for example: the development of low-GHG emission technology for fossil fuels in Nova Scotia, New Brunswick, Saskatchewan, and Alberta; the development of effective storage technology in Newfoundland and Labrador, Quebec, Ontario, Manitoba and British Columbia; facilitating an interconnection between Manitoba and Ontario which would encourage the flow of GHG-free electricity in either direction between eastern and western networks; participation in international programs on advanced nuclear reactors by Quebec and Ontario; load sharing across the country by improved high voltage long distance transmission and/or export to a continental market.

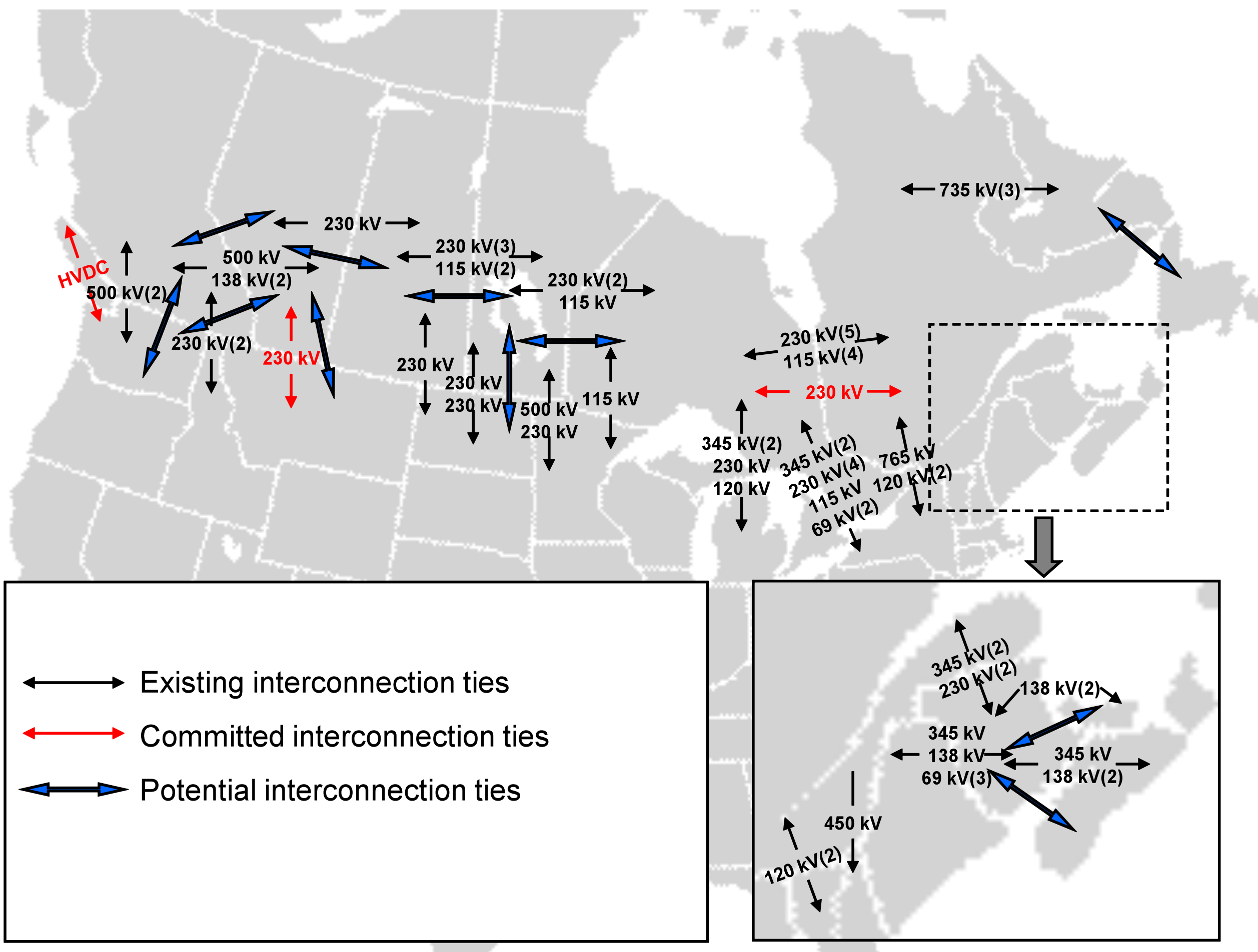
[8] Private communication from various electric utilities, and Internet sources

5. EXISTING AND PLANNED INTERCONNECTION PROJECTS

Canada at present has more electrical connections with the U.S. than it has among all the provinces (34 to the U.S. compared to 31 among provinces). In addition, the interprovincial connections tend to have small transfer capabilities whereas many of the connections to the U.S. can transfer quantities equivalent to the output from major hydro or nuclear plants.

