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The Muskrat Falls Project Development

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ABSTRACT

In the 2012 Edition of "Canada: Winning as a Sustainable Energy Superpower," three fundamental objectives for the Canadian electrical energy system were identified:

- Achieving a major reduction in greenhouse gas emissions
- Resolving the intermittency of renewable energy sources
- Completing our energy corridors through the establishment of high-capacity east-west power and pipeline grids

A key observation was also made:

"Many of these challenges are beyond the capacity of individual companies and will likely need the support and collaboration of a number of private and public sector organizations …" (vol. 2, page 45)

The Muskrat Falls development in Newfoundland and Labrador, along with associated transmission development in Atlantic Canada, demonstrates that these challenges can be fully addressed, and that support and collaboration are essential elements of this success.

As a result of these projects, Newfoundland will no longer be an electrical island and the province's hydroelectric resources will be fully integrated. Storage will be available throughout the system which will increase flexibility and optimize market deliveries. Interconnection of the Newfoundland and Labrador system with that of the Maritime Provinces will provide opportunities for broader reserve sharing, load following and regulation services. The integration of renewables can be pursued on a regional basis. With the completion of the projects, a firm transmission path will be available from Newfoundland and Labrador through Nova Scotia, New Brunswick, and into New England. This path will enable new export opportunities throughout the region.

The development of Muskrat Falls is the result of collaboration and co-operation among Atlantic Canada governments and provincial energy companies, along with the Government of Canada, and sets the stage for the future transformation of Atlantic Canada's electricity system.

Introduction

The hydroelectric developments at Gull Island and Muskrat Falls on the Churchill River in central Labrador have a long history. The Churchill River was a traditional travel route, and archaeological investigation at Muskrat Falls has produced artifacts that date back over 3,000 years.

Gull Island and Muskrat Falls were seen as natural next steps for hydroelectric generation after the development of Churchill Falls. These downstream sites were straightforward developments, and could rely on the storage and regulation provided by the upstream facility.

To British Newfoundland Corporation (Brinco), the principal shareholder in Churchill Falls (Labrador) Corporation, the development of the lower Churchill sites were the natural next locations for development after the completion of the Churchill Falls hydroelectric development. Brinco had undertaken engineering studies for the Gull Island and Muskrat Falls sites (Figure 1), along with early studies for high voltage dc transmission through Newfoundland, Nova Scotia, and into New England. These alternatives were not economical at the time.

During the 1970s, a concerted effort to develop the lower Churchill was advanced. A federal-provincial (NL) crown corporation, Lower Churchill Development Corporation (LCDC), was established. Studies for both Gull Island and Muskrat Falls were advanced, various HVdc transmission configurations were considered, and in 1980, LCDC recommended that the development of Muskrat Falls and an HVdc transmission system to Newfoundland's Avalon Peninsula be pursued.

Unfortunately, the project could not be economically justified at the time[1], and terms for financing and federal support could not be established.

Further efforts to advance the lower Churchill in 1998 and 2002 were made with Hydro-Québec but, in each case, market access, commercial negotiations, interest rates, and

Figure 1
The Provinces of Atlantic Canada

[1] A combination of crippling interest rates and relatively inexpensive oil rendered the project uneconomical in the late 1970s.

aboriginal relations precluded the development of the lower Churchill. These factors, combined with the long-standing inequity of the Churchill Falls power contract, have strained relations between Newfoundland and Labrador and Quebec. Another important factor stalling development of the lower Churchill was the impact of the development of Churchill Falls on the traditional lifestyle of the Labrador Innu, and the inability to reach an agreement addressing those impacts and the impacts of the lower Churchill development.

Newfoundland and Labrador's Energy Plan

In September 2007, the Government of Newfoundland and Labrador released its Energy Plan. The plan underscored the importance of energy development to Newfoundland and Labrador. Newfoundland and Labrador holds a veritable "energy warehouse"' of non-renewable and renewable resources in quantities far beyond those necessary for its own needs, which the Government of Newfoundland and Labrador committed to be developed in the best interests of the people of Newfoundland and Labrador (Figure 2).

