Report

Technical and Economic Potential Assessments: Hydropower Refurbishments and Redevelopments in Canada

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Table of Contents

List of Tables

List of Figures

Executive Summary

In response to the federal government’s commitment to achieving a net-zero emissions electricity supply by 2035 and a net-zero economy by 2050, WaterPower Canada commissioned this study to help assess the total potential incremental generation available through hydropower refurbishments and/or redevelopment of existing facilities in Canada.

The overall objectives of this study were to describe the various types of enhancements, engage with major public and private hydroelectricity producers to help assess the total incremental generation capacity that is feasible through refurbishment or redevelopment, and identify factors affecting investments in existing hydropower facilities.

The total potential incremental generation was estimated based on direct survey responses as well as plant age while taking into consideration typical turbine-generator service life replacements.

Hatch surveyed Canadian hydropower plant owners and producers representing about 55,500 MW or 67% of the total installed Canadian fleet capacity of approximately 83,000 MW. Owners and producers were asked about their potential refurbishment or redevelopment projects as well as the challenges they may face in the development of their projects.

Based on this assessment, a summary of key findings are as follows:

- Canada’s total existing hydropower capacity consists of approximately 566 stations with a total installed capacity of approximately 83,000 MW.
- The estimated incremental generation ranges from approximately 2,200 MW (age-based approach) to approximately 5,400 MW (scaled survey approach) which represents an increase range of 2.66% to 6.48%.
- 36 hydropower plants will likely begin or undergo refurbishment or redevelopment by 2035, while 12 are being considered between 2035 and 2050 and six are being considered beyond 2050.
- For projects being completed before 2035, the survey results indicate that most will combine life extension and refurbishment into one program. Most of these plants have several units and their actual full completion date may extend beyond 2035.

Key factors affecting investments in existing hydropower facilities:

- Survey responses indicated most projects would be realized when it is deemed necessary to extend the life of the assets rather than based on a capacity/generation increase alone. This suggests that any efficiency or incremental capacity benefits are typically a byproduct of overall life extension investments. This finding also suggests that the construction costs for incremental capacity or energy versus expected benefits for

incremental generation, alone may not be economic. However, when combined with already planned or needed life extension investments, the incremental cost of additional generation becomes attractive.

- Project benefits include contributions to the grid and stability, contributions to the environment, and social acceptability.
- Noted obstacles to the progression of such projects include permitting/regulatory, power purchase agreements, costs, supply chain/labor, capital allocation and economic value versus other renewables.

Based on direct survey feedback, some key challenges/recommendations are:

- The important role of hydropower in supporting the introduction and expansion of new forms of intermittent renewable energies should be further reviewed.
- Financial and regulatory incentives should be considered to help hydropower plant owners support efforts to increase the output of existing stations.
- To ensure the energy industry is able to meet the 2035 to 2050 goals of greenhouse gas (GHG) reduction, an improved view of potential projects to come will help the industry plan ahead to help ensure the development of industrial and labor capacity to meet demand.

1. Introduction

In the coming decades, approximately half of Canada's installed hydropower generation capacity will benefit from investments to either extend their operating lifetime, and/or increase efficiency and performance. When considering these investment opportunities, there is potential to also increase generation and storage capacity, and/or increase ability to contribute to reliability and resilience (i.e., including increasing flexibility to support the reliable integration of wind and solar power).

The overall objectives of this study are as follows:

- Describe the types of enhancements that are available within the existing Canadian hydropower fleet.
- Engage with major public and private hydroelectricity producers to help assess the total potential incremental generation capacity in Canada.
- Estimate the total incremental generation capacity that is feasible through refurbishment and/or redevelopment.
- Identify factors affecting investments in refurbishment and/or redevelopment of existing hydropower facilities, including some of the intrinsic benefits and major inhibitors.

2. Background

WaterPower Canada (WPC) is the national trade association of hydroelectricity producers in Canada. In response to the federal government's commitment to achieving a net-zero emissions electricity supply by 2035 and a net-zero economy by 2050, WPC commissioned various research projects to explore opportunities to support the increase of hydropower capacity in Canada by 2035, and beyond.

This study focuses on assessing the potential for hydropower refurbishments and redevelopments across Canada; greenfield hydropower development is outside the scope of this study.

For the purposes of this study the following definitions are considered.

- **Refurbishment** implies the restoration or renewal and life extension of existing assets. This work is expected to provide benefits such as, but not limited to, an increase in efficiency, output (capacity and energy), reliability and operability.
- **Redevelopment** implies the replacement of existing infrastructure (partial or full redevelopment), and in some scenarios, the addition of incremental generation capacity where excess water may be available, or to support the integration of additional non-dispatchable renewables. Similar to refurbishments, this work is expected to provide benefits such as, but not limited to increases in efficiency, output (capacity and energy), reliability, and improved operability.

3. Study Approach

Although the Government of Canada maintains a list of all hydropower facilities and their registered capacity, this list does not contain the necessary technical information that would help determine the potential for refurbishment or redevelopment of existing hydropower facilities.[1]

Thus, to help determine the potential for additional generation at existing hydropower facilities, a survey of hydropower plant owners was completed. The intent of the survey was to collect relevant information to help assess the refurbishment or redevelopment potential while also seeking feedback on some of the challenges faced by owners in the development of such projects.