Several new major interconnections are being considered by various planning authorities, including a line to transfer power from a future Lower Churchill Falls project in Labrador to New Brunswick, a line across Confederation Bridge feeding potential expansion in wind power in Prince Edward Island to New Brunswick, a connection to bring Manitoba hydro power to Ontario, possible connections for transferring power from Labrador directly to Ontario, potential for capacity increases in the connections between Manitoba and Saskatchewan, a second Alberta-BC interconnection and a new line from Fort McMurray Alberta through BC to the U.S. The existing, committed and potential interconnections are shown in Figure 5.1.

Figure 5.1 Existing, Committed and Potential Interconnections Lines Between Jurisdictions



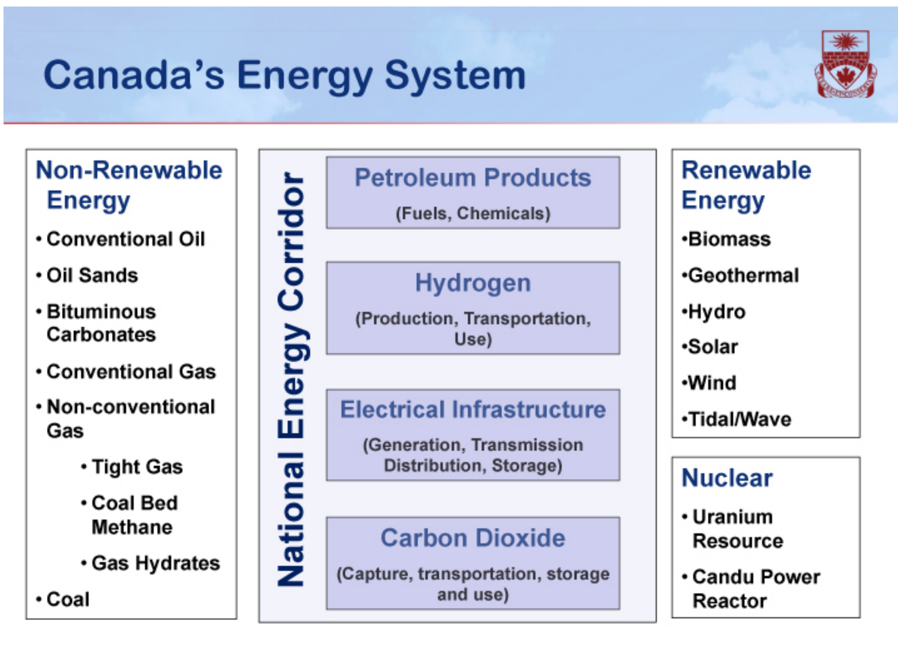
New interconnection projects will continue to be justified on the basis of the respective economics of each interconnection. It would seem reasonable to consider undertaking a strategic evaluation of a strengthened east-west grid capacity with the above interconnections forming important and key links. Opportunities for distributed regional renewable energy sources to tie into the grid would increase the attendant opportunities to bring such renewable energy sources to wider markets through an appropriately interconnected network of provincial grids.

It is not hard to visualize that the committed and potential interconnections shown in Figure 5.1 could evolve into a future national east-west grid. But it would be prudent to ensure that new interconnections have the ‘head room’ to meet all expected future requirements (as was done with the Bloor-Danforth viaduct).

6. ELECTRICAL GRID – RELATION TO CANADA'S ENERGY CORRIDORS

Previous studies have stressed that Canada's energy endowment should be viewed as an integrated system, with strong interconnected flows of feedstocks, products and by-products, including fossil fuel derived fuel and chemical products, hydrogen, electricity and carbon dioxide. Figure 6.1 defines the constituents of Canada's energy system, various energy sources, renewable and non-renewable, and the derived products and by-products.

Figure 6.1 Constituents of Canada's Energy System



Canada's release of GHG per exajoule of electrical power is 34 megatonnes versus 162 in the U.S. Canada's electrical generating capacity is one of the lowest GHG emitting in the world, with 73% of its capacity derived from non-GHG emitting technology.