Newfoundland and Labrador's crown-owned energy corporation, Nalcor Energy, was established in 2008 to participate in all aspects of the energy sector. Its vision:

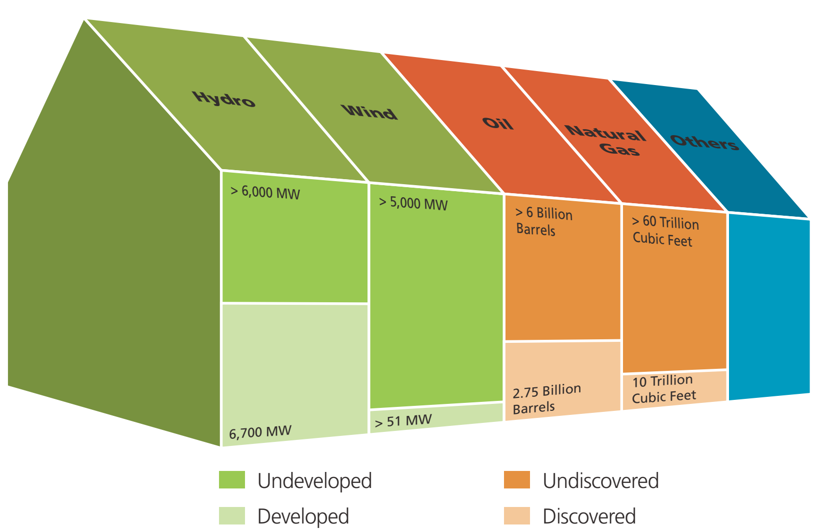
"To build a bright economic future for successive generations of Newfoundlanders and Labradorians" speaks to the need to consider long-term – both development horizon and benefits considerations – as well as the importance of the energy sector to the province's economy.

The Energy Plan recognizes two key themes:

1. The importance of the province's energy resources to the province's economy
2. The need to leverage the province's benefits derived from non-renewable resources to sustain a renewable future

These themes translate into Nalcor's lead role in the lower Churchill development. From 2005 to 2010, a comprehensive planning effort was undertaken for moving it forward, and a multi-discipline project team was established. Six primary objectives were set:

Figure 2
Newfoundland and Labrador's Renewable and Non-renewable Energy Resources



1. Develop a team, practices, and capabilities for megaproject execution
2. Complete the engineering design work necessary for all project components
3. Steward the generation and transmission projects through the environmental assessment process
4. Complete aboriginal negotiations and consultations
5. Develop a financing strategy
6. Develop a commercial framework to support the business case for the investment

The results of these efforts were evident with the November 18, 2010 announcement by the Government of Newfoundland and Labrador that terms for the development of Muskrat Falls and associated transmission infrastructure had been reached by Nalcor Energy and Emera Inc. of Nova Scotia.

The Project Components

The major elements of the development include (Figure 3):

a. The construction of an 824 MW hydroelectric generating facility at Muskrat Falls,
b. The construction of a pair of 250 km, 315 kV transmission lines between Muskrat Falls and Churchill Falls, NL (the Labrador Transmission Asset),
c. The construction of an 1,100 km, 900 MW HVdc transmission link between Muskrat Falls and Soldier's Pond, 30 km from St. John's, NL (the Labrador Island Transmission Link), and
d. The construction of a 500 MW HVdc transmission link between Bottom Brook on the west coast of Newfoundland and Cape Breton, NS (the Maritime Link)

The development also includes ac transmission system upgrades to both the Newfoundland and Labrador, and Nova Scotia transmission systems.

Figure 3
The Muskrat Falls Project Components

The commercial underpinnings of the development, however, clearly establish long-term benefits for both Newfoundland and Labrador, and Nova Scotia electricity customers, and establish a foundation for further opportunities for regional benefits.