More specifically, the survey asked:

- How much increase in capacity (MW) and energy (GWh) is expected from refurbishment or redevelopment?
- What would be the timing of these projects?
- What would help support the realization of these projects?
- What other benefits are expected from these refurbishments or developments?
- What would be the largest challenges or obstacles preventing these projects from occurring?

The results of this survey are summarized in this report within the limitations of the answers returned by participants.

4. Overview of Canada's Fleet

Canada has the fourth largest installed hydropower fleet in the world after China, Brazil and the USA and was third in 2021 in terms of annual hydroelectric generation with more than 383 TWh .[2]

Hydropower was first introduced in Canada in 1881.[3] Since then, at least 566 hydropower stations have been constructed, with a total installed capacity of 82,990 MW as of 2023.[4] The most rapid expansion in capacity occurred between the 1950s and 1990s with the development of new hydropower slowing by the late 2000s.

In the past 5 years, new hydropower generation was approximately 2,400 MW with the majority of this capacity coming from some of the larger station developments such as Romaine-3 (395 MW) and Romaine-4 (245 MW) in Quebec in 2017 and 2023, respectively, and Keeyask (695 MW) in Manitoba in 2022 and Muskrat Falls (824 MW) in Newfoundland and Labrador in 2021.

The cumulative and incremental hydropower capacity across Canada (up to 2020) by decade is presented in Figure 4-1.

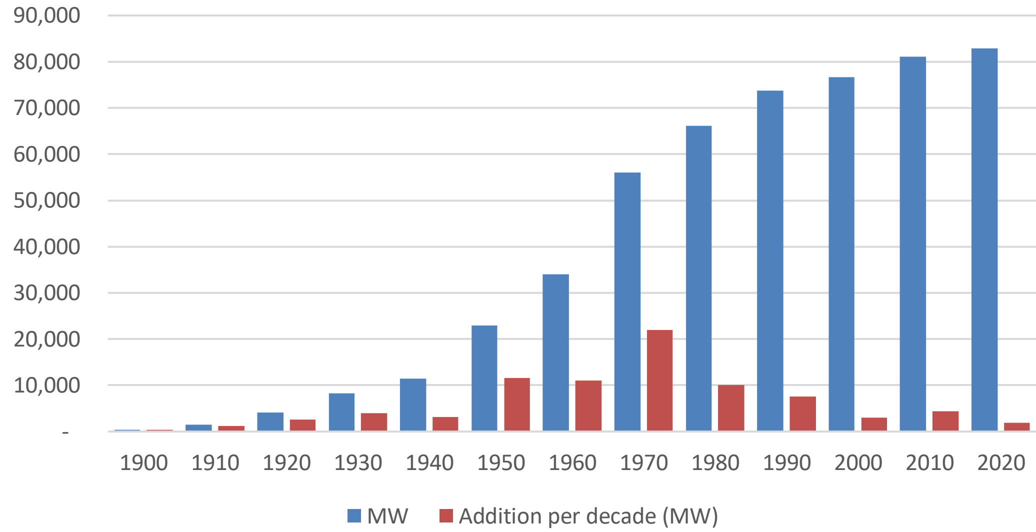

Figure 4-1: Cumulative and Incremental Hydropower Generation History in Canada

The installed capacity by province (in 2023) is also presented in Table 4-1 while a graphical representation showing percentage of capacity by province is provided in Figure 4-2 (with the twenty largest stations identified).[5]

Table 4-1: Estimate of Installed Hydropower Capacity by Province (2023)

Province	Number of Stations	Installed Capacity (MW)	Proportion (%)
Alberta	22	914	1.1
British Columbia	122	15,924	19.2
Manitoba	16	5,923	7.1
New Brunswick	11	950	1.2
Newfoundland and Labrador	34	7,783	9.4
Nova Scotia	35	413	0.5
Northwest Territories	6	56	<0.1%
Ontario	157	8,816	10.6%
Quebec	153	41,255	49.7%
Saskatchewan	7	864	1.0
Yukon	4	92	0.1%
Total	**566**	**82,990**	**100%**