GHG emissions from oil sands production are much higher than from conventional oil recovery. However, there are opportunities to significantly reduce GHG emissions from the oil sands through improved system integration, for example by using low-GHG emitting inputs, as illustrated in Table 6.1.

Table 6.1 Options for Low-GHG Inputs to Oil Sands Processing

Energy Inputs for Oil Sand Production	Current Processes (high-GHG emitters)	With Energy Integration (low-GHG emitters)
Heat	Burning coke, residues, coal	Nuclear
Hydrogen	Reforming natural gas	Renewable or nuclear electricity or coal gasification with CO_2 capture and storage, or thermo-chemical production of hydrogen.
Electricity	Burning coal	Electricity from renewable, nuclear, or coal gasification with CO_2 capture and storage.

The ability to upgrade resources inside Canada can best be accomplished in Canada's energy corridors – for petrochemicals, the Alberta Industrial Heartland and the Sarnia/Lambton Petrochemical and Refining Complex are such examples. An examination of Canada's record in other sectors of the economy indicates that its failure to develop a capability from raw materials to upgraded value-added products has prevented it from achieving a sustainable leadership position.

7. DRIVERS AND SHAPERS

Supply Side Issues:

Hydroelectric power is a major Canadian strength and now provides about 57% of Canada's energy production (73,000 MW generating capacity) and there is the technical potential to more than double this as illustrated in Table 7.1. Hydro power is site specific and usually involves long transmission lines to load centres. Seasonal variability and storage are key factors in hydro site design. However, Canada has the ability to significantly increase its electrical generating capacity by harnessing clean, **dispatchable** and exportable hydropower that brings with it an immense, sustainable, competitive advantage.

Table 7.1 – Hydropower Generation: Present & Untapped Potential (MW)

Provinces / Territories	Present[9]	Untapped Potential [10]
Alberta	909	11,775
British Columbia	12,609	33,137
Manitoba	5,029	8,785
New Brunswick	923	614
Newfoundland & Labrador	6,796	8,540
Northwest Territories	25	11,524
Nova Scotia	404	8,499
Nunavut	0	4,307
Ontario	8,350	10,270
Prince Edward Island	0	3
Québec	37,459	44,100
Saskatchewan	855	3,955
Yukon	78	17,664
Canada	**73,437**	**163,173**

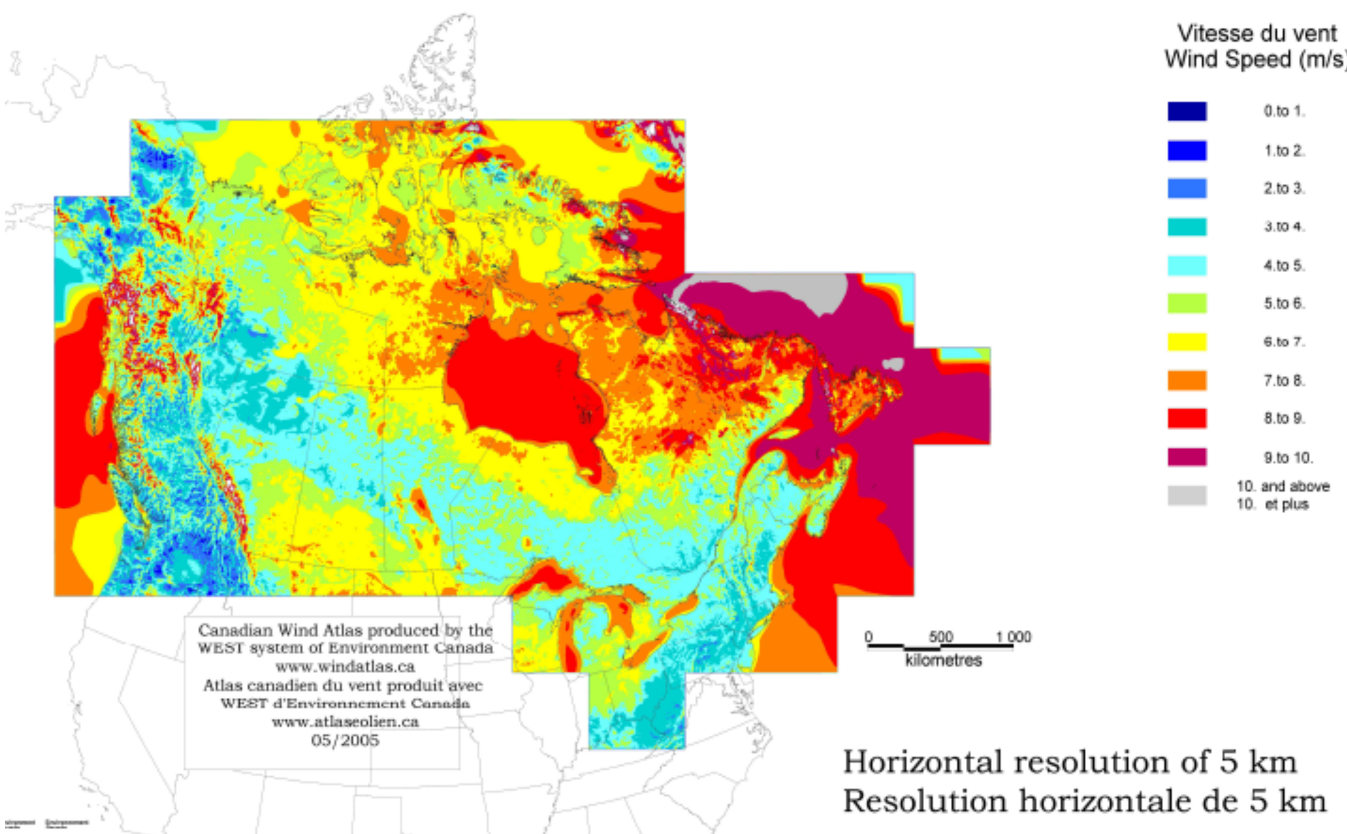
Wind power provides about 0.5% of Canada's electrical power. The availability of higher quality (i.e. higher average wind speed and lower cost) potential is site specific. High quality potential sites are widely