Newfoundland and Labrador's Electrical Options

A key factor leading to the development of Muskrat Falls was an evaluation of the lowest cost electricity supply option for the island of Newfoundland. While approximately 80% of Newfoundland's electricity supply is derived from hydroelectric generation, including generating facilities at Bay d'Espoir, Cat Arm, Upper Salmon River, Hinds Lake, and Granite Canal, the largest and most attractive generation sources have been developed, and thermal generation will dominate Newfoundland's future electricity supply. Newfoundland's electrical system is isolated from North America, and opportunities for integrating non-dispatchable renewables such as wind are limited.

An optimized portfolio of generation expansion alternatives with the island of Newfoundland operating on an isolated basis (Newfoundland's Isolated Island Alternative) was compared to an optimized portfolio that included Muskrat Falls and the Labrador-Island Transmission Link (Newfoundland's Interconnected Island Alternative). The Interconnected Island Alternative demonstrated a $2.4 billion[2] cumulative present worth preference over the Isolated Island Alternative.

Muskrat Falls, however, will provide substantially more energy than will be required by the island of Newfoundland, and efforts to develop value for this surplus focused on Nova Scotia.

Nova Scotia's Energy Outlook

Nova Scotia is heavily dependent on thermal generation, with thermal alternatives making up 80% of the energy supply in that province. In 2010, the Government of Nova Scotia introduced legislation requiring that 25% of Nova Scotia's energy supply be derived from renewable alternatives by 2015, growing to 40% in 2020. Energy from Muskrat Falls qualified for inclusion under Nova Scotia's regulations. With a surplus of energy from Muskrat Falls and a market for renewable energy in Nova Scotia, Nalcor and Emera turned their attention to developing a technical solution to deliver energy from Muskrat Falls and to develop a business case for that solution.

In some jurisdictions, renewable portfolio standards are sometimes limited to only include domestic projects, and the Government of Nova Scotia's decision to qualify imported energy as a renewable source was a key factor in facilitating this regional project, as energy supplied from Muskrat Falls was demonstrated as the lowest-cost means of meeting Nova Scotia's renewable energy targets.

Canada's Support

Requests for support of the lower Churchill development have been made by successive governments of Newfoundland and Labrador, and on November 30, 2012, Prime Minister Harper announced Canada's commitment to a federal loan guarantee for the projects. The loan guarantee was predicated on it demonstrating benefits not just for Newfoundland and Labrador, but on a regional basis to Atlantic Canada.

[2] This analysis, completed in October 2012, was based on the Project obtaining a loan guarantee from the Government of Canada, which was ultimately obtained.

Over a period of two years following the announcement of the term sheet, Nalcor, Emera, the Governments of Newfoundland and Labrador and Nova Scotia, and the Government of Canada concluded the work activities, approvals, and negotiations necessary to enable construction of the projects, and on December 17, 2012, the projects were sanctioned for construction.

The Facilities and Assets

By mid 2014, engineering design and financing have been concluded; the characteristics and features of the various facilities have been established. Each of the project components can be described as a megaproject in its own right.

Muskrat Falls

The scale of work at the Muskrat Falls site is evident with the completion of site excavation. Over 2.2 million cubic metres of rock were removed in 2013 from the powerhouse and spillway locations in preparation for construction of the respective concrete structures (Figure 4).

Figure 4
Site of Muskrat Falls Powerhouse and Spillway (2013)

The powerhouse and spillway structures will require the placement of 560,000 cubic metres of conventional concrete, and the dams at site will require another 200,000 cubic metres of roller compacted concrete (RCC); all in all enough concrete to construct five offshore petroleum gravity base structures.

While the Muskrat Falls site is not complex as large hydroelectric projects go, it does offer unique challenges, particularly when considering the effort required to place the necessary concrete quantities in a timely manner. The entire powerhouse site will be enclosed under a structure that creates a controlled environment and provides coverage by overhead cranes over the entire site. This will provide better working conditions and improved productivity over working outdoors during the Labrador winter.