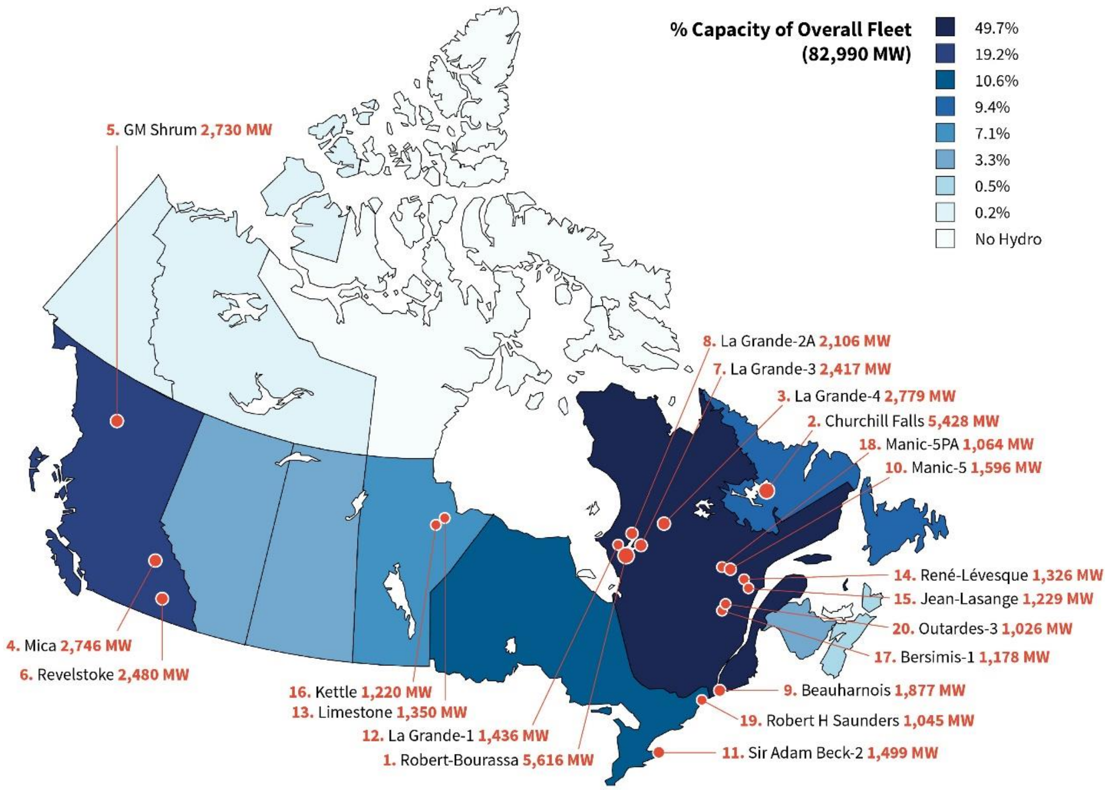

Figure 4-2: Percentage of Hydropower Capacity by Province (20 Largest Stations Identified)

Based on available data, the average age of Canada's 82,990 MW hydropower installed fleet is approximately 53 years old.[6] Given that the average recommended expected life of a turbine-generator unit is approximately 50 years, and based on station age, one can estimate that more than 290 stations consisting of an estimated 60,500 MW may need a first or second refurbishment within the next 20 years.[7]

It is also worth noting that the largest plants have a significant impact on the total generation in Canada. Plants above 100 MW in capacity represent 21.5% of the total fleet based on number of plants while also representing more than 91.1% of the total generation capacity (see Figure 4-3 and Table 4-2).

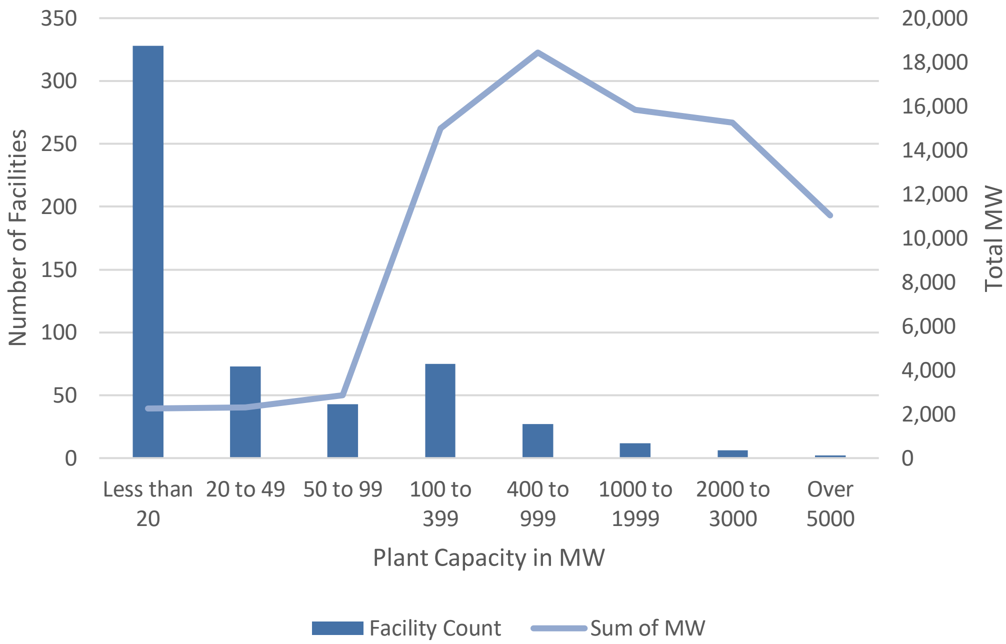

Figure 4-3: Distribution of Canadian Fleet by Plant Capacity

Table 4-2: Distribution of Canadian Fleet by Plant Capacity

Facility Size (MW)	Total Number of Facilities	Total Sum of MW	% of Total MW
Less than 20	328	2,255	2.7%
20 to 49	73	2,304	2.8%
50 to 99	43	2,851	3.4%
100 to 399	75	14,995	18.1%
400 to 999	27	18,438	22.2%
1,000 to 1,999	12	15,846	19.1%
2,000 to 3,000	6	15,258	18.4%
Over 5,000	2	11,044	13.3%
TOTALS	**566**	**82,990**	**100%**

5. Types of Enhancements

There are several approaches to the possible refurbishment or redevelopment of existing plants and equipment. The timing of such projects and potential performance improvement is dependent on the overall age of the station and components, existing condition, operational reliability, maintenance and refurbishment history, and the overall business case for the type of potential enhancement relative to incremental in generation and operations.