[9] Electric Power Generation, Transmission and Distribution – 2007, Statistics Canada
[10] Study of Hydropower Potential in Canada - Canadian Hydropower Association - 2007

distributed. Most are located near the Great Lakes and coastal regions as well as northern Ontario and Quebec but some are found in the great plains and British Columbia (Figure 7.1). Short term variations are large and make balancing supply more difficult. Interconnecting dispersed wind farms can alleviate the variability, while on a seasonal basis wind tends to complement hydro. A national or continentally interconnected grid would enable each wind farm to operate at its optimum output level and reduce back-up reserve requirement. Canada has abundant opportunities for creating synergies between wind and hydro generation, particularly in northern Ontario and Quebec through shared transmission corridors for both types of renewable energy sources.

Figure 7.1 Canada's Wind Power Potential

- **mean wind speed (m/s) at 50 m above ground**



Nuclear power now appears more likely to expand due to its absence of GHG emissions, but that growth will in many cases result in nuclear clusters or parks, and impact grid location. The exception to this would be specific dedicated applications, such as the use of nuclear power to provide input energy for the Alberta oil sands.

Coal combustion now generates one-fifth of Canada's electrical supply, compared to 50% to 80% in other energy intensive economies; yet coal combustion is being phased out in Ontario. The GHG footprint of coal can be reduced significantly by gasifying coal with steam and oxygen, and capturing and sequestering the concentrated stream of carbon dioxide, at the cost of reduced energy efficiency. Successful coal gasification would be a platform technology for application to a wide variety of high carbon containing fossil fuel and biomass feedstocks.

Rights of Way for power lines are highly constrained in both the U.S and Canada. The various enhanced or new interconnections that have been proposed will give rise to different issues on power line location. There may be considerable value in exploring the use of existing pipeline rights of way as potential rights-of-way candidates for electric power transmission, thereby aiming for multiple usages of existing rights of way.

Demand Side Issues

The Smart Grid concept has two applications – 1) interactions with consumers to flatten the load, and 2) managing power generation and power line assets to improve reliability. It would not appear to have a major influence on the need for greater connectivity between provincial grids, but would impact on the design, operation and control of existing grids.

The main contender for electricity use in transportation is the Plug-in Hybrid (batteries charged from the grid at night with an onboard fuel powered battery charger to extend range). Analysis suggests that the likely increase in power demand even with rapid introduction of the Plug-in Hybrid would not be large, if linked with Smart Grid technology.

Air pollution is another major health and environmental problem throughout the growing metropolises globally, including Canadian cities. The problems arise primarily from the use of coal and automobiles. Power generation from hydro, nuclear and renewables in conjunction with the adoption of electric vehicles are vital to the health of Canadian citizens living in large urban environments.