The Muskrat Falls facility will be equipped with four 206 MW (229 MVA) turbine – generator sets. The turbines are Kaplan units, and are among the largest Kaplan turbines in the world (Figure 5).

Figure 5
Turbine Blade and Stay Ring Fabrication

Transmission Lines

As illustrated in Figure 3, the transmission facilities for the project are extensive, and over 2,000 km of transmission lines are required to integrate the Muskrat Falls facility into the Newfoundland and Labrador transmission system, and to interconnect with the Nova Scotia system.

Labrador Transmission

This system consists of a pair of 315 kV ac transmission lines between Muskrat Falls and Churchill Falls. Each line is approximately 250 km, and generally parallels the Trans Labrador Highway. The interconnection will enable water management between the Muskrat Falls and Churchill Falls facilities, as Newfoundland and Labrador legislation requires producers on a river system within the province to coordinate their production so as to optimize the use of water. This coordination between Churchill Falls and Muskrat Falls will require that energy be transferred between the two generating facilities. The transmission interconnection is also required in order to ensure stability of the Newfoundland and Labrador electrical system.

The project also includes the construction of a new switchyard at Muskrat Falls to interconnect the generating plant, HVdc converter station, and transmission lines, as well as a new 735 kV/315 kV switchyard at Churchill Falls to interconnect the new transmission lines to the existing facilities at Churchill Falls.

Labrador – Island Transmission Link

While the Labrador – Island Transmission Link is not the longest High Voltage (HVdc) transmission line in the world, and numerous systems operate at higher voltages and transmit more power, the link between Labrador and Newfoundland has a number of design and construction considerations that have created unique engineering and construction challenges.

Approximately 1,100 km long, the line traverses central and southern Labrador, crosses the Strait of Belle Isle, and Newfoundland's Northern Peninsula on its way from Muskrat Falls to Soldiers Pond, just outside St. John's.

With the long distance, underwater crossing, and need to interconnect the relatively weak Newfoundland electrical system to Labrador, HVdc technology is a natural choice. The system incorporates unique features in order to maintain a high level of reliability:

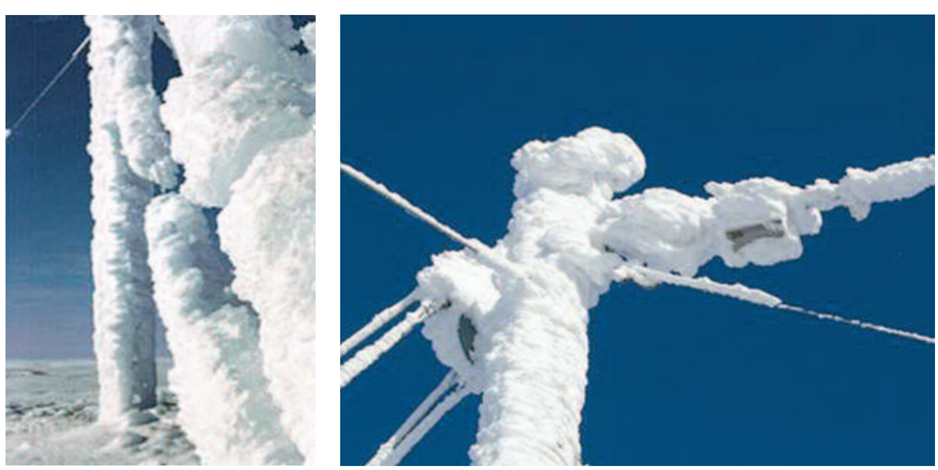
- While the system will operate as a bipole transmitting 450 MW per pole, the system is designed to operate as a 900 MW monopole for short periods to ensure stable operation of the Newfoundland system during a permanent pole fault. This provides sufficient time to reconfigure the island system after a fault.
- High-inertia synchronous condensers will be included in the island system in order for the system to ride through temporary (both pole and bipole) faults. The synchronous condensers, located at Soldier's Pond, will provide 525 MVAR of reactive power for the system, and 3,675 MW-s of system inertia for the Newfoundland electrical system.