Increased generation can be from an efficiency improvement and/or incremental capacity.

With respect to efficiency improvements, hydropower is one of the most efficient forms of electrical power generation and has been instrumental to Canada's economic development. Hydropower continues to supply more than 60% of Canada's electricity needs and is the backbone of its electric network, affording it capacity, energy, flexibility and resiliency. This is a testament to the fact that this industry is mature and has proven itself over the decades. The efficiency of hydropower plants and machines, with modern units, can reach upwards of 95% and exceed all other forms of renewable energy. The older the turbine units the more the potential for an efficiency improvement.

In terms of capacity improvements, this can be a result of a more modern turbine-generator design or an additional turbine-generator unit at an existing facility. In some cases, and for several technical reasons, hydropower plants built before the year 2000 may typically have the potential for both an efficiency improvement and incremental capacity improvement. A study published by the World Bank in 2011 estimated a unit commissioned or refurbished in the 1970s could benefit by an average of 6.0% in turbine capacity and 7.5% in generator capacity.[8] Some sites may also have untapped hydraulic potential due to excess available water, planned unit additions that were never built, lack of water management optimization, or changes in plant operational regimes.

Regarding the overall age of the station and components, typical service lives and equipment condition play a factor in the site-specific options analysis and selection of a preferred refurbishment or redevelopment option. For general background, typical service lives for some of the major equipment at hydropower facilities are:

- Major dam structures: 100 years
- Turbine runner: 45 years
- Stator windings: 30 years
- Stator core: 50 to 100 years
- Excitation systems: 40 years
- Gate equipment: 50 years.

Additional details on the types of enhancements and benefits are presented below.

5.1 Turbine Upgrades

A turbine upgrade typically consists of a turbine or runner replacement and can provide the following benefits:

- Increased efficiency at part load, peak, or full load.
- Increased turbine output.
- Improved mechanical design to operate at speed no load and part load.
- Improved operating range over head and power.

5.2 Generator Upgrades

A generator upgrade typically consists of an improved design of the stator core or winding and can provide the following benefits:

- Increased efficiency.
- Increased output, or improved reactivity.
- Potential for improvement in inertia for improved grid stability.

5.3 Cascade System Optimization

Hydropower plants in Canada are generally either run-of-river or storage reservoir type. Some plants are part of a cascade system where multiple stations are located upstream and/or downstream of each other on the same river system.

Where a cascade scheme exists, new technologies and updated hydraulic studies can help optimize the generation of each plant to make the best use of the available water over the associated cascade network. This will help ensure that water usage for generation is maximized instead of being spilled due to high water levels and/or flows at one or more of the plants.

5.4 Plant Expansion

Either due to cascade optimization, an increase in water availability, change in utilization, or other reasons, it is possible for some plants to consider expansion by installing an additional unit into an existing powerhouse (where provision for an additional unit was made during original construction), expanding the powerhouse, or building a new plant next to an existing one. These additions can provide a significant increase in power on an existing plant. They are generally more expensive than turbine-generator replacements because they require additional civil/structural works. Being an addition to an existing plant, the development schedule is generally faster relative to new equivalent greenfield developments.

Because an expansion at an existing facility uses the existing reservoir, the environmental footprint of an expansion may be considerably less than that of a greenfield site.

When integrating non-dispatchable renewables, the benefits of additional firm capacity at an existing facility may be substantial for grid operators, providing dispatchable energy when other forms of renewables are not available, or supporting electrical stability.

5.5 Others

There are several other minor incremental methods to increase generation:

- A change in operating head can allow for higher generation output. This can be accomplished when: dam height is increased with major reconstruction of the civil works, inflatable dams are built, tailwater level is modified (associated with improved turbine cavitation performance), or surface roughness of the waterway is reduced.
- Reduction of surface roughness in turbine water passages may also increase plant efficiency and output.
- Improving auxiliary system inefficiencies can help reduce station service power supply losses and hence the net output of the plant.

5.6 Project Duration

Refurbishment of existing hydropower stations typically focus on upgrading electromechanical components. Generally, this corresponds to the turbine, generator, transformers, and associated auxiliaries. Depending on the scope of the refurbishment, a project can take an average of 36 to 72 months from the start of the planning phase to the commissioning of the upgraded unit. These durations exclude any environmental or permitting activities, should they be required.

On the other hand, a redevelopment of an existing site would likely require environmental studies and/or additional governmental approvals which can add significantly to the overall project schedule.

5.7 Publicly Available Case Studies

5.7.1 Bay d'Espoir – Expansion

The Bay d'Espoir Hydroelectric Generating facility in Newfoundland was built in three different stages over a 12-year period.[9] The first stage included four generating units, with an installed capacity of 300 MW. Stage two added two generating units and 150 MW to the plant in 1970. The seventh unit was added in 1977, boosting the installed capacity of the plant by another 154 MW to 604 MW total.[10] In 2022, Newfoundland and Labrador Hydro announced a proposed $522 million project to construct an 8th unit, to add another 154 MW to the facility bringing it to 758 MW.[11]