The U.S. expects to have increased electrical trade inside the country as a result of new interregional connections. It is not as yet planning any significant increase in import of electrical power from either Canada or Mexico, as shown in Table 7.2. However, if Canada had enhanced grid interconnections with the U.S. grid network, it would have a strong argument to support a major increase in the sale of low-GHG electrical power to the U.S.

Table 7.2 US International Trade in Electricity, Recent and Projected (TWh)[11]

	2006	2007	2010	2020	2030
Imports from Canada and Mexico					
Firm Power [a]	14	16	17	7	0
Economy [b]	29	36	29	31	46
Total	***42***	***51***	***46***	***39***	***46***
Exports to Canada and Mexico					
Firm Power [a]	3	4	1	1	0
Economy [b]	21	16	21	20	19
Total	***25***	***20***	***21***	***21***	***19***
Net Exchange with Canada and Mexico					
Firm Power [a]	10	12	16	7	0
Economy [b]	7	19	9	11	27
Total	***18***	***31***	***24***	***18***	***28***
Total US Net Generation to the Grid	**3906**	**4004**	**4042**	**4396**	**4859**

[a] Firm Power Sales are capacity sales, meaning the delivery of the power is scheduled as part of the normal operating conditions of the affected electric systems.

[11] U.S. Annual Energy Outlook – 2009; Reference Case

8. ENERGY STORAGE TECHNOLOGIES

Energy storage goals are to level peak demand loads, support modernized base-load generation (nuclear and coal), and to store energy produced by renewable energy sources when such energy cannot be immediately consumed by grid customers. The importance of energy storage grows in response to the challenges of reducing the GHG footprint of electric power generation, transmission and utilization. This section provides a brief overview and analysis of existing electric energy storage options.

Traditional Hydroelectric Storage ("Ponding") – This involves reducing river flow through a hydroelectric installation, thereby storing water behind the dam for later generation. This method has a long and successful history of storing large amounts of electricity in a reservoir, which is of special significance to an interconnected grid. Hydroelectricity is already the spine of the Canadian electric system, supplying 58% of the country's electrical needs whether for base load, peak load, or export. Ponding is identified as the most important storage technology due to the future need for more base-load generation, the massive unexploited hydro power available in Canada's North in close proximity to large wind resources, and the ability to divide the costs of HVDC line construction between hydro and wind power operators, while creating transmission corridors to allow further wind power installation. Unfortunately, information on the energy storage capacity in Canada's hydroelectric system is not publicly available.

Pumped Hydroelectric Storage – This involves elevating and storing water in large reservoirs for later hydro generation, on daily, weekly, and seasonal cycles. It is similar to "ponding" in the use of the gravitational potential of water, but the need for pumping introduces some inefficiency relative to traditional hydro. Pumped storage has the ability to fit either a large central grid or smaller regional grids, and is mature enough for implementation.

Compressed Air Storage (CAES) – This involves compression of air and storage in underground caverns for later electricity generation in turbines. CAES is dependent to a large extent on geology for the right geological formations to store the compressed air. A large central grid would allow more transmission lines to reach the suitable formations, something smaller regional grids cannot do. The technology is relatively mature and a project is being considered on the Saskatchewan/Alberta border.

Molten Salt Storage – This involves storage of solar heat in salts such as sodium and potassium nitrates, with later heating of water to generate steam for electricity generation. It is mainly used in unison with concentrated solar power (CSP), and therefore not very feasible in the Canadian context.

Hydrogen Energy Storage – Production of hydrogen, storage, and later power generation has too low an overall efficiency (< 25%) to be considered for large stationary applications. Hydrogen could be produced by electrolysis during off-peak periods and stored for use by industrial processes as a chemical feedstock. However, if the demonstration of thermochemically-produced hydrogen from the waste heat of nuclear power plants is successful, this will likely transform the economics of hydrogen as an energy currency for electric power generation and other potential applications.

Battery Energy Storage – Seven battery systems were investigated, with four main uses in a grid system: 1) time shifting or leveling the intermittency of smaller distributed renewable power sources, 2) short term peak shaving for base loads (with flow batteries), 3) improvement of power quality at problematic nodes 4) providing short-term uninterrupted power supply and bridging between power outages and generator start-up, at modest power levels or discharge times.