Given the transmission requirements for the HVdc system, a conventional line commutated converter (LCC) will be implemented for the Labrador – Island Transmission Link. The dc system voltage will be 350 kV.

The 1,100 km long HVdc transmission line traverses areas with particularly severe meteorological conditions. Notable locations include coastal areas in Labrador and northern Newfoundland, the Long Range Mountains[3], and Newfoundland's Avalon Peninsula. Each of these areas presents situations where extreme wind and ice conditions will be encountered, and the transmission line design must withstand these severe conditions.

Thirteen different wind and ice loading zones have been established for the line. The meteorological design criteria are based on the results of decades of operational experience, measured conditions at local weather stations along the route, measurements taken from test spans in known high loading areas, as well as applicable design standards for high voltage transmission lines. The most severe conditions along the route will be in the Long Range Mountains, where the line will be required to withstand either continuous winds of 180 km/h or 135 mm radial rime ice loads (Figure 6).

Figure 6
Long Range Mountains Meteorological Test Site Under Winter Icing Conditions

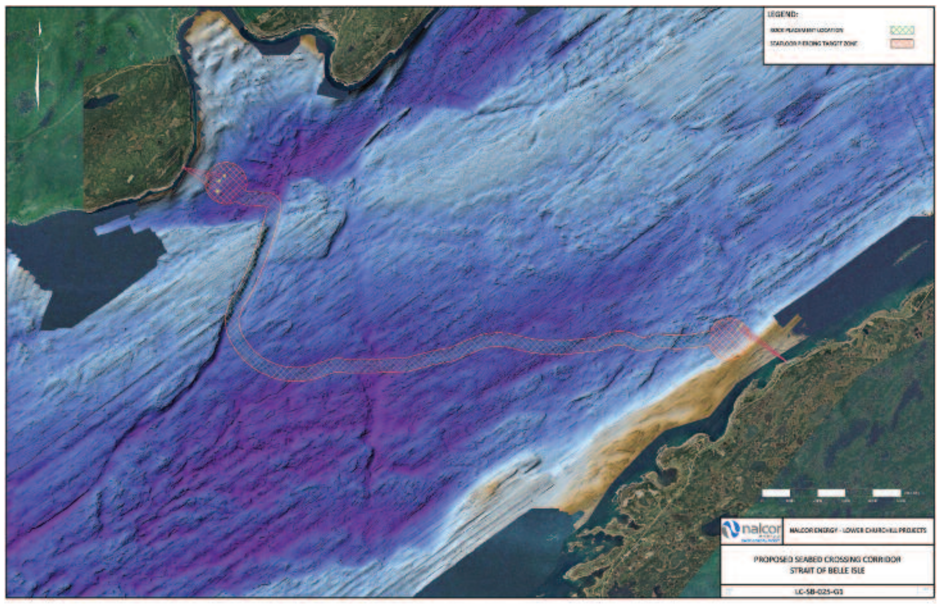


[3] The Long Range Mountains on Newfoundland's Northern Peninsula are the northeastern extent of the Appalachian Mountain Range.

The transmission line will also be required to cross the 19 km wide Strait of Belle Isle between Newfoundland and Labrador. The potential for damage to the cables from icebergs in the strait is a key design feature that separates the Strait of Belle Isle crossing from most other electrical cable crossings.

The design approach to address this issue has been a topic of study since the earliest days of planning for the project, and various concepts (including tunneling and seabed trenching) have been proposed in pre-feasibility studies for the project. Field investigations, including bathymetric, seismic and drill programs, ultimately narrowed the crossing options to two: a tunnel crossing and a protected seabed crossing (Figure 7).