5.7.2 Churchill Falls – Refurbishment and Expansion

The Churchill Falls Generating Station, at 5,428 MW, is the second-largest hydropower station in Canada (16th largest in the world), located in Labrador. Originally constructed from 1971 to 1974, the plant currently has 11 turbine-generator units, each of them rated individually at about 494 MW. The units have not yet been uprated, and each unit has an approximate potential for an additional 50 MW. With the additional possibility to add a 12th and 13th unit, rated at 550 MW each, the overall potential increase for this plant is 1,650 MW, which would bring its total installed capacity to 7,078 MW making it the 9th largest hydropower station in the world. [9,12]

5.7.3 E. B. Campbell, Couteau Creek, Island Falls and Nipawin – Refurbishment and Expansion

SaskPower is in the process of implementing a major refurbishment of the E. B. Campbell hydropower facility including upgrading six of the eight turbines for an anticipated plant increase from 289 MW to 295 MW. They also expect to implement major life extensions including turbine upgrades at their other larger hydropower facilities including Coteau Creek, Island Falls and Nipawin, in a 10- to 20-year timeframe. These upgrades may result in a modest capacity increase of 0.5 to 1.5%, however the design focus will likely be on improving operational flexibility to support inverter-based resources (such as wind, solar, and batteries) and achieve finer control of outflow.

Redevelopments, including capacity additions may also be considered in the future at some facilities. For example, the 186 MW Coteau Creek facility on the South Saskatchewan River was constructed in 1969 with five tunnels, only three of which were connected to generating units. SaskPower has plans to investigate the viability (impacts, benefits and cost) of adding additional generating capacity at the facility in the future.

5.7.4 Mica – Expansion

The Mica Generating Station, in British Columbia, was originally designed to house six generating units, however only four of them were installed in 1977, for a capacity of 1,805 MW at the facility completion. BC Hydro undertook a project in 2011 to install the final two units, Unit 5 and Unit 6, rated at 500 MW each.[13] The project was completed in 2016 increasing the total station capacity to 2,805 MW.

5.7.5 Revelstoke – Expansion

The Revelstoke Generating Station, in British Columbia (BC), was originally completed in 1984, with four generating units providing an installed capacity of 1,980 MW. BC Hydro undertook an expansion project in 2011, commissioning a 5th unit, adding 500 MW to the plant, for a total capacity of 2,480 MW.[14] There is a 6th bay at the facility, which currently remains empty, that could potentially accommodate another 500 MW unit, which could potentially increase the total capacity to 2,980 MW.

5.7.6 Sir Adam Beck – Refurbishment and Expansion

Originally constructed in 1921, Sir Adam Beck I GS, operates 10 units for a combined capacity of 446 MW.[15] Further expansions to the complex include the Sir Adam Beck II GS (1954 – 1,516 MW), and the Sir Adam Beck Pump GS (1957 - 174 MW). In 2022, after having been out of service since 2009, the full replacement of Unit 1 and Unit 2 was completed (the first ever for Sir Adam Beck I), and the new modernized units added roughly 125 MW of incremental capacity to the station.[16] From 2006 to 2013, the Sir Adam Beck II plant underwent a major civil engineering rehabilitation, including the Niagara Tunnel Project, which, along with other upgrades to the complex, was able to increase the nameplate capacity by 150 MW.

5.7.7 Carillon, Rapide-Blanche, Trenche and Outardes-2 – Refurbishment

As part of their Strategic Plan 2022-2026, Hydro Quebec announced an initiative to pursue various projects to add up to 2,000 MW of capacity to their existing hydropower generating stations by 2035.[17] Under the scope of this initiative, work is currently being carried out at four generating stations – Carillon, in Outaouais, Rapide-Blanc and Trenche, in Mauricie, as well as Outardes-2, on the North Shore. These works will make it possible to increase the production capacity by 10% within 5 years, adding 178 MW to a current capacity of 1,789 MW.[18]

5.7.8 Waneta – Expansion

The Waneta Dam and Powerhouse, located in British Columbia, constructed in 1954 on the Pend d'Oreille River, includes four generating units with a total installed capacity of 490 MW. A separate, two-unit powerhouse was constructed from 2010 to 2015 for $900 million to increase the generating capacity of the dam. The installed capacity of the Waneta Expansion Facility is 335 MW, bringing the complex total installed capacity to 825 MW.[19,20]

5.7.9 Manic-5 and Manic-5-PA – Expansion

Built as part of the Manic-Outardes Hydroelectric Complex Project (1959 to 1978), the Manic-5 Generating Station sits at the foot of the Daniel-Johnson Dam on the Manicouagan River. With eight Francis units commissioned in 1971, the facility has installed capacity of 1,596 MW. Less than 20 years later, a second powerhouse was commissioned at this site, to meet an increased demand for electricity during winter peak periods. The Manic-5-PA ("PA" referring to puissance additionnelle (additional capacity)) generating station expansion added four more Francis units and 1,064 MW to the existing development in 1990, bringing the total installed capacity to 2,660 MW.[21]

5.7.10 René-Lévesque (Manic-3) – Refurbishment

Another generating station built for the Manic-Outardes project, René-Lévesque (formerly known as Manic 3) was commissioned in 1976. With six Francis units rated at 208 MW each, the total installed capacity was originally 1,244 MW. During life-extending maintenance works completed between 2012 and 2014, the facility was upgraded to 1,326 MW.[22,23,24] As of 2023, further uprating is possible, and work is currently in the planning stage.[18]

6. Potential for Incremental Generation

The primary goal of this study was to help estimate the potential additional generation in MW that would be possible through refurbishment or redevelopment of existing hydropower facilities across the Canadian hydropower fleet.