Superconducting Magnetic Energy Storage (SMES) – In this case, energy is stored in the magnetic field of a current circulating in a superconducting material, and discharged in short bursts of about 10 seconds. SMES can be used in regional grids to control instantaneous power surges or sags caused by the intermittency of renewable sources, and in large centralized grids as a power quality insurer at grid nodes on long transmission lines.

Electrochemical Capacitors – This involves the separation of charge on surfaces separated by an electrolyte. They can be used at transmission nodes to offset power sags and as bridging power between power outages and generator start-up. The ability to maintain power quality gives capacitors a role in integrating various power generation sources.

Electric Vehicle to Grid (V2G) Storage – This represents the ability of passenger cars to absorb electrical power from the grid in off-peak periods and return some of that power in peak periods. A cautious estimate of the near-term impact is that the Canadian electric car population could deliver on the order of 1% of our daily demand to the grid in the evening. Although it would have minimal contribution to the base load demand, it could reduce the peak load problem by providing a distributed storage capability near demand locations. The life expectancy of batteries has been raised as an issue. The principles behind the technology are sound and the major hurdles lie in the field of regulation, commercial arrangements, and incentives.

Summary – Storage technologies will have an important role to play either regionally or nationally by leveling the peak-load, and have the potential to allow intermittent renewable resources to be more fully exploited. Hydroelectric power could aid the national grid by increasing both the base and peak load generation and the practice of “ponding” is the eminent player among the available storage technologies, in all evaluated attributes. Pumped Hydro and Compressed Air Energy Storage would also have application for a National Grid, albeit with more difficulty. Batteries, Capacitors, and Superconducting Magnetic Storage would be important tools in aiding the design of a national grid, but not necessarily contributing large storage capacities or power levels. Production of hydrogen from electricity would normally be a one-way street to a chemical raw material due to low conversion efficiencies, though the emergence of hydrogen produced thermo-chemically may well provide an opportunity to review this conclusion. Molten salts, although very favourable in CSP application, will have little relevance for Canada. Finally, V2G technology is very promising but largely dependent on consumer adoption and effective regulatory practices.

9. HIGH VOLTAGE TRANSMISSION TECHNOLOGIES

This section presents the technologies and equipment available to transport bulk electricity over long distances. It provides a summary overview of transmission and interconnection options, in particular high voltage DC and AC transmission, indicating the advantages and limitations of both technologies and the available solutions. Clearly, there are a variety of options now available to transmission planners to strengthen existing grids, increase transmission capacity and provide high-power interconnections to large neighbouring networks without sacrificing either power system security in normal utility operations, or the long term power system reliability of any interconnected system.

High Voltage Direct Current (HVDC) conventional transmission technologies – Conventional line commutated systems are based on thyristor technologies, with typical voltages of up to 500 kV, and bulk power transfer capability of up to 3000 MW. Technical issues include the converter configurations (monopolar, bipolar, multi-terminal), valve ratings, reactive power requirements, grounding electrode design and reliability. On the AC side, considerations include AC system strength, temporary overvoltages, commutation failure, and fault recovery. Ultra high voltage systems, with higher bulk transmission capabilities, and ratings of up to 800 kV, 6000 MW, are being developed and installed at the present time. These systems extend the capabilities of existing systems.

High Voltage Direct Current (HVDC) transmission technologies using voltage source converters (VSC) – These systems are based on force commutated devices, with typical voltages above 300 kV and bipolar power transfer levels of 1100 MW now possible. They use mostly cable systems, with overhead transmission being developed. Advantages include full real and reactive power control, and the capability of feeding any type of load. Technical issues include the converter configurations (two level and multi-level), device ratings, transformers, cables, AC filters and reliability. Performance issues include real and reactive power control, AC faults, DC faults, overloads, and environmental aspects.

High Voltage Alternating Current (HVAC) transmission – Although the majority of the electrical power is transmitted by means of AC lines, a number of improvements have been made. Voltages of up to 765 kV are currently used for bulk power transfer of up to 3000 MW. Technologies for voltages of up to 1200 kV are being developed. Operating considerations are addressed, namely stability and voltage control. New devices, called FACTS devices, are available that can enhance transmission system performance and increase transmission capacity. These comprise thyristor based devices, including the static Var compensator and the thyristor controlled series capacitor, and force commutated based systems, including the static synchronous compensator, the static synchronous series compensator and the unified power flow controller.