Figure 7
Strait of Belle Isle Subsea Crossing Route



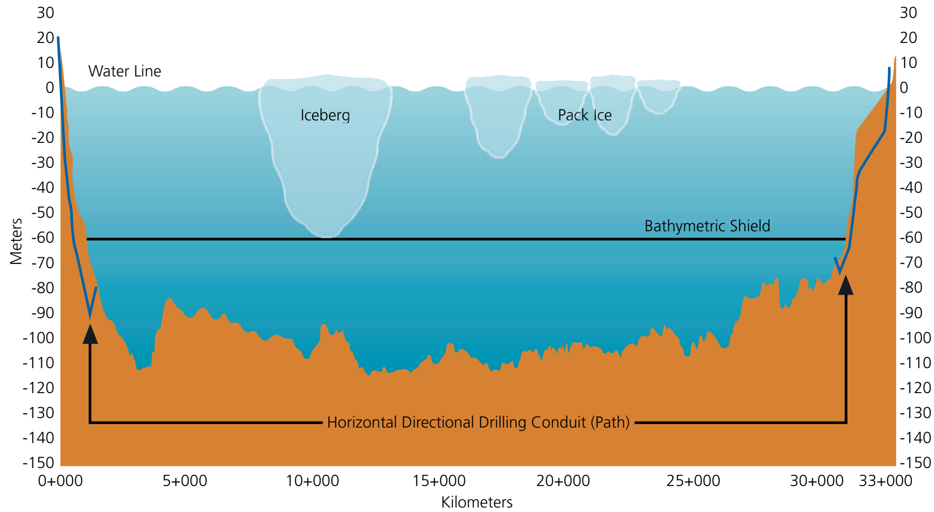
The installation and protection of subsea structures have been important design considerations for the Newfoundland offshore Memorial University's Centre for Cold Ocean Resources Engineering (C-CORE), which concluded that the risk from iceberg damage would be mitigated if the cables were protected to a water depth of 70 metres or greater. Horizontal directional drilling (HDD) was identified as a protection method, and the feasibility of this approach was confirmed with the completion of a test bore at site.

The HDD bores are up to 2,050 metres long, and extend to a depth of 70 metres on the Newfoundland side of the strait and to 75 metres water depth on the Labrador side (Figure 8). Once placed on the seabed, the cables will be protected by a rock berm.

Maritime Link

The Maritime Link will provide an interconnection between Newfoundland and Labrador Hydro's Bottom Brook terminal station on the west coast of Newfoundland, and Nova Scotia Power's terminal station at Woodbine, near Sydney, Nova Scotia. This HVdc system will operate at 200 kV, and will have a rated capacity of 500 MW. The HVdc system has been specified as a Voltage Source Converter (VSC), which will better interconnect the Nova Scotia and western Newfoundland electrical systems with less extensive system upgrades than a line commutated converter.

Figure 8
Strait of Belle Isle Bathymetric Profile



Project Benefits

Optimizing benefits from resource development is a fundamental theme for the Government of Newfoundland and Labrador as well as the Government of Nova Scotia. Both governments have established benefits strategies to achieve this goal. The principal objectives of both strategies are to prioritize employment during construction, and to ensure the local supply community has full and fair access to project opportunities.

Employment

The employment requirements for the projects are substantial; construction of Muskrat Falls, the Labrador Transmission Assets, and the Labrador-Island Transmission Link will require 9,100 person-years of direct employment, and construction of the Maritime Link will require another 1,200 person-years. On a national scale, and when indirect and induced economic activities are considered, 59,500 person-years of employment activity are associated with the projects.

Over 5,800 person-years of direct employment will occur in Labrador, and increasing workforce capability has been a key initiative for the project team. The Labrador Aboriginal Training Partnership (LATP) has been established to coordinate training programs for aboriginal residents of Labrador. With the support of the Government of Canada and the Government of Newfoundland and Labrador, and the participation of Innu Nation, Nunatsiavut Government, and the NunatuKavut Community Council, over 500 aboriginal workers have participated in training programs to prepare for project employment.