6.1 Methodology

Recognizing that it is not possible to screen all existing facilities and obtain detailed information from all plant owners or operators, three approaches were used to estimate the potential for additional incremental generation.

6.1.1 Survey

The first approach consisted of direct survey responses from various utilities. The intent of the survey was to collect relevant information to help assess the refurbishment or redevelopment potential while also seeking feedback on some of the challenges that may prevent projects from occurring. The objective of the survey was to determine the amount of MW or GWh expected from refurbishment or redevelopment, the timing of these projects, the benefits, the obstacles and the support needed to overcome such challenges.

The survey was sent to multiple utilities representing approximately 80% of the installed capacity in Canada. Responses were received representing approximately 55,500 MW or 67% of the installed fleet capacity.

Based on the responses received the percentage of incremental generation was estimated and then scaled up to represent the total potential incremental generation of Canada’s hydropower fleet.

6.1.2 Plant Age

The second approach is a conservative estimate based on overall plant age and turbine-generator recommended service life. This approach used the construction and/or in-service date of the facility, and then applied a first, second, and possibly a third major overhaul period at a frequency of 50 years to estimate the current facility performance and potential performance. Based on the timing of the last theoretical refurbishment, the estimated potential remaining incremental generation (based on theoretical technological progression), was estimated as follows:

- Units commissioned or last overhauled pre-1960 could gain 10% incremental generation.
- Units commissioned or last overhauled between 1960 and1980 could gain 5% incremental generation.
- Units commissioned or last overhauled post-1980 could gain 1% incremental generation.

6.1.3 Combined Approach

The third approach, used to help validate the total estimated potential incremental generation, consisted of the following:

- Start with age-based data.
- Replace age-based data with applicable results of the survey.

- Replace additional age-based data based on publicly available information on plants with refurbishment or redevelopment potential.

6.2 Potential Incremental Generation Based on Survey

For the survey-based estimate, WaterPower Canada generator-member answers varied from exact MW values, to estimated percentage increases by plant or for the respondent's overall fleet. Numbers were consolidated into two categories: additional MW due to refurbishment (uprating) and additional MW due to redevelopment (new units).

Based on the survey results, the estimated potential incremental generation is approximately 2,840 MW through uprates and 760 MW through new units, resulting in a total approximate increase of 3,600 MW.

6.3 Refurbishment Potential Incremental Generation Based on Plant Age

For the age-based approach, it was assumed that the typical interval for turbine runner and rotor winding replacements (and thus opportunities for uprating), fall roughly once every 50 years. Assuming owners have followed this approximate interval and considering the plant's initial construction date, the potential last full unit overhaul year was estimated (e.g., construction year + 50 years or + 100 years = most recent full overhaul year prior to 2023). Then, when considering technological advancements over the last 60 to 100 years, a percent increase for potential uprating was estimated and assigned based on the calculated year of the potential last full unit overhaul.

This approach does not account for units that may have required premature replacement for various reasons and would thus have been uprated as part of repairs on a different schedule than the estimated every 50 years.

6.4 Redevelopment/Expansion Potential Incremental Generation

Potential redevelopment/expansion incremental generation only includes capacity based on survey results. This study does not include potential from non-powered dams, or other publicly known plants having redevelopment/expansion potential.

6.5 Estimated Incremental Generation

Based on the three approaches outlined above, the estimated incremental generation results are summarized in Table 6-1.

Table 6-1: Estimated Incremental Generation

Method	Combined Increase		Refurbishment		Redevelopment		Fleet Representation
	MW	%	MW	%	MW	%	MW
Survey[1]	3,600	6.48	2,840	5.12	760	1.37	66.9% (55,500)
Survey (Scaled)	5,381	6.48	4,245	5.12	1,140	1.37	100% (82,990)
Age-Based	2,209	2.66	-	-	-	-	100% (82,990)
Combined Approach	5,025	6.05	-	-	-	-	100% (82,990)

[1] As noted in Section 6.1 above, the cumulative fleet that responded to the survey represents approximately 55,500 MW (67%).

Considering the results of the survey and the combined approach, the approximate potential incremental generation is estimated to be in the range of 5,000 and 5,400 MW. The age-based method returns lower incremental generation because it averages potential across all sites, even if project specific refurbishment/rehabilitation on major projects usually exceed available statistical potential, particularly for larger plants.

7. Timing of Projects

Based on the responses from the survey for a representative fleet of 55,500 MW, 36 hydropower plants will likely begin or undergo refurbishment or redevelopment by 2035, while 12 are being considered between 2035 and 2050 and six are being considered beyond 2050 (Table 7-1).

Table 7-1: Planned Incremental Generation based on Survey

Timeline	Refurbishment			Redevelopment			Total
	Number	MW	%	Number	MW	%	
By 2035	35	2,240	4.0	1	40	<0.1	**36**
2035-2050	11	540	1.0	1	N/A	N/A	**12**
Beyond 2050	1	50	<0.1	5	720	1.3	**6**
Total	**47**	**2,840**	**5.1**	**7**	**760**	**1.4**	**54**

For those projects being completed before 2035, the survey results indicate that most will combine life extension and refurbishment into one program. As well, because most of these plants have several units, their actual full completion date may extend beyond 2035.