Comparison of HVDC and HVAC technologies – The High Voltage chapter in the Annex to this report compares line commutated and voltage source converter technologies, summarizing the technical features related to control, power quality, transformers, and cables, among others. The high voltage DC and AC technologies are also compared from the viewpoint of control and grid regulation, short circuit conditions, reactive power, harmonics, reliability, tower size and right of way, losses, electric and magnetic fields, and other features.

Applications of HVDC transmission – Features and advantages include capability of bulk power transmission across long distances, improved utilization of existing infrastructure, interconnection of asynchronous systems, integration of remote energy resources, infeed to congested load areas and supply of isolated loads. The full chapter in the Annex to this report concludes with the applicability and potential advantages of these features in the development of a Canadian electrical grid.

Summary – At the present time, conventional Line Commutated Converter (LCC) HVDC is a mature technology with proven application in bulk power transfers over long distances, typically over 1000 km, interconnection of asynchronous AC systems, and long cable transmission systems. Conventional LCC HVDC has the disadvantages of the associated reactive power compensation requirements, dependence on the AC system strength for performance, and not being easily tapped along the transmission line. Newer Voltage Source Converter (VSC) HVDC technology addresses these issues and others, along with providing a means of independent control of the converter real and reactive power. VSC technology has advanced quickly and continues to, with overhead line applications now being possible. As the power transfer capabilities of VSC converters continue to increase it is expected that the application of VSC technology will continue to increase, including the development of multi-terminal VSC HVDC based systems.

10. CAE ENERGY PATHWAYS PROJECT – STATUS AND PLANS

The Canadian Academy of Engineering has evaluated Canada's energy potential through the establishment of various Task Forces leading to the following reports and activities.

1. 'Energy and Climate Change', published in March 2002.

This report documented the challenges facing the planet in meeting the future energy needs of the developed and developing countries. One of the major conclusions of the report is that "a long-term, sustainable energy strategy needs to be developed, which will necessarily require a larger choice of energy sources and energy technologies".

2. 'Energy Pathways – Phase 1', published in May 2007.

This report made four recommendations:

Recommendation 1: Canada should proceed with three National Technology Projects

- Gasification of fossil fuels and biomass
- GHG emission reduction (carbon dioxide capture followed by transportation, long term storage and/or use)
- Upgrades to electrical infrastructure, with improved access by wind and solar sources, and capacity for energy storage

Recommendation 2: Establish a network for bioconversion demonstration projects

Recommendation 3: Pursue technology development on 11 energy opportunities and challenges

Recommendation 4: Maintain watching brief on magnetic confinement fusion and initiate a university-based laser fusion project as an international contribution

3. Follow-up on Recommendation 1

A workshop was held on the three national technology projects in Calgary on Oct 11, 12, 2007, outlining next steps in each of these projects. A report on the workshop is available from CAE.

4. Follow-up on Recommendation 2

A workshop was held on bioenergy on May 22, 23, 2008 in Sarnia to define potential bioenergy demonstration projects. A report on the workshop is available from CAE.

5. Follow-up on Electrical Infrastructure recommendation.

A Task Force was established to examine potential electrical infrastructure upgrades, which resulted in this report, 'Electricity: Interconnecting Canada – A Strategic Advantage'.

6. Canada's progress in meeting energy objectives

The Canadian Academy of Engineering is undertaking periodic reviews of Canada's progress in meeting the energy objectives documented in the CAE Energy Pathways Phase 1 Report.

11. CONCLUSIONS

Canada's electricity system was designed and built historically on a province by province basis, with limited emphasis on provincial interconnections. This report has addressed the question of whether Canada should invest in enhanced east-west electrical interconnections. We have been told with current business practices that this would negatively affect ratepayers and that economics for new interconnections favour north-south connections to the U.S.

The climate change imperative and the potential for new low GHG emitting generation are important signals that the situation has changed. The International Energy Agency has estimated that Canada's electricity sector will require US$190 billion in new investment from now to 2030. This may be the time to consider strategic national electrical infrastructure investments.

Energy may be Canada's last chance to achieve *a sustainable competitive advantage*, something we have not succeeded in building in other key sectors of the economy. We have a unique opportunity to prepare an electrical energy plan that is more than the sum of its parts.

The Canadian Academy of Engineering is therefore making the two recommendations presented in this report in the belief that they will help chart the way forward through immediate cost-shared infrastructure projects and also provide a longer-term electric power strategic plan.

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