Early into the second year of construction, Labrador residents comprise 40% of the 1,000 strong project workforce in Labrador, and 20% of the workforce identifies as a member of one of the Labrador aboriginal groups.

Throughout the five year construction period, the workforce requirements will peak at over 3,100 workers and require over 70 different trades and professions, as illustrated in Table 1.

Table 1
Muskrat Falls Project Workforce Requirements
(Number of Workers)

	2013	2014	2015	2016	2017
Management	34	56	79	45	19
Business Support Services & Administration	148	169	176	144	72
Engineering & Geosciences	126	146	188	120	45
Technologists & Technicians	102	112	126	99	64
Researchers & Scientists	13	10	10	7	4
Inspectors	35	61	89	40	9
Site Services	110	242	344	216	90
Truck Drivers	69	73	99	43	14
Logging, Forestry & Mining	78	103	95	37	1
Heavy Equipment & Crane Operators	194	210	335	176	29
Structural Trades	35	93	162	61	11
Electrical Trades	59	232	440	313	81
Construction Labourers	219	278	464	257	34
Carpentry Trades	59	150	314	155	27
Other Trades	35	35	51	29	5
Mechanical Trades	84	122	215	158	55
Totals	1400	2091	3186	1898	557

Business Opportunities

Although the electrical industry is highly globalized, and key equipment is sourced from specialized suppliers, enabling the local supply community is an important objective. The project team has worked with chambers of commerce, economic development associations, and contractor organizations to communicate both opportunities and expectations to the supplier community.

During the first 15 months of construction, over $420 million has been spent with Newfoundland and Labrador-based businesses.

On a provincial scale, total expenditures in Newfoundland and Labrador (including wages, salaries, and payments to Newfoundland and Labrador-based businesses) are expected to exceed $1.9 billion.

Supply Chain

The project draws on a global supply chain for material, equipment, and contractor capability. With project procurement almost two thirds complete, the suppliers and contractors for the projects represent major players around the world (Figure 9).

Procurement activities are continuing, and contract award information is available at the project's website at muskratfalls.nalcorenergy.com.

Figure 9
Key Muskrat Falls Project Suppliers

As of April 2014, Major suppliers include:	
Andritz Hydro Canada:	Turbine / generator sets and hydromechanical equipment
Nexans	Submarine cable, Labrador Island Link and Maritime Link
Midal	HVac conductors
General Cable	Hvdc conductors
Sa Ra	HVac transmission structures
Jyoti	HVdc transmission structures
As of April 2014, the major construction contractors include:	
Valard Construction	HVac transmission line construction
Astaldi	Powerhouse civil works
IKC-ONE L.P.	Muskrat Falls Powerhouse/Spillway Excavation
Liannu L.P.	Muskrat Falls Accommodations Complex and Access Road
Labrador Catering L.P.	Catering Services
Johnson's Construction	Reservoir and Right of Way Clearing
HJ O'Connell Construction	Soldiers Pond Earthworks

Future Development in Labrador

While the construction benefits for regional economies are substantial and long-term, the development of Muskrat Falls will establish a capability for further resource development in the region. The key enablers are:

- Increased human resource capability. The training and experience gained by hundreds of workers in Labrador will better enable them to benefit from future development in the region. From mining to construction to future energy development, the skills and experience gained on Muskrat Falls will increase capability in the region.

- Increased business capability. The local business community will also acquire increased capacity and experience with the project, and will be better able to serve the requirements of future developments in the region.

- Increased regional infrastructure. The completion of the projects will increase the power supply in the region and extend power transmission capability in the region. Both of these are essential elements for future development. Communications infrastructure in Labrador has been established for the project, and the installation of fibre optic transmission facilities will further improve infrastructure in Labrador.