In addition, while not confirmed, we understand and anticipate that several utilities may be conducting studies prior to 2035 to plan for projects to be performed between 2035 and 2050. Thus, it is reasonable to assume that the number of hydropower plants being refurbished and redeveloped will increase in future.

8. Support, Benefits and Challenges for the Realization of Projects

8.1 Survey Questionnaire

As part of the survey, participants were also asked to provide opinions or suggestions on three questions, for both potential refurbishments and redevelopments respectively. The questions were as follows for each potential category:

- Does your organization currently have plans to refurbish (restore capacity to original, or with an uprate or more efficient turbine-generator) any of your existing hydropower plant turbine-generator equipment?
- What kind of benefits are expected from these refurbishments? How much incremental power (MW) and incremental generation (GWh) are expected fleetwide? What other types of benefits are expected (i.e., social acceptance, environmental, others, etc.)?
- Are there other reasons that help support your business case for refurbishment of your hydropower plants (i.e., carbon credits, grid stability with other forms of renewables, renewed power purchase agreement, providing ancillary services, etc.)?

Participants were also asked to provide some insight into the challenges they face on refurbishment or redevelopment projects. These questions were as follows:

- What are some of the major challenges/obstacles preventing your organization from moving forward with refurbishment or redevelopment (i.e., policy, technical, economic, changing political landscape, regulation, social acceptance, others)?
- How can government and policymakers help in supporting the refurbishment and redevelopment of hydropower plants? What winning conditions are necessary to help your organization move forward with your projects?

8.2 Survey Questionnaire Responses

Survey responses were consolidated, and the following is noted:

- Opinions or responses may reflect situations prevailing in a specific province and not another.
- Providing exact figures on potential for refurbishment or redevelopment is sensitive information.
- The survey attempted to determine when the projects might be realized and if they would align with the federal government objective of reducing greenhouse gas emissions before or after 2035. Most major generators declined to provide this information.
- Responses represented both large and small, and public and private generator members.

- The extent of responses varied as some generator members limited the extent of their responses given the sensitive nature of the information needed to complete the survey.

8.2.1 Factors Driving Realization

Most of the responses indicated projects would be realized when it is deemed necessary to extend the life of the assets rather than based on a capacity and/or generation increase alone. This suggests that any efficiency or incremental capacity benefits are typically a byproduct of overall life extension investments.

This finding suggests that the construction costs for incremental capacity or energy versus expected benefits for incremental generation alone may not be economic. However, when combined with already planned or needed life extension investments, the incremental cost of additional generation becomes attractive.

8.3 Other Benefits from Projects

8.3.1 Grid and Stability [25]

As more intermittent forms of renewable energy such as wind and solar are connected to the grid, there will be increased issues with low inertia, reactive power, grid voltage and transient stability. Hydropower refurbishments and redevelopments have the potential to help mitigate potential transmission issues that may be unique to parts of the system. They may also permit greater levels of intermittent renewables to interconnect in the future.

8.3.2 Contributing to the Environment

Hydropower already contributes to reducing GHG emissions. Programs to refurbish or redevelop existing hydropower facilities will help support the retirement of thermal generation and support the addition of other forms of renewable energy such as wind and solar.

Refurbishment and redevelopment projects may also provide the opportunity to modify or redesign some major components to help address issues such as oxygenation, fish friendliness, or improve water management for surrounding communities.

8.3.3 Social Acceptability

Hydropower, like other infrastructure projects, requires social acceptance before it can proceed, and needs to remain acceptable during its execution and after. Acceptability may have many points of view: environmental, profitability, or acceptability by local communities. Social acceptability of hydropower varies from province to province, but it is generally viewed positively from an economic and job creation point of view. Public surveys have shown a large majority of Canadians support the development of large-scale hydropower projects.

8.4 Obstacles Preventing Projects from Occurring

8.4.1 Approval, Permitting, Regulations

Nearly all respondents expressed concerns regarding the rules and regulations the hydropower industry is subjected to. Concerns are divided into three general trends: a perception of stringent regulation, a lengthy process, and finally a process that may ultimately be unpredictable.[26,27,28]

Before a refurbishment or redevelopment project can move forward, it must be determined if it will require a change in status quo with respect to existing permitting or require undergoing a partial review or complete review process of potential applicable various regulations such as environmental impact assessments, fisheries, navigable waters, provincial and municipal regulations, etc.

At times, these requirements present a challenge for any potential project as significant upfront investments and time are required, with significant uncertainty over the process or the outcome. As some entities surveyed indicated, they face complex and “unnecessary barriers”.

8.4.2 Power Purchase Agreements

In the regions where power purchase agreements (PPAs) are in place, nearly all respondents expressed various concerns. Some of the concerns raised included: duration of PPAs, cost inflation while under fixed rates, low rates, and adequate compensations for ancillary services with respect to integration of other forms of renewables.

Where applicable, the duration of a PPA and its economic model may determine if a refurbishment or redevelopment will be completed within the PPA duration. In other words, while not always the case, the PPA duration may limit the incentive to invest in a refurbishment or redevelopment project.

8.4.3 Costs

Uncertainty on the cost of refurbishment or redevelopment, and inflation were challenges mentioned by a few respondents.