Conclusion

While the development of Muskrat Falls is the least-cost supply option for both Newfoundland and Labrador and Nova Scotia, the project sets the stage for transformation of the Atlantic Canada electrical system, and paves the way for further large-scale renewable energy development in the region. Further development will be enabled by:

Development of Transmission Interconnection

Newfoundland will no longer be an electrical island. With the interconnection of Newfoundland and Labrador, energy resources throughout the province can be developed to meet domestic needs or for export markets, and transmission paths are available between Newfoundland and Labrador, between Labrador and Quebec, and from Newfoundland to Nova Scotia, and on to the Maritime Provinces and New England (Figure 10).

Figure 10
Potential Electricity Export Routes from Newfoundland and Labrador

Integrated Hydroelectric Operations for Newfoundland and Labrador

A further benefit of the transmission interconnection of Newfoundland and Labrador is that the province's hydroelectric resources are integrated. While Newfoundland and Labrador legislation requires that facilities on a river system be operated on an integrated basis, the transmission interconnection permits all of Newfoundland and Labrador's hydro resources to be operated as an integrated system.

While the Churchill Falls reservoir holds the equivalent of approximately 22 TWh of storage, the major reservoirs on the island hold the equivalent of approximately 2.5 TWh of storage. This greatly increases the flexibility of the provincial hydroelectric system, as storage will be available throughout the system to optimize market deliveries.

Renewable Integration

Building on storage flexibility and transmission interconnections, the level of non-dispatchable renewable generation on the Newfoundland and Labrador system can be dramatically increased. The integration ability of the existing Newfoundland system is constrained by its isolation and limited frequency regulation capability. Both of these constraints are eliminated with the interconnection to Muskrat Falls via the HVdc link. Operating as a rapid acting frequency controller, the HVdc link will provide regulation for the island system, and the wide operating range of the Muskrat Falls Kaplan units (from 50% to 98%) will enable significant levels of variable resources to be added to the Newfoundland and Labrador electrical system.

Regional Integration

The capabilities of the region are enhanced through the interconnection of the Newfoundland and Labrador system with that of the Maritime Provinces. Opportunities for broader reserve sharing, load following and regulation services, and renewable integration can be pursued on a regional basis.

Export Opportunities

With the completion of the projects, a firm transmission path will be available from Newfoundland and Labrador through Nova Scotia, New Brunswick, and into New England. This path will enable new export opportunities throughout the region, and given that Canadian generation resources are required to meet winter peaks in their domestic markets, renewable resources backed by firm capacity will be available to take advantage of New England market requirements during their summer peaks.

These opportunities, combined with the ability to import off peak energy through regional interconnections open a host of market opportunities.

Biography

Gilbert Bennett joined Nalcor Energy in May 2005 and he is responsible for the development of Phase 1 of the Lower Churchill Project - Muskrat Falls Project. The lower Churchill River is one of the most attractive undeveloped hydroelectric sites in North America and is a key component of the province's energy warehouse. The Muskrat Falls hydroelectric development on the lower Churchill River in Labrador includes construction of an 824 megawatt (MW) hydroelectric generating facility and more than 1,500 km of associated transmission lines that will deliver electricity to homes and businesses in Newfoundland and Labrador, Atlantic Canada and Northeastern United States. The development of Muskrat Falls will provide a clean, renewable source of electricity to meet the province's growing energy demands. It will provide Newfoundland and Labrador homes and businesses with stable electricity rates well into the future, and will be a valuable power-producing asset for the province well into the future. In addition, the development will help Canada's efforts to reduce greenhouse gas emissions. Gilbert Bennett is a former Vice President of 360networks Canada, and has served in a number of senior engineering and operations roles with GT Group Telecom Services, Cable Atlantic and Newfoundland Telephone/Aliant. He has a Bachelor of Engineering (Electrical) degree from Memorial University of Newfoundland, is a member of the Professional Engineers and Geoscientists of Newfoundland and Labrador, and is a member of the Memorial University Board of Regents, the College of the North Atlantic Board of Governors, and the Canadian Hydropower Association.