In some cases, the study and permitting phase for a project can be lengthy and predictability on cost becomes a concern given the uncertainty on the outcome.

Inflation was mentioned as a concern that may influence the decision to move forward with a project. Power producers have started to face increased costs due to inflation, particularly since the COVID-19 period. When operating under a fixed rate PPA, inflation may also have an even greater impact on whether a refurbishment or redevelopment may proceed.

8.4.4 Supply Chain, Procurement and Labor

Concerns related to availability of resources (industrial capacity) to complete refurbishment or redevelopment projects was mentioned by one respondent. A lack of available resources could have an impact on the ability to complete projects on time and on budget.

8.4.5 Capital Allocation

Many respondents commented on challenges to allocate financial resources for refurbishment and redevelopment projects. Financial resources are generally allocated for life extension projects and although refurbishment and redevelopment potential increases are desired, they may not be a priority for capital investments.

Several participants proposed that in order to support new initiatives for efficiency increases, modifying existing units to support new renewables, or to complete more studies to explore additional refurbishment and redevelopment potential, new sources of funding would be required or welcomed.

8.4.6 *Economic Value of Hydropower versus Other Renewables*

There is a perception that hydropower, although as renewable and sustainable as other forms of energy that are typically more recognizable as renewable, is not generally treated in the same manner or open to similar engagement.

A common theme by respondents was adequation between current revenue models and the benefits hydropower brings to the energy market. In other words, other sources of revenues should be made available to owners of hydropower stations because they help to support the reduction in GHG or support other forms of renewables.

For example, it was suggested that future PPAs might also include provisions for carbon credits (e.g., Renewable Energy Credits). Such measures may already exist, but the ownership of these credits may sometimes be retained by other entities than the hydropower plant owner itself, thus limiting their incentive to improve generation, which in turn may have otherwise supported GHG reduction.

Several owners of hydropower facilities are also concerned that the value of their dispatchable, non-emitting resource, that provides daily or seasonal energy storage, is not adequately compensated with regards to other forms of intermittent renewable energies when supporting grid stability.

9. Path for Hydropower Refurbishment and Redevelopment

The scaled survey results indicate that the Canadian hydropower fleet can potentially increase its generation output through refurbishment and redevelopment by upwards of 5,000 to 5,400 MW between now and 2050. The Canadian electricity market is also undergoing profound transformations. Based on survey results, opportunities for incremental generation through refurbishment and/or redevelopment are available to explore and develop.

Based on the feedback from the survey, the following are some of the key challenges:

- **Review compensation mechanism**. The role of hydropower in supporting the introduction and expansion of new forms of intermittent renewable energies should be further reviewed.

- **Incentives for refurbishment and redevelopment**. Financial and regulator incentives should be considered to help hydropower plant owners support their efforts to increase the output of existing generating stations.
- **Coordinated effort**. To ensure the energy industry, as a whole, is able to meet the 2035 to 2050 goals of GHG reduction, an improved view of potential projects to come will help the industry plan ahead to help ensure the development of industrial and labor capacity to meet demand.

10. Conclusions

The overall objectives of this study were to describe the various types of enhancements, engage with major public and private hydroelectricity producers to help assess the total incremental generation capacity that is feasible through refurbishment or redevelopment, and identify factors affecting investments in existing hydropower facilities.

The total potential incremental generation was estimated based on direct survey responses as well as plant age while taking into consideration typical turbine-generator service life replacements.

Hatch surveyed Canadian hydropower plant owners and producers representing about 55,500 MW or 67% of the total installed Canadian fleet capacity of approximately 83,000 MW. Owners and producers were asked about their potential refurbishment or redevelopment projects as well as the challenges they may face in the development of their projects.

Based on this assessment, a summary of key findings are as follows:

- Canada's total existing hydropower capacity consists of approximately 566 stations with a total installed capacity of approximately 83,000 MW.
- The estimated incremental generation ranges from approximately 2,200 MW (age-based approach) to approximately 5,400 MW (scaled survey approach) which represents an increase range of 2.66% to 6.48%.
- 36 hydropower plants will likely begin or undergo refurbishment or redevelopment by 2035, while 12 are being considered between 2035 and 2050 and six are being considered beyond 2050.
- The key drivers and challenges for hydropower refurbishment and/or redevelopment are:
  - Refurbishment and redevelopment projects for incremental generation are typically realized when it is deemed necessary to extend the life of the assets rather than based on a capacity/generation increase alone.
  - Hydropower has the potential to help integrate additional intermittent renewables, as well as provide added elements such as inertia to aid in grid stabilization.

- Refurbishment and redevelopment projects benefit local economies.
- Approvals and permitting processes can present a challenge for some projects. Improvements in the regulatory process may help projects advance faster with more predictable outcomes.
- Power Purchase Agreements (PPA) can have a significant influence on whether a refurbishment or redevelopment may proceed.
- Cost uncertainty and inflation is a concern and can affect the viability of a potential project.
- Resource availability is important to ensure projects can be completed on time and budget.
- Without incentives, projects intended to extend the life of hydropower plants may be prioritized over refurbishment and redevelopment projects that could bring new additional capacity earlier.
- Additional financial incentives or improvements to the revenue model (PPA, RECs, tax credits, etc.) may help stimulate investment to support the advancement of refurbishment or redevelopment projects which can help in the reduction of GHGs as well as support integration of other renewables.